PROCEEDINGS

THA 2022 International Conference on

Moving Towards a Sustainable Water and Climate Change Management After COVID-19

January 26-28, 2022

Online platform

CONTACT INFORMATION AND DETAILS:

For your related question, please contact:

Contact Person: **Assoc. Prof. Dr. Sucharit Koontanakulvong**
Email: sucharit.k@chula.ac.th
Contact Person: **Assist. Prof. Dr. Supattra Visessri**
Email: supattrav@hotmail.com

Water Resources System Research Unit
Room 203, Bldg. 2 Faculty of Engineering,
Chulalongkorn University , Bangkok
Tel: +66-2-218-6426, +66-81-646-9750
Fax: +66-2-218-6425

For more detailed information you are more than welcome to visit our website:
http://www.watercu.eng.chula.ac.th
http://aseanacademicnetwork.com

For more materials from this document can be downloaded from
http://project-wre.eng.chula.ac.th/aseanacademicnetwork/?q=node/11

ขอขอบคุณที่มารูปหน้าปก
https://www.kaohoon.com/news/๕๓๐๖๘๘ - รูปโควิด
https://www.springnews.co.th/spring-life/๘๑๔๗๐๗ - รูปโรงงาน
https://www.designingbuildings.co.uk/wiki/Sustainable_water - รูปน้ำ

CONTENTS

CONTENTS (Con't)

CONTENTS (Con't)

CONTENTS (Con't)

CONTENTS (Con't)

CONTENTS (Con't)

Preface

The THA 2022 International Conference on "Moving Towards Sustainable Water and Climate Management After COVID-19" was organized from January 26th to 28th, 2022 via Zoom online platform. The event was organized by Chulalongkorn University, in association with 9 national partners, 4 international collaborative agencies and 1 supportive agency. The 9 national co-organizers are the Thai Hydrologist Association (THA), Office of the National Water Resources (ONWR), Royal Irrigation Department (RID), Department of Water Resources (DWR), Department of Groundwater Resources (DGR), Kasetsart University (KU) Kamphaengsaen Campus, Asian Institute of Technology (AIT), Thailand Science Research and Innovation (TSRI), and National Research Council of Thailand (NRCT). The 4 international collaborative agencies include Kyoto University, National Taiwan University (NTU), Korea Water Resources Association (KWRA), Japan International Cooperation Agency (JICA). The supporting agency is Electricity Generating Authority of Thailand (EGAT). The objective is to provide a platform for researchers, scientists, practitioners, policy makers and private executives to share and present new advances, research findings, perspectives, and experiences in water management and climate change, new technology, and water management towards SDGs. Special attention will be given to developing certain skills, competence, or general upgrading of performance ability for climate change adaptation, applied technology for predictions, and sustainable development in the monsoon Asia. The conference will bring together leading researchers, engineers, scientists, private executives and officials in the domain of interest from around the world.

The THA 2022 international conference was successful according to the main objective of serving as the public assembly. Welcome speech of the THA 2022 international conference was given by Prof.Dr.SupotTeachavorasinskun, Dean of Faculty of Engineering, Chulalongkorn University. The opening remarks was given by Air Chief Marshal Chalit Pukbhasuk, the Privy Council of Thailand. At this conference we had three keynote speakers, 290 participants from 16 countries including Thailand, Japan, Korea, Switzerland, Myanmar, Cambodia, Taiwan, Lao, India, Malaysia, Philippines, Nepal, Vietnam, United States, Australia, Indonesia. The three keynote presentations given by distinguished speakers who were invited to participate in the conference emphasized water and disaster management under climate change and post COVID-19. There were 25 guested papers and 69 technical paper selected papers to present under 3 subthemes. There are 23 papers on theme A: Water Management and Climate Change, 16 papers on theme B: New Technology in Water and Irrigation Management, and 30 papers on theme C: Water Management Towards SDGs. Details of each subtheme are provided as follows:

Theme A on Water Management and Climate Change covers the topic of climate change projections, water-related disasters, economic impacts caused by climate change and water security issues, and climate change adaptation.

Theme B on New Technology in Water and Irrigation Management covers weather forecast, reservoir operations, irrigation technology, and technology for improving water quality

Theme C on Water Management Towards SDGs covers water management towards SDGs, groundwater management towards SDGs, water Security (Urban, Productivity etc.), and NEXUS (Food, Energy, Water, Land) towards SDGs.

Apart from the presentations based on the above-mentioned themes, three workshops were organized in parallel to the THA 2022 international conference. Workshop A: Training courses for hydrologicanalysis using GCM climate projection outputs, Workshop B: Training courses forwater security index, and Workshop C: Science-Policy interface dialogue on water and climate change.

Applications, opportunities for further research direction and collaboration were discussed among the participants.

Virtual exhibition at the THA 2022 International Conference consisted of 5 VDO clips from DWR, DGR, ONWR, RID and CU-SIP showing water and disaster management principles, applications, models, tools, modern technologies, and research initiatives.

Major outputs obtained from the THA 2022 can be summarized below:

- Knowledge dissemination and exchange from the presentations. At this conference and workshops we had 3 keynote speakers, 290 participants from 16 countries including Thailand, Japan, Korea, Switzerland, Myanmar, Cambodia, Taiwan, Lao, India, Malaysia, Philippines, Nepal, Vietnam, United States, Australia, Indonesia, 25 guested papers, 69 technical papers participated.
- A technical training on "Hydrologic analysis using GCM climate projection outputs", "Water security index", and "Science-Policy interface dialogue on water and climate change".
- Virtual exhibition displaying water-related technologies, products and services from governmental agencies, universities, research institutions and private companies

Major outcomes are listed below:

- Creating an opportunity for being a coordinator in research and education regarding Water & Disaster Management and Climate Change which has already started.
- Presenting technologies and water management in Thailand to other countries outside.
- Strengthening collaboration internationally in the area of water and climate change and bringing it towards the achievement of SDGs.

This document presents main conclusions from the THA 2022 International Conference on "Moving Towards Sustainable Water and Climate Management After COVID-19". Related materials that will be issued separately are the THA 2022 proceedings.

Lastly, we would like to take this opportunity to express our sincere gratitude to all participants for their contributions and support that driving the THA 2022 International Conference toward the desired objectives and achievement.

Assoc. Prof. Dr. Sucharit Koontanakulvong
Assist. Prof. Dr. Supattra Visessri
Editors of THA 2022 Proceeding and Report

The organizers of the THA 2022 International Conference on "Moving Towards Sustainable Water and Climate Management After COVID-19"

Organization committees

Advisory Committees:		
1	Prof. Dr. Bundhit Eua-arporn	Chulalongkorn University
2	Mr.Praphit Chanma	Director General of Royal Irrigation Department
3	Mr. Surasi Kittimonthon	The Secretary-General,Office of the National Water Resources
4	Mr.Bhadol Thavornkitcharat	Director General of Department of Water Resources
5	Mr. Sakda Vicheansil	Director General of Department of Groundwater Resources
6	Dr. Chongrak Watcharinrat	Kasetsart University
7	Dr. Eden Y Woon	Asian Institute of Technology
8	Assoc.Prof. Dr. Patamawadee Pochanukul	Directorof Thailand Science Research and Innovation
9	Dr. Wiparat De-ong	Director of National Research Council of Thailand

Boards of Committees:		
1	Prof. Dr. Supot Teachavorasinskun	Chulalongkorn University
2	Mr. Chalit Damrongsak	President of the Thai Hydrology Association
3	Assoc.Prof. Dr.Chouw Inprasit	Dean of Engineering Faculty, Kasetsart University
4	Dr. Sangam Shrestha	Asian Institute of Technology
5	Prof.Dr. Chanatip Pharino	Thailand Science Research and Innovation
6	Ms. Kannika Durongkadej	National Research Council of Thailand
7	Asst. Prof. Dr. Anurak Sriariyawat	Head of Department of Water Resources Engineering Faculty of Engineering Chulalongkorn University

Academic committees:		
1	Asst.Prof. Dr. Chaiyapong Thepprasit	Kasetsart University
2	Assoc. Prof. Dr. Sucharit Koontanakulvong	Chulalongkorn University
3	Asst.Prof. Dr. Pongsak Suttinon	Chulalongkorn University
4	Asst.Prof. Dr. Supattra Visessri	Chulalongkorn University
5	Asst.Prof. Dr. Piyatida Hoisangwan	Chulalongkorn University
6	Prof. Dr. Chavalit Ratanatamskul	Chulalongkorn University
7	Dr. Chokchai Suthidhummajit	Chulalongkorn University
8	Assoc. Prof. Dr. Bancha Kwanyuen	Kasetsart University
9	Assoc. Prof. Dr. Chaisri Suksaroj	Kasetsart University
10	Asst. Prof. Dr. Wisuwat Taesombat	Kasetsart University
11	Asst. Prof. Dr. Nithirat Sanguanduean	Kasetsart University
12	Dr. Ketvara Sittichok	Kasetsart University
13	Dr. Chuphan Chompuchan	Kasetsart University
14	Mr. Thana Suwattana	Royal Irrigation Department
15	Dr. Phattaporn Mekpruksawong	Royal Irrigation Department
16	Dr. Noppadon Kowsuvon	Royal Irrigation Department
17	Dr. Chanchai Srisutham	Royal Irrigation Department
18	Dr. Chkaphon Singto	Royal Irrigation Department
19	Dr. Supapap Patsinghasanee	Department of Water Resources
20	Mr. Surin Worakittamrong	Department of Groundwater Resources
21	Ms. Tassanee Netatat	Department of Groundwater Resources
22	Dr. Winai Chaowiwat	Hydro - Informatics Institute
23	Prof. Dr. Chaiyuth Chinnarasri	King Mongkut's University of Technology Thonburi

24	Asst.Prof.Dr.Chaiwat Ekkawatpanit	King Mongkut's University of Technology Thonburi
25	Prof. Dr. Chavalit Chaleeraktrakoon	Thammasat University
26	Asst. Prof. Dr. Chanyut Kalakan	Burapha University
27	Assoc.Prof. Dr. Areeya Rittima	Mahidol University
28	Prof. Sangam Shrestha	Asian Institute of Technology
29	Prof. Ashim Das Gupta	Asian Institute of Technology
30	Dr. S. Mohana Sundaram	Asian Institute of Technology
31	Dr. Ho Huu Loc	Asian Institute of Technology
32	Dr. Sarawut Ninsawat	Asian Institute of Technology
33	Dr. Tuan Pham Van	Asian Institute of Technology
34	Dr. Thi Phuoc Lai Nguyen	Asian Institute of Technology
35	Prof.Dr.Taichi Tebakari	JICA
36	Prof.Dr. Kiguchi Masash	JICA / The University of Tokyo
37	Assoc.Prof.Dr. Yoshida Koshi	JICA / The University of Tokyo
38	Prof.Dr. Tebakari Taichi	JICA / Chuo University
39	Assoc.Prof.Dr. Noda Keigo	JICA / Gifu University
40	Assoc.Prof.Dr. Udo Keiko	JICA / Tohoku University
41	Assoc.Prof.Dr. Nakamura Shinichiro	JICA / Nagoya University
43	Asst.Prof.Dr. Koyama Naoki	JICA / Chuo University
43	Prof. Dr. Yasuto Tachikawa	Kyoto University, Japan
44	Prof.Dr.Sumi Tetsuya	Kyoto University, Japan
45	Prof.Dr.Tanaka Shigenobu	Kyoto University, Japan
46	Assoc.Prof.Dr.Yutaka Ichikawa	Kyoto University, Japan
47	Assoc.Prof.Kazuaki Yorozu	Kyoto University, Japan
48	Asst.Prof.Dr.Tomohiro Tanaka	Kyoto University, Japan
49	Prof.Dr. Li-Chi Chiang	National Taiwan University
50	Prof.Dr. Yo-Jin Shiau	National Taiwan University
51	Prof.Dr.Shu-Yuan Pan	National Taiwan University
52	Prof.Dr.Jui-Pin Tsai	National Taiwan University
53	Prof.Dr.Ming-Che Hu	National Taiwan University
54	Prof.Dr.Dongkyun Kim	Korea Water Resources Association
55	Prof. Dr.Seongjin Noh	Korea Water Resources Association
56	Prof. Dr.Changhyun Jun	Korea Water Resources Association
57	Prof. Dr.Kyuhyun Byun	Korea Water Resources Association
58	Prof. Dr.Yeolwoo Kim	Korea Water Resources Association
59	Prof. Dr.Byounghyun Kim	Korea Water Resources Association

Working Committees:

1	Assoc.Prof.Dr. Sucharit Koontanakulvong	Chulalongkorn University
2	Asst.Prof. Dr. Pongsak Suttinon	Chulalongkorn University
3	Asst.Prof. Dr. Supattra Visessri	Chulalongkorn University
4	Asst.Prof. Jutithep Vongphet	Kasetsart University
5	Mr. Chaiwat Pholpirun	Thai Hydrology Association
6	Mr. Somkiat Kitsuwannakun	Thai Hydrology Association
7	Ms. Supicha Kongplee	Royal Irrigation Department
8	Mr. Atthapong Chantanumut	Office of the National Water Resources
9	Mrs. Wassana Roiamphang	Department of Water Resources
10	Ms.Wanwisa Intana	Department of Water Resources
11	Ms. Kanokwan Yoowong	Department of Water Resources

12	Mr. Asada Teeka	Department of Water Resources
13	Mr. Kulawat Kaewkao	Department of Water Resources
14	Ms. Wannaporn Makanong	Department of Water Resources
15	Ms. Alin Chintrarak	Department of Groundwater Resources
16	Ms. Akpasorn Akkarat	Department of Groundwater Resources
17	Asst. Prof. Dr. TanaponPhenrat	Thailand Science Research and Innovation
18	Ms. Umaporn Kowong	National Research Council of Thailand
19	Ms. Daunpen Punayangkool	Chulalongkorn University
20	Ms. Napaporn Noppakhun	Chulalongkorn University
21	Ms. Wichuta Hemsatien	Chulalongkorn University
22	Mr. Toranin Pawsanga	Chulalongkorn University
23	Mr. Sak Sakulthai	Chulalongkorn University
24	Ms. Chawanporn Boonkerd	Thai Hydrology Association

Conference Organizing Institutes

Chulalongkorn University (CU), Thailand

Thai Hydrologist Association, Thailand

Office of the National Water Resources, Thailand

Royal Irrigation Department, Thailand

General of Department of Water Resources, Thailand

Conference Organizing Institutes (con't)

Department of Groundwater Resources, Thailand

Faculty of Engineering at Kamphaengsaen, Kasetsart University, Thailand

Asian Institute of Technology, Thailand

Thailand Science Research and Innovation, Thailand

National Research Council of Thailand

Collaborative agency

Kyoto University, Japan

National Taiwan University, Taiwan

Korea Water Resources Association,
Republic of Korea

Japan International Cooperation Agency

AIMS AND SCOPE

The objective is to provide a platform for researchers, scientists, practitioners, and policy makers to share and present new advances, research findings, perspectives, and experiences in water management and climate change, new technology, and water management towards SDGs. Special attention will be given to developing certain skills, competence, or general upgrading of performance ability for climate change adaptation, applied technology for predictions, and sustainable development in the monsoon Asia. The conference will bring together leading researchers, engineers, scientists, and officials in the domain of interest from around the world.

Topics of the conference are:

1. **Water Management and Climate Change**
   - 1.1) Climate Change Projections
   - 1.2) Water-Related Disasters
   - 1.3) Economic Impacts caused by Climate Change and Water Security Issues
   - 1.4) Climate Change Adaptation
2. **New Technology in Water and Irrigation Management**
   - 2.1) Weather Forecast
   - 2.2) Reservoir Operations
   - 2.3) Irrigation Technology
   - 2.4) Technology for Improving Water Quality
3. **Water Management Towards SDGs**
   - 3.1) Water Management towards SDGs
   - 3.2) Groundwater Management towards SDGs
   - 3.3) Water Security (Urban, Productivity etc.)
   - 3.4) NEXUS (Food, Energy, Water, Land) towards SDGs

Welcome Speech

THA 2022 International Conference on Moving Towards Sustainable Water and Climate Management After COVID-19 (January 26, 2022, Online via Zoom)

Given by Prof.Dr.Supot Teachavorasinskun,
Dean of Faculty of Engineering, Chulalongkorn University

1) Dear His Excellency Air Chief Marshal Chalit Pukpasuk, the Privy Councilor of Thailand; co-organizing agencies; collaborative agencies; supporting agencies; keynote speakers; and all honorable guests.
2) It's my privilege and pleasure to welcome you to the THA 2022 International Conference on Moving Towards Sustainable Water and Climate Management After COVID-19.
3) Today's conference in 2022 is the fourth in the series. We have had this conference since 2015 and continued for every two years. Unfortunately, this year we have to have the conference online due to the pandemic of COVID-19.
4) The theme of the THA2022 conference is designed to match with on-going challenges and global trends. In this conference we have 3 keynote presentations from the representatives of World Bank, UNDP and the Office of the National Water Resources of Thailand or ONWR. There are 4 executive panel discussions on the topics of water management with climate change, SDG, water security, and sustainable groundwater management. We have 3 themes for technical presentation including water and climate change, modern technology in water or irrigation management, and sustainable water management. Two hands-on technical trainings on GCM, downscaling and water security assessment. Two side events of Science-Policy Interface Dialogue by UNDP and another side event on Water Conservation, Climate Change and Ecosystem-based Adaptation in ASEAN by the Department of Water Resources of Thailand.
5) Climate change places disastrous impacts on water crisis. For example, unusual cycle of flood and drought, sea water level rises, rapid erosion of shoreline etc. In order to slow down these impacts of climate change, Thai government committed to lead the country to achieve carbon neutral by 2015 and ambitiously to have zero emission by 2065. Water from the flood might be decreasing but we remember that the disastrous flood can come back any time in the near future. Noted that water shortage may seem to disappear but our problem in water management, growth can definitely come back any time in the future. Damages and losses on lives and properties can be redeemed, repaired or subsidized. We attempt to forget how suffering and sadness we have in abnormal cycle of floods and droughts. Those painful feelings should be forgotten and live should go on. However, please be reminded that the experience from such event should always be remembered. Most importantly, it should be learned and shared among people because only properly learning and sharing from our own experience makes humankind evolution. However only human evolution and development do not guarantee sustainability.

6) Inclusive participation from all stakeholders can cause sustainable development. Those are the main reasons why we are gathering today in the THA2022 conference. We are gathering today to share and to learn from our experiences, to transform our knowledge and experiences to make water being the most sustainable resource for all stakeholders.

7) Welcome all delegates and distinguished participants. Please allow me to mention the names of our valuable partners. We cannot hold this conference without them. The co-organizing agencies are the Thai Hydrologist Association, ONWR, the Royal Irrigation Department, the Department of Water Resources, the Department of Groundwater Resources, Kasetsart University (Kamphaeng Saen Campus), Asian Institute of Technology or AIT, Thailand Science Research and Innovation or TSRI, and National Research Council of Thailand or NRCT.

8) Our thanks are also extended to our supporting agencies including Kyoto University, National Taiwan University or NTU, Korea Water Resources Association or KWRA, Japan International Cooperation Agency or JICA and Electricity Generating Authority of Thailand or EGAT.

9) We thank World Bank, RBAP, ONWR, GIZ, IWMI, Bappenas Indonesia, DWR Vietnam, FTI, ADB, UNESCO, PELA GeoEnvironment USA., Chinese Academy of Sciences, RIHN Kyoto, Korea University and NAHRIM Malaysia for the speakers in the keynote and executive panel discussion sessions.

10) Kasetsart University, Chulalongkorn University, AIT, NTU, Kyoto University and other universities in our network are acknowledged for their contributions on providing the chairs, readers and commentators to the conference.

11) Most importantly, the conference cannot be held without generosity and support from our sponsors including EGAT, CKPower, Metropolitan Waterworks Authority or MWA, AEON Thailand Foundation, Team Consulting Engineering and Management Public Company Limited and Siam Steel International. Very long list of support we received.

12) Finally, I hope that discussions generated from this event can be the great steppingstone to make our world better and most sustainable, not only for us but for the next generations. Thank you again to everyone for being here and welcome to the THA2022.

Opening Speech

THA 2022 International Conference on Moving Towards Sustainable Water and Climate Management After COVID-19
(January 26, 2022, Online via Zoom)

Given by H.E. Air Chief Marshal Chalit Pukbhasuk, Privy Councillor of Thailand

1) Good morning Ladies and Gentlemen, Dear Distinguished delegates, in my capacity as Privy Councillor, whereby I am responsible for Royal Initiative projects to promote the well-being of Thai people. This also support the implementation of global Sustainable Development Goals, or SDG. I would like to convey to all of you participating in the THA 2022 conference my heartfelt welcome.

2) The past two years are certainly the years that none of us will ever forget. The world has faced a critical moment in history. There are a number of global threats including growing crises in natural disaster, climate change, biodiversity, and environmental degradation—as well as COVID-19.

3) The THA 2022 International Conference is therefore set under the theme of Moving Towards Sustainable Water and Climate Management After COVID-19. The THA 2022 is organized by Chulalongkorn University, in association with 9 national partners, 4 international collaborative agencies and 1 supportive agency. It is high time that such an event took place to address critical issues regarding water, climate change and sustainability especially after COVID-19 that changes the way we live.

4) The growing consequences of climate change have been all too visible across the world this year with extreme temperature, severe storms, floods and droughts. The latest assessment of the science by the Intergovernmental Panel on Climate Change or IPCC, published in August 2021, concluded that there is a clear link between rising greenhouse gas concentrations in the atmosphere and increases in the frequency and intensity of extreme weather events. It states: "Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes." The people in developing and least developed countries are often most exposed and vulnerable to the effects of climate change, even though they are the least involved actor driving the causes.

5) Countries must set ambitious national climate commitments if they are to live sustainably and recover from the COVID-19 pandemic which has impacted almost every corner of our life, causing sluggish growth of global economies, changing the way we work and interact. The COVID-19 pandemic has stimulated the need to catalyse positive change to meet the Sustainable Development Goals (SDGs) and fulfil the environmental agenda. This message was also amplified at the recent United Nations Climate Change Conference or COP26.

6) Despite the challenges, we also have an enormous opportunity in research and collaboration to transform the global economy and drive greater well-being and prosperity. To address water management issues, knowledge exchange, technology transfer and innovations are much needed. We all can help to move our community towards sustainability by focusing our research efforts around the 2030 Agenda for Sustainable Development Goals and attempting to explore better solutions for water-related problems specifically the impacts of climate change, disaster and other pressing challenges.

7) The THA2022 provides a valuable opportunity for scientists, researchers, policy planners and decision-makers to discuss and share knowledge and experiences to seek for cutting-edge solutions for water management and climate change challenge for our region and our world. I would like to thank both local and international participants attending this conference. I wish the THA2022 great success and I hope you have a fruitful discussion and rewarding experience in the THA2022. The THA conference series is expected to continue playing an important role in facilitating technical knowledge dissemination and networking in the future.

8) Now it is time to declare the THA2022 International Conference on Moving Towards Sustainable Water and Climate Management After COVID-19 officially. I hope the conference will proceed towards fostering sustainable, resilient, and inclusive development and shaping the future for us all in terms of wellbeing and its sustainability. A return to 'normal' way of living is what we are hoping. I wish all of you being healthy and safe and hope we can see each other in person in the next THA conference.

SESSION A:
WATER MANAGEMENT AND CLIMATE CHANGE

TA-102S

Managing Flash Flood and Drought in Rainfed Agriculture – The Context of Water Crisis Management in Thailand

Supapap Patsinghasanee
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
supapap.p@dwr.mail.go.th

Jeerapong Laonamsai
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
jeerapong.lao@gmail.com

Jirawat Pracheepchai
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
anspalo@hotmail.com

Punyawee Sawanyapanich
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
mickie136@hotmail.com

Ratda Patsinghasanee
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
ratdas@gmail.com

Thanat Saprateth
Department of Water Resources, Ministry of Natural Resources and Environment
Bangkok, Thailand
thanat.spt@gmail.com

ABSTRACT

In the context of water crisis management, the urgent need for water resources management in agriculture and disaster management to meet future food and livelihood needs is highlighted, especially given the pressure and stress on water management as well as the uncertainty caused by climate variability. Rainfed agriculture, in particular in rural Thailand, plays and will remain an important role in providing food, generating livelihoods, and ensuring water security. The major aims of the project are to forecast and evaluate the Flash Flood Guidance System for real-time hydrological forecasting of flash flood risk during tropical storm "SINLAKU" on August 2–5, 2020. In the dry season from 2019 to 2020, the water balance process has also been used to determine water deficit areas at the sub-district level. Furthermore, the disaster management is being used to establish water crisis prevention and mitigation plans prior to, during, and after a disaster. As a result, water crisis prevention and mitigation procedures have been implemented in rainfed agriculture to reduce the severity of disasters.

Keywords—rainfed agriculture; flash flood guidance system; drought forecasting system; water crisis management

INTRODUCTION

The agricultural industry is critical to economic growth [1] and alleviating poverty [2]. However, in Asia, where rainfed agriculture is the dominant agricultural activity [3], a large proportion of poor households still endure hunger, food insecurity, and malnutrition. The significant of rainfed agriculture is varied by regionals and climate conditions but it mostly contributes food for poor communities in developing countries. Nevertheless, the challenges of rainfed agriculture are complicated by climate variability, climate change, population growth, health pandemics, degraded natural resources bases, poor infrastructure, and land-use change [2, 4].

In Thailand, the water resources are managed through an area-based approach that includes irrigation and rainfed agriculture. There are roughly 238,720 km^2 of agricultural land. Irrigation covers approximately 52,400 km^2 (22 percent of the agriculture area), whereas rainfed agriculture covers approximately 187,200 km^2 [5]. The Master Plan on Water Resources Management is a framework and guideline for addressing water resource challenges in terms of natural resources, economics, and social issues in order to improve national water security.

The purpose of this paper is to showcase the work of the Department of Water Resources (DWR), Ministry of Natural Resources and Environment, Thailand, in the context of the rainfed agriculture water crisis management. The DWR's works on this paper only include the flash flood warning system, the seasonal drought forecasting system, and the water crisis mitigation plan.

1 FLASH FLOOD WARNING SYSTEM

A flash flood is a large-volume local flood that occurs quickly and unexpectedly. It has a short duration and occurs within a few hours of heavy or extreme rainfall [6]. It is difficult to deal with the flash flood using the typical riverine flood forecasting system because of its characteristics. Due to the high slope and thin surface soil layers, flash floods are more common in mountainous areas or in the foothills than riverine floods. A flash flood is a local hydrometeorological phenomena that requires the integrated hydrological and meteorological tools for real-time forecasting and warning. Furthermore, flash flood forecasting and warning systems necessitate additional particular procedures based on the flash flood's features. As a result, the outcomes of DWR's flash flood guidance and early warning systems are presented in this section.

1.1 Flash Flood Guidance System

The flash flood guidance system (FFGS) was implemented to assess the flash flood risk for Haiti prior to the Hurricane Tomas causing heavy precipitation, landslides, and debris flow in November 2010 [7], and it was then used to forecast the flash flood risk in Southern Thailand during the typhoon season between November to December 2017 [8]. In Haiti and Thailand, the FFGS evaluation results were verified in terms of mean areal precipitation (MAP), forecasting mean areal precipitation (FMAP), average soil moisture content (ASM), and flash flood risk (FFR). For the evaluation results, the FFGS accurately reproduced MAP, ASM, and FFR. Recently, Flash Flood Potential Index (FFPI) and Dynamic Flash Flood Hazard Index (DFFHI) were developed in Thailand for forecasting the flash flood by considering physical-geographic factors, rainfall index, soil moisture index [9].

For the FFGS, further information is given by [7, 8]. From August 2 to 5, 2020, the FFGS was examined for real-time flash flood forecasting during tropical storm "SINLAKU." On August 2, 2020, the tropical storm moved into the South China Sea and weakened to a tropical depression over Lao PDR and Northern Thailand, causing heavy rainfall over Northern Thailand for consecutive days (Fig. 1). Therefore, the preliminary assessment indicated localized flooding in Northern Thailand. The evaluation results of FFGS during "SINLAKU" in Northern Thailand were verified in terms of MAP, FMAP, and FFR, respectively. The MAP products and observed rainfall were compared with the perfect agreement line, which fell inside a 30% error line with 0.73 of the coefficient of determination (R^2, Fig. 2). Nevertheless, numerous points fell beyond the 30% error line, indicating that the predicted daily MAP significantly underestimated observed daily rainfall. The daily FMAP products and observed data were also compared to the perfect agreement line, which fell outside a 30% error line with 0.46 of R^2 value (Fig. 3). The daily FMAP substantially underestimated actual daily rainfall. Therefore, the local forecasting rainfall systems, radar stations, and forecaster abilities are essential to consider with the FMAP product for making a good decision. The FFGS produced a product to identify the flash flood risk area during the passing of a low-pressure cell. The FFR product was compared with the inundation areas reported by the disaster management agency. However, the inundation areas did not specify the actual type of flooding (e.g., flash flood, riverine flood, and debris flow). The comparison results of FFR are exhibited in Fig. 4. The comparison results between FFR products and inundation areas are illustrated in good agreement in Northern Thailand. After all, the FFGS needs to highlight the uncertainty characterization of forecasting products due to uncertainties in the qualitative forecasting rainfall on the hydrological and climatological systems. Therefore, the forecasters are required to consider the in-situ stations (e.g., rainfall and water level) for implementing the FFGS.

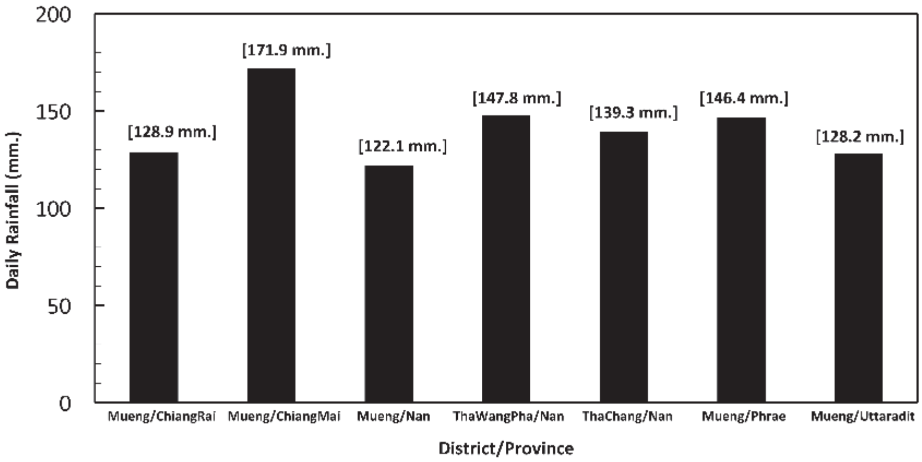


Fig. 1 Daily rainfall during August 2-5, 2020

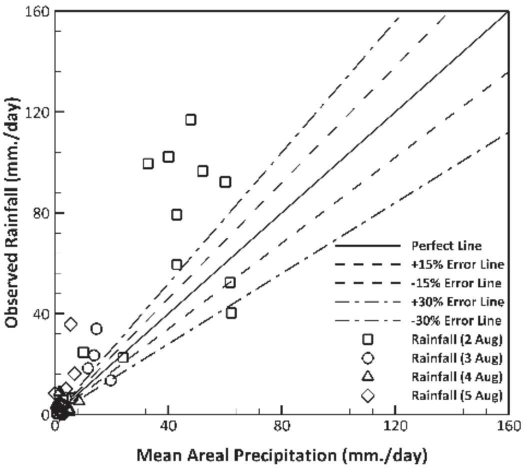


Fig. 2 Comparison results between MAP and observed data during August 2-5, 2020

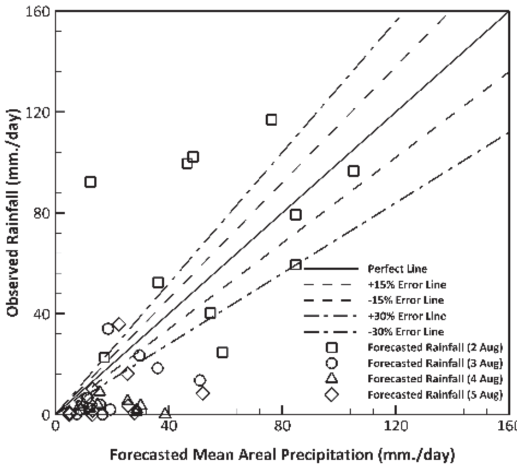


Fig. 3 Comparison results between FMAP and observed data during August 2-5, 2020

1.3 Early Warning System

The Early Warning System (EWS) has been established by DWR to monitor and warn for flash floods in mountainous areas. Approximately 188 times throughout the consideration period, the EWS delivered warning information to policymakers in disaster management agencies and local authorities, covering 606 risk villages. Furthermore, the evacuation warning (red alert) was issued 8 times in Nan, Chaing Mai, Chaing Rai, Uttaradit, Phisanulok, and Mae Hong Son (Fig. 5). During the tropical storm "SINLAKU," the DWR's flash flood warning systems used a combination of the forecasting system (FFGS) and in-situ stations (EWS) to clarify the flash flood risk areas in Northern Thailand. The results indicated that the coupling system for flash flood warning system from DWR is clearly effective for implementing the actual situation in Northern Thailand.

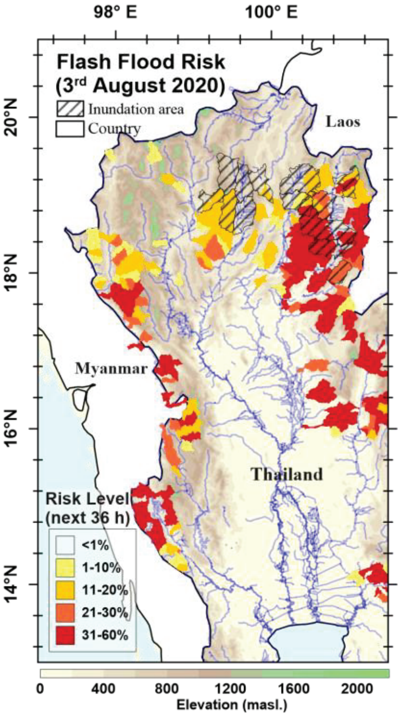


Fig. 4 Comparison results between FFR and the inundation areas on August 2, 2020

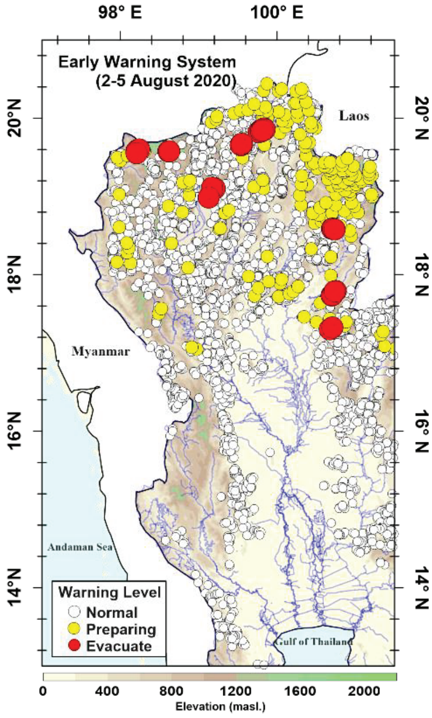


Fig. 5 Alarms of the EWS during tropical storm "SINLAKU" between 2-5 August 2020

2 DROUGHT FORECASTING SYSTEM

Drought was the river discharge or water level steadily decreases, affecting living and growing conditions in the surrounding areas. In addition, the drought definition refers to abnormally low rainfall or a prolonged period of less rainfall, causing deficiencies of drinking water and water scarcity. This condition resulted in water shortages, crop damage, steam flow reduction and, therefore, low quality of life in the affected area. Droughts can continue for months or years, and there are consisted of three stages of drought (meteorological drought, agricultural drought, hydrological drought, respectively) that increasing the impact on people in drought-affected areas.

Over the past decades, Thailand has experienced droughts, affecting the economy, agriculture, ecosystem, and industry [5], due to less annual rainfall than average (1,554 mm./year). The records have shown that Thailand has 42,880 km^2 of drought risk areas and 7,490 villages with water shortages for consumption (9.98% of villages in the country). Drought risk analysis and forecasting systems implemented in the past have considered the hydro-meteorological data, irrigation areas and village water supply systems to predict drought areas at the provincial level [10]. After that, the water balance concept was applied in Thailand's rainfed agriculture by considering the water supply (forecasting rainfall, river discharge, and available water in the water bodies) and water demand (domestic, ecological, agricultural, and industrial uses) [11]. Furthermore, Standardized Precipitation Index based on the historical data (1985-2016) was used to predict the meteorological drought in the Lower Mekong region [12]. Recently, Reconnaissance Drought Index application and daily weather data (temperature, relative humidity, sunlight count and wind speed) during 1979 – 2015 were employed to analyze the drought risk areas over Thailand. In addition, the Standardized Precipitation Index (SPI) and Theory of Runs (TOR) were applied for meteorological drought analysis based on rainfall in the eastern regions between 1951 and 2017 [13]. However, most of these analyses are only based on water supply and hydro-meteorological data, which have not yet been considered the water demand as a factor in predicting drought risk areas. Therefore, to better drought mitigation in rainfed agriculture, this study predicted drought risk at a sub-district level by analyzing and evaluating the water supply (forecasting rainfall, river discharge, and available water in the water bodies) and the water demand (domestic, agriculture, ecological, and industrial sectors) and the water balance during the dry season (October 2019 – April 2020). The method for analyzing and evaluating the water supply-demand and water balance analysis was detailed by [14].

2.1 Water Supply

Water supply evaluation was started at the beginning of the dry season. Therefore, the forecasted rainfall was used to estimate the expected runoff during the period of interest using the Rainfall-Runoff Model (NAM model). The modelling revealed that the forecasting rainfall could change to about 652 x 10^6 m^3 of surface water. Furthermore, another source of water supply in the rainfed agriculture was from 102,112 water bodies, with about 8,748 x 10^6 m^3, and the amount of water available from streams flowing through the given areas. The flow rate from the 137 runoff stations showed that 2,366 x 10^6 m^3 of river water could be used as a water supply during the dry season. Therefore, the total water supply for the rainfed areas during the dry season was approximately 11,766 x 10^6 m^3 (Fig. 6).

2.2 Water Demand

The water demand estimation includes the four sectors: domestic water use, agricultural demand, ecological conservation, and industrial usage. The result showed that 927 x 10^6 m^3 of water was required for domestic use. Agriculture water demand by considering the dry-season farming showed a plan for planting 3,520 km^2 of paddy field, 1,360 km^2 of maize, 4,576 km^2 of sugarcane, and 2,544 km^2 of cassava which were estimated at 5,692 x 10^6 m^3 of total water demand. In addition, the water uses to preserve the ecosystem, and industrial sectors were approximately 927 x 10^6 m^3 and 401 x 10^6 m^3, respectively. As a result, the total water demand for rainfed agriculture during the dry season was about 7,957 x10^6 m^3. The intense water demand was seen in the lower northern and upper central regions due to multiple cultivations a year (Fig. 7).

2.3 Water Balance

Water balance in rainfed agriculture during the dry season was analyzed based on water supply and demand at the sub-district level. The results displayed that drought risk areas covered 984 sub-districts of 305 districts of 57 provinces (Fig. 8.). Severe drought risk areas were found in the lower northern and upper central regions, corresponding to the water demand. On the other hand, mild drought risk areas were seen in Northeastern Thailand. Furthermore, this result was also consistent with other observations at 71% of forecasted drought areas. For example, the Department of Disaster Prevention and Mitigation reported that water scarcity occurred in 782 sub-districts of 145 districts of 24 provinces in the meantime.

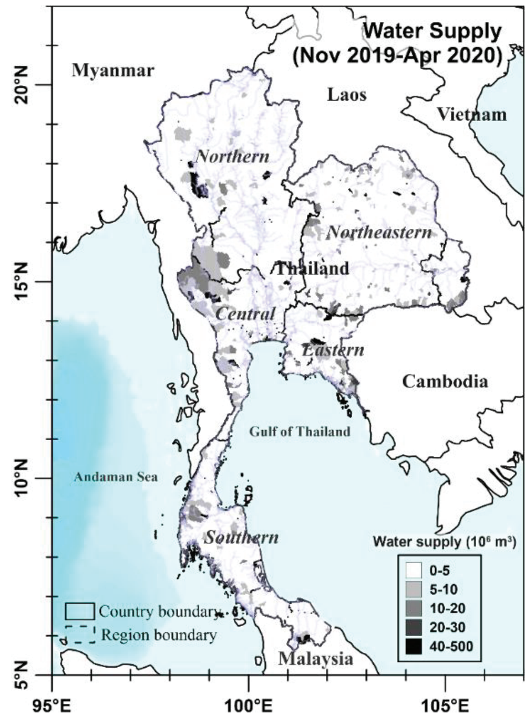


Fig. 6 Water supply in the dry season 2019/2020 in the rainfed agricultures

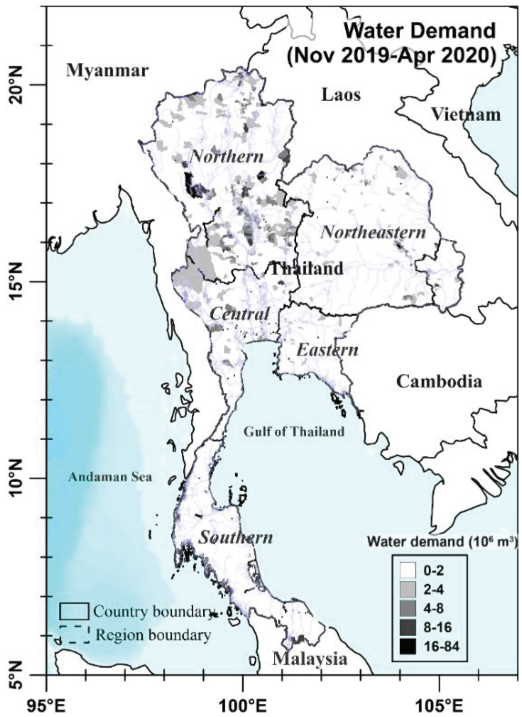


Fig. 7 Water demand in the dry season 2019/2020 in the rainfed agricultures

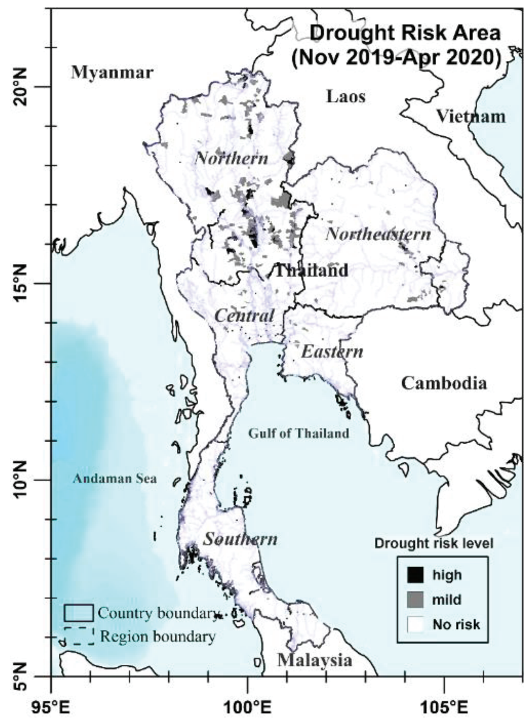


Fig. 8 Drought risk areas in the dry season 2019/2020 in the rainfed agricultures

3 DISCUSSIONS ON WATER CRISIS PREVENTION AND MITIGATION PLANS

Water crisis prevention and mitigation measures by DWR were adopted to minimize the magnitude of water disasters in rainfed agriculture mainly. The measurements were taken in order to improve the efficiency of water resource management and reduce the impact of water disasters. The disaster management was employed to prepare the water crisis prevention and mitigation plans in the before, during, and after the disaster strikes. The disaster management are detailed as the following.

3.1 Prevention and Mitigation Measures

The prevention and mitigation measures are the before-disaster management for reducing the losses of life and property from water disasters. Moreover, the impacts are felt by human suffering and property damage and loss of livelihood, economic deterioration, and environmental destruction. Therefore, DWR considered the issues and needs associated with implementing a national disaster agency and the provincial offices of natural resources and environment as described in the following information.

(1) Information on water resources is critical for monitoring and warning of water crisis in the high-risk areas. At each phase of the disaster management cycle must be made that require getting the right information to the right people at the right time. Therefore, decisions are made in both the public and the private sectors and often at local or individual levels.

(2) Flash flood, and drought risk assessments for sub-district levels in rainfed agriculture were generated by applying the techniques of hydrology and water resources management.

(3) The raising awareness of forecasting and warning systems is contingent upon wide promotion. The problem is how to make this information available to many groups in a strategic manner. DWR planned awareness-raising activities to define the target group. Following that, we assigned each group a topic and selected an appropriate strategy.

3.2 Preparation Measures

The preparation measures for preventing and mitigating water crisis in rainfed agriculture have consisted of mitigation plans and warning systems. The details of preparation measures in rainfed agriculture are as follows.

(1) Mitigation plan at the local level by DWR was initiated with all those interested: those at risk, those who are competent in assisting risk reduction activities (e.g., crisis service, water management service, and forecasting service). Therefore, cooperation and discussion between the groups at risk and professionals in drawing up the action plans bring many measurable advantages.

(2) Inventory preparation is the most important element for identifying possible solutions and preparing an implementation plan. Consequently, DWR prepared and maintained the real-time stations in the mountainous areas and flood plain areas. In addition, for crisis service, the machinery and equipment were available for crisis management in the regional offices of the Department of Water Resources.

3.3 Emergency Management Measures

During the water crisis, the Department of Water Resources has established the water operation center in the headquarter office and the 11 regional offices for emergency management in raising awareness of residents for evaluating the scale of danger, the various methods of countering damage, and behavior during a water crisis.

3.4 Rehabilitation Measures

Rehabilitation and reconstruction are post-disaster measurements. Therefore, it is critical to prevent the creation of and to reduce disaster risk by "Building Back Better". For example, DWR rehabilitated and reconstructed its infrastructures damaged from the disaster, such as hydraulic structures, water bodies, real-time stations, water distribution projects, and solar-powered irrigation systems.

4 SUMMARY

In view of rising demand and stress on water management, as well as climate variability, the urgent need for water resources management in agricultural and disaster management to meet future food and livelihoods is highlighted. The rainfed agriculture plays and thus will continue to play a dominant role in providing food, generating incomes, and ensuring water security. This study described the flash flood warning system, seasonal drought forecasting, and water crisis mitigation strategy in the context of DWR's water crisis management in rainfed agriculture.

For flash flood monitoring and forecasting, DWR installed the Early Warning System to observe rainfall and water level in mountainous areas. Furthermore, the flash flood warning systems are coupling used the forecasting system and in-situ stations to clarify the flash flood risk. The results indicated that the coupling system for the flash flood warning system is clearly effective for implementing the actual situation in flash flood forecasting. In terms of a drought forecasting system, the water balance process was applied to determine the water deficit areas at the sub-district level in Thailand. The water supplies were evaluated by measuring all the available water in rainfall-runoff, water bodies, and watercourses. Furthermore, the water demands were calculated for domestic, agriculture, ecology, and industry sectors. The study results on water balance were in good agreement with drought areas identified by the disaster management agency.

DWR implemented water crisis preventive and mitigation strategies to reduce the severity of water disasters, primarily in rainfed agriculture. The measurements were taken in order to improve the efficiency of water resource management and reduce the impact of water disasters. Additionally, the disaster management was employed to prepare the water crisis prevention and mitigation plans in the before, during, and after the water disaster. To begin, prevention and mitigation measures are used to reduce the loss of life and property caused by water disaster prior to the occurrence of the disaster. Therefore, the DWR considered the issues and needs associated with implementing a national disaster agency and the provincial offices regarding water resources information and forecasting systems. Secondly, the preparation measures for preventing and mitigating water crisis consist of mitigation plans and warning systems. Thirdly, in emergency management, DWR has established the water operation center in the headquarter office and the regional offices for emergency management to raise residents' awareness for evaluating the scale of danger. Lastly, rehabilitation are post-disaster measurements. Consequently, it is critical to prevent the creation of and to reduce disaster risk by "Building Back Better".

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to the Department of Water Resources for providing the Early Warning System information and preparing Water Crisis Prevention and Mitigation Plans. The Flash Flood Guidance System in Lower Mekong member countries was developed by the World Meteorological Organization, Mekong River Commission, and Hydrologic Research Center (CA, USA).

REFERENCES

(1) World Bank, (2005), Agricultural Growth for the Poor: An Agenda for Development, US: World Bank, Washington, DC.
(2) Patsinghasanee S, Laonamsai J, Suwanprasert K, Lakmuang M, Parasirisakul R and Patsinghasanee R (2019), Classification of the rainfed areas for the water development projects in Thailand. Proc. of the THA 2019 International Conference on Water Management and Climate Change towards Asia's Water-Energy-Food Nexus and SDGs, Bangkok, pp. 257-261.
(3) Wani SP, Sreedevi TK, Rockström J and Ramakrishna YS (2009), Rainfed Agriculture – Past Trends and Future Prospects, Rainfed Agriculture: Unlocking the Potential, CAB International, London, pp. 1-35.
(4) Ryan JG and Spencer DC (2001), Challenges and Opportunities Shaping the Future of the Semi-Arid Tropics and their Implications, India: International Crops Research Institute for the Semi-Arid Tropics, Andhra Pradesh.
(5) Office of the National Water Resources (2019), The 20-year master plan on water resources management B.E.2561-2580 (2018-2037) in Thailand, Royal Thai Government Gazette, Bangkok, pp. 46. (in Thai)
(6) Association Programme on Flood Management (2012), Integrated Flood Management Tools Series, Vol. 16, World Meteorological Organization, Geneva.
(7) Shamir E, Georgakakos KP, Spencer C, Modrick TM, Murphy MJ and Jubach R (2010), Evaluation of real-time flash flood forecasts for Haiti during the passage of Hurricane Tomas, November 4–6, 2010, Natural Hazards, Vol. 62, No. 2, pp. 459-482.
(8) Patsinghasanee S, Laonamsai J, Suwanprasert K and Pracheepchai J (2018), Evaluation of MRC flash flood guidance system for the Southern Thailand: Case study from 28th November to 4th December 2017, Proc. of the 23rd National Convention on Civil Engineering, Nakhon Nayok, pp. 313.
(9) Chantip S, Marjang N and Pongput K (2020), Development of dynamic flash flood hazard index (DFFHI) in Wang river basin, Thailand, Proc. of the 22nd IAHR-APD Congress, Hokkaido.
(10) Tovichakchaikul S, Chitprom P and Patsinghasanee S (2007), Annual report of Thailand drought situation and forecasting 2007, Proc. of the 4th Kasetsart University Kamphaengsane Campus Conference, Nakhon Pathom, pp. 328-335. (in Thai)
(11) Laonamsai J, Patsinghasanee S, Suwanprasert K, Pracheepchai J and Wangpimool W (2018), Evaluation of water balance process in dry season for the rainfed areas in Thailand: Case study from 2016 to 2018. Proc. of the 3rd Mekong River Basin International Conference, Siem Reap, pp. 62.
(12) Zhang X and Liu H (2020), Analysis of drought character in the Mekong River Basin, Springer Tracts in Civil Engineering, Singapore, pp. 95-107.
(13) Promping T and Tingsanchali T (2021), Meteorological drought hazard assessment for agriculture area in eastern region of Thailand, Proc. of the 26th National Convention on Civil Engineering, online, pp. WRE-06-1 - WRE-06-7.
(14) Patsinghasanee S, Pracheepchai J, Suwanprasert K, Saprateth T and Laonamsai J (2020), Drought management for the rainfed areas in Thailand: A case study of October 2019 to April 2020 period, Srinakharinwirot Engineering Journal, Vol. 15, No. 3, pp. 54-64. (in Thai)

TA-103L

INVESTIGATION OF HYDROLOGICAL INTERACTIONS IN THE CHAO PHRAYA RIVER SYSTEM IN BANGKOK USING STABLE ISOTOPIC COMPOSITIONS AND HYDROCHEMICAL FACIES

Jeerapong Laonamsai[1]*, Supapap Patsinghasanee[1], Kiattipong Kamdee[2], Kimpei Ichiyanagi[3]

[1]Department of Water Resources, Ministry of Natural Resources and Environment, Bangkok, Thailand
[2]Thailand Institute of Nuclear Technology (Public Organization), Nakonnayok, Thailand
[3]Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan
*Email: jeerapong.lao@gmail.com

Stable isotopic compositions of water ($\delta^{18}O$ and $\delta^{2}H$) have been used as environmental tracers to understand the complicated hydrogeological processes such as paleoclimate, groundwater-surface water interactions, groundwater recharge, and precipitation sources. The isotopic signatures in precipitation and groundwater identify the recharge processes and their hydrological connectivity. Therefore, the present study focuses on a detailed seasonally varying interaction and flux quantification between the river and monsoon precipitation and groundwater in the Chao Phraya River basin. This river system feeds an enormous population in central Thailand. Therefore, hydrological interaction and groundwater chemistry are necessary for the effective strategy of water conjunction.

The Chao Phraya basin is the largest watershed in Thailand, covering 35% of the country and draining 157,924 km^2. The precipitation amount is controlled by two monsoons (southwest and northeast monsoons) with 1160 mm of annual precipitation. The study area is in the mainstream, 372 km long, and covers a basin area of 20,126 km^2. Precipitation generates 23,346 million m^3 of annual runoff. The high-flow period starts from May to October, which accounts for 74% of the runoff of the entire year. The groundwater aquifer forms the geological basis as a depositional flood plain from North to Southeast with mountains of volcanic rocks surrounded in the West. The aquifer system was defined as a two-layered aquifer with the thickness of the upper, semi-confining layer varying between 10-70 m and lower confining layer between 100-300 m based on the geological conditions of similar hydrogeologic properties and their confining boundaries.

Water samples were collected in Bangkok during 2013-2015 and 2019. Most samples were shallow groundwater, precipitation, and the Chao Phraya River. Water $\delta^{18}O$ and $\delta^{2}H$ values were measured using a cavity ring-down spectroscopy isotopic water analyzer (L2130-i, Picarro Inc., Sunnyvale, CA, USA) at the Thailand Institute of Nuclear Technology and reported relative to the Vienna Standard Mean Ocean Water (VSMOW). The analytical precision (1σ) for $\delta^{18}O$ and $\delta^{2}H$ were 0.16 ‰ and 0.45 ‰, respectively. Furthermore, samples in 2019 were also measured for hydrochemical facies using an ion chromatography analyzer (Systronics, 883 Basic IC plus) at the Isotope Hydrology Laboratory in Kumamoto University.

Based on the isotope of precipitation, river water, and groundwater, the mean isotope of surface water was highest compared with others. It can be attributed to the evaporative enrichment in river water as its fundamental characteristic. On the other hand, the rainfall isotope had a wider range. This result is indicative of the altitude effect in the basin. Moreover, the relationships of $\delta^{18}O$ and $\delta^{2}H$ in precipitation are shown as the LMWL. Groundwater and river water fell along this LMWL, indicating that precipitation is the primary source supplying groundwater aquifer and river runoff.

Moreover, contributing parameters to the total river discharge on a temporal scale were estimated through three-component hydrograph separation and end-member mixing analysis using high-resolution water isotope ($\delta^{18}O$) and electrical conductivity. This model reports groundwater discharge in the river to be the highest in the dry season (26% of total discharge). In contrast, the contribution lowers to 2% during the monsoon. Monsoon precipitation directly generates river runoff during monsoon, which is also justified using the isotopic amplitude damping approach of river water and precipitation. The mean water residence time is about 30 days, meaning that monsoon precipitation molecules have stayed in the river for a month. Furthermore, hydrological interaction reflects quantitative variability depending on river morphometry.

The current study also provides insight into aquifer vulnerability due to chemical mixing through interaction and reasonable water resources management efforts. The results of the chemical analysis of 266 groundwater samples were evaluated by using the Piper diagram. The groundwater was generally found in 3 main types: Na-K-CO_3-HCO_3, Na-K-Cl-SO_4, Ca-Mg-CO_3-HCO_3. The shallow groundwater in the coastal areas had a high concentration of Na-K-Cl-SO_4. Furthermore, evaluation of the groundwater types suggested a mixing process between the upstream freshwater and saline water showing in the shallow groundwater. There was a clear indication of the contribution from the weathering of rocks. The dissolution of the minerals was the primary process occurring in the groundwater environment. Dominated Ca and Mg elements in groundwater were found in the upstream area, representing the recharge water. However, the dominance of Na and HCO_3 suggested an ion exchange process owing to sufficient rock-water interaction. The Na and Cl ions dominated the lower basin area, which represented the discharge zone and possible salt intrusion from saline water.

In conclusion, this study integrated the isotopic compositions of precipitation-river-groundwater in the lower Chao Phraya River basin for investigating a hydrologic interaction. The comparison result of water isotope suggests that the monsoon precipitation supplies the river water directly during the wet season. However, groundwater discharge increased during the post-monsoon season due to decreasing upstream runoff and rainfall, representing a distinct seasonal variation of river components. Furthermore, the result of the hydrochemistry suggests that the groundwater in the lower Chao Phraya river basin is alkaline type in nature. The groundwater quality is controlled by the cation exchange process, mineral dissolution, and saltwater intrusion. These findings are helpful information in understanding the hydrogeological processes at the rainfall-river-aquifer boundary and how they are connected to the geochemical processes and the policies for conjunctive water allocation.

Keywords: Isotopes, Hydrochemistry, watershed

TA-105S

SENSITIVITY ANALYSIS OF THE RUNOFF IN THE LAND SURFACE MODELS FORCED BY THE OUTPUT OF MRI-AGCM 3.2 CLIMATE MODEL

Aulia Febianda Anwar Tinumbang
Department of Civil and Earth Resources Engineering Graduate School of Engineering
Kyoto University
Kyoto, Japan
anwar.febianda.28n@st.kyoto-u.ac.jp

Kazuaki Yorozu
Department of Civil and Earth Resources Engineering Graduate School of Engineering
Kyoto University
Kyoto, Japan

Yasuto Tachikawa
Department of Civil and Earth Resources Engineering Graduate School of Engineering
Kyoto University
Kyoto, Japan

Yutaka Ichikawa
Department of Civil and Earth Resources Engineering Graduate School of Engineering
Kyoto University
Kyoto, Japan

ABSTRACT
The risks of flooding in the future are projected to increase in magnitude and frequency under global warming. To make such projections, runoff output from general circulation models (GCMs) or regional climate models (RCMs) are widely used to simulate the river flow. Some studies have pointed out there are some gaps between the estimated discharge forced by the runoff from GCMs/RCMs and the observed discharge. In the GCMs/RCMs, runoff is estimated by the land surface model (LSM). To improve the accuracy of the simulated discharge forced by the runoff generated by LSM, it is necessary to figure out the sources of uncertainty in the model. Therefore, this study aims to is to conduct a sensitivity analysis of the runoff generated by two LSMs: SiBUC and MRI-SiB. This study utilized atmospheric data from the output of atmospheric general circulation model MRI-AGCM 3.2 as forcing in both LSMs. The numerical experiments were applied in the upper part of the Ping River Basin in Thailand, with the total catchment area is about 26,176 km^2. We found that even though the same forcing data forced both LSMs, the estimated runoff and its simulated discharge were different depending on the model. To figure out why such differences happened, different settings (e.g., parameters, structures) between the two models were examined. This study identified different settings that mainly affected the runoff generation and the simulated discharge in both LSMs. For example, incorporation of direct infiltration pathway from the soil surface into deeper soil layer in MRI-SiB caused a decrease of surface runoff and increase of subsurface runoff, consequently resulting in a slower response of the simulated discharge to the rainfall. It is thought that the findings in this study could provide some insights to identify the sources of uncertainty in LSMs and propose better settings for improving the runoff accuracy to reproduce the observed river flow.

Keywords— climate change; runoff; land surface models; river discharge

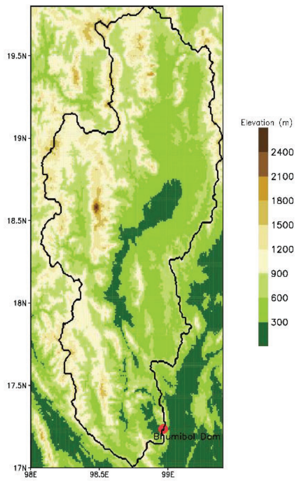


Fig. 1. Topography of upper part of Ping River. Black line shows basin boundary. Red circle shows Bhumibol Dam location.

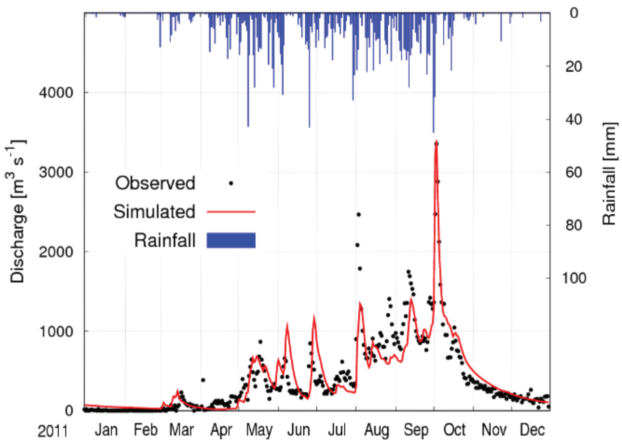


Fig. 2. Reproducibility of river discharge by SiBUC in 2011 at the outlet of Bhumibol Dam. Reproduced from Yorozu *et al*. (10).

INTRODUCTION

Many regions worldwide have been affected by unprecedented extreme floods and droughts in recent years. The latest assessment report by the Intergovernmental Panel on Climate Change (1) predicts that water-related disasters increase in magnitude and frequency owing to global warming. Previous impact assessment studies (2, 3) sought to project changes in future river discharge using runoff (ROF) output from general circulation models (GCMs) and regional climate models (RCMs). However, they pointed out that the simulated discharge by runoff from GCMs/RCMs is biased. This bias could be due to precipitation and/or runoff bias. The latter, ROF, is the focused in this study. The runoff is estimated using the land surface model (LSM) embedded in GCMs/RCMs. It is necessary to evaluate the performance of LSMs with respect to river discharge because runoff plays an essential role in river discharge simulation. In addition, it is important to identify sources of uncertainty in runoff generation processes in LSMs to enhance the model performance. In this study, we aimed to evaluate streamflow simulated by runoff from LSMs and investigate the sources of runoff uncertainty by analyzing the runoff generation schemes in the LSMs. Analysis of the sources of uncertainty in LSMs is necessary for improving the runoff accuracy to reproduce the observed river flow.

1 METHODOLOGY

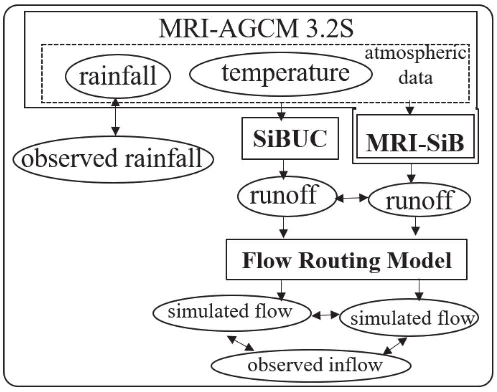
1.1 Overview

In this study, two LSMs were utilized: Simple Biosphere including Urban Canopy (SiBUC) (4) and Meteorological Research Institute - Simple Biosphere Model (MRI-SiB) (5). Both LSMs have been developed based on Simple Biosphere (6). Therefore, the main functions are similar in both models. For example, soil water movement in both LSMs is described by three soil layers utilizing simplified Richards's equation. However, as the two of them have been developed independently, parameter settings, detailed model structures, etc., are different (described in section 1.3).

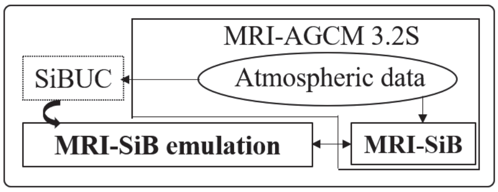
Numerical experiments for both LSMs were conducted in the upper part of the Ping River Basin in northern Thailand, as shown in Fig. 1. The basin is one of the main tributaries of the Chao Phraya River. The main dam in the basin is the Bhumibol Dam, which has a total catchment area of approximately 26,176 km^2.

In this study, both LSMs were forced by atmospheric data from MRI-AGCM 3.2S, a GCM with a mesh size of about 20 km (7). MRI-SiB is embedded in this climate model. SiBUC applied in this basin was developed by Yorozu et al. (8). They confirmed that the generated runoff by SiBUC could well reproduce the 2011-big flood event in this basin, as shown in Fig. 2, with Nash-Sutcliffe Efficiency (NSE) is 0.79, Root Mean Square Error (RMSE) is 219 m^3 s^{-1}, and the correlation coefficient is 0.90. Therefore, SiBUC was selected for this study.

Fig. 3 shows a framework of this study, which is divided into two parts: evaluation of discharge simulated by runoff from both LSMs, and investigation of runoff generation schemes in the LSMs.



1. Evaluation of discharge simulated by LSMs.



2. Investigation of runoff generation schemes in LSMs.

Fig. 3. Framework of this study.

1.2 Evaluation of discharge simulated by runoff from LSMs

First, we investigated the applicability of runoff generated by both LSMs to streamflow simulation. Before runoff simulation is performed, estimated rainfall by GCM was compared with observed historical data. In this study, CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) (9) rainfall dataset was selected as a reference. This dataset is a quasi-global satellite data product with in-situ station rainfall data. Observation data from rain gauges installed in this basin was not utilized in this study.

After the rainfall assessment, a runoff simulation was performed. We investigated the difference in water budget and runoff components by both SiBUC and MRI-SiB. Next, river flow was simulated by a flow routing model 1K-FRM (10) using the runoff from both LSMs. 1K-FRM is a distributed flow routing model developed based on a one-dimensional kinematic wave theory. The discharge simulated by both LSMs was evaluated with respect to observed inflow at the outlet of Bhumibol Dam. This study only utilized historical output data from MRI-AGCM 3.2S, consisting of 25 years from 1979-2003. Numerical simulations were performed for the whole 25 years. The first five-year results were discarded as model spin-up, and the last twenty years were used for analysis.

1.3 Investigation of runoff generation schemes in the LSMs

Past research has shown a considerable spread in runoff output among different LSMs (3, 11, 12). However, it is unclear whether this spread is related to parameters settings (i.e., soil parameters), model structures (i.e., infiltration mechanisms), or other reasons. Identifying uncertainty sources is challenging owing to the complexity of and different ways in which runoff generation schemes are described. To address such problems, we conducted sensitivity analysis which enabled us to investigate the effect of various settings on runoff estimation in LSMs.

Some different settings between the two LSMs are summarized in Table 1, based on the findings of our previous study (13). In both LSMs, land surface parameter settings (including soil and vegetation parameters) are different. For instance, soil parameters related to runoff and infiltration processes such as saturated hydraulic conductivity and saturated matric potential in MRI-SiB are higher than SiBUC. In contrast, soil depth in SiBUC is significantly deeper than in MRI-SiB. In addition, detailed model structures in both LSMs are also different. In MRI-SiB, there is a direct infiltration pathway into the second soil layer, which we called as “P_2 scheme” in this paper. Due to the incorporation of the P_2 scheme, when rainfall happens, some rainwater can infiltrate into the surface

TABLE 1 COMPARISON OF DIFFERENT SETTINGS BETWEEN SIBUC AND MRI-SIB

Settings	**LSMs**	
	SiBUC	**MRI-SiB**
Land surface parameters, for instance[a]:		
Saturated hydraulic conductivity, K_s (m s^{-1})	1.44×10^{-6}	2×10^{-5}
Saturated matric potential (m)	-0.63	-0.086
Soil depth (m)	up to 12	up to 3.5
Direct infiltration pathway into a deeper soil layer	no	yes
Soil-water flow equation	Eq. (1a)	Eq. (1b)
Subsurface runoff equation	Eq. (2a)	Eq. (2b)

[a] based on dominant value

TABLE 2 EXPERIMENTAL DESIGNS

Experiments	**Settings**
1	Using MRI-SiB land surface parameters
2	MRI-SiB parameters and incorporating P_2 scheme
3	MRI-SiB parameters and neglecting gravitational drainage for calculating soil-water flow
4	MRI-SiB parameters and including hydraulic diffusion for estimating subsurface runoff
5	Combining all above settings

soil layer and directly into deeper soil layer. In SiBUC, such structure does not exist. The rainwater can only enter into the surface soil. Another difference is related to soil-water flow calculation. In SiBUC, soil-water flow between adjacent soil layers is based on Darcy's Law by considering hydraulic diffusion and gravitational drainage, as shown in Eq. (1a). In MRI-SiB, the gravitational drainage term is neglected, and it is only based on hydraulic diffusion, as indicated in Eq. (1b). Subsurface runoff calculation is also treated differently. SiBUC is based on gravitational drainage only, as indicated in Eq. (2a)., while in MRI-SiB, hydraulic diffusion is also considered, as shown in Eq. (2b).

$$Q_{i,i+1} = K\left[\frac{\partial\varphi}{\partial z} + 1\right] \tag{1a}$$

$$Q_{i,i+1} = K\left[\frac{\partial\varphi}{\partial z}\right] \tag{1b}$$

$$Q_3 = sin\emptyset_s K_s W_3^{2B+3} \tag{2a}$$

$$Q_3 = sin\emptyset_s K_s W_3^{2B+3} + \frac{\varphi_2 - \varphi_3}{z_3} \tag{2b}$$

note that $Q_{i,i+1}$ is soil-water flow between adjacent soil layer, K is hydraulic conductivity, K_s is saturated hydraulic conductivity, φ is matric potential, z is soil depth, Q_3 is subsurface runoff, $sin\emptyset_s$ is slope, W_i is soil wetness of i^{th} layer, and B is parameter.

In this study, sensitivity analysis was conducted to investigate the impact of different model settings on runoff estimation. The numerical experiments were performed by SiBUC by adopting MRI-SiB parameters and structures, and the results by MRI-SiB were set as a reference. In total, five experimental cases were conducted by SiBUC, as shown in Tabel 2. Experiment 1 was carried out to investigate the impact of different land surface parameters. Experiments 2 – 5 were conducted by changing land surface parameters and model structure. The impact of each setting was evaluated with respect to the change of runoff components (surface and subsurface runoff).

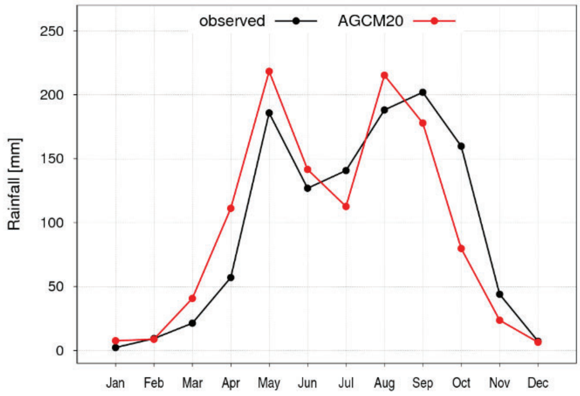


Fig. 4. Climatological mean of monthly rainfall

TABLE 3 COMPARISON OF WATER BUDGET COMPONENTS BETWEEN SIBUC AND MRI-SIB

Water budget components (mm year^{-1})	LSMs	
	SiBUC	**MRI-SiB**
Evapotranspiration (ET)	976	999
Runoff (ROF)	194	146
Surface runoff (Qs)	58	3
Subsurface runoff (Qsb)	136	143
Change of soil moisture (delSM)	-17	1

2 RESULTS: EVALUATION OF DISCHARGE SIMULATED BY LSMs

2.1 Assessment of rainfall output from MRI-AGCM 3.2S

Fig. 4 shows a comparison of 20-years-mean monthly rainfall from observation and simulation by GCM. Observed rainfall shows a distinct rainy season (from May to October) and dry season (from November to April). As seen, the GCM rainfall could capture the seasonal cycle of precipitation in this basin. The peak of observed rainfall is in September, while the GCM rainfall produces an earlier peak in August.

Basin average annual rainfall from GCM is close to the observation, which is 1144 mm. More than 80% of the annual rainfall occurs in the wet season, and the rest in the dry season. Simulated rainfall by GCM in the wet season slightly underestimates, while it overestimates the observed precipitation in the dry season.

2.2 Comparison of water budget components between LSMs

Table 3 shows 20-years-mean water budget components estimated by SiBUC and MRI-SiB. MRI-SiB tends to estimate higher evapotranspiration and lower runoff than that by SiBUC. In terms of runoff components, SiBUC predicts higher surface runoff and lower subsurface runoff than MRI-SiB. Surface runoff and subsurface runoff by SiBUC occupy about 30% and 70% of the total runoff, respectively. While, in MRI-SiB, subsurface runoff is dominant, and surface runoff only counts for 2% of the total runoff. This analysis has revealed the differences in water budget estimation and the ratio of runoff components between the two LSMs, even though they were forced with the same atmospheric forcing data. More detailed investigations to find out the reason for such differences are described in section 3.

2.3 Evaluation of streamflow simulated by runoff from LSMs

Before the streamflow simulated by both LSMs is evaluated, we examined characteristics of daily discharge by the two LSMs. Fig. 5 shows daily discharge estimated by SiBUC and MRI-SiB in 1991, as an example. In this figure, the observed discharge is not added as both of LSMs were forced by the output of the climate model, not the observation data. Both LSMs show different abilities in simulating the streamflow due to the differences in runoff estimation. As seen, simulated discharge

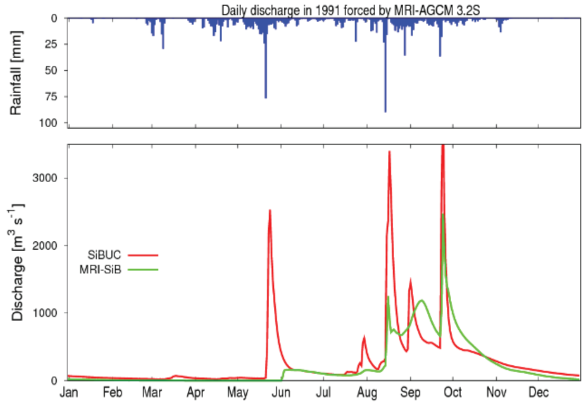


Fig. 5. Simulated daily discharge in 1991 by SiBUC (red line) and MRI-SiB (green line).

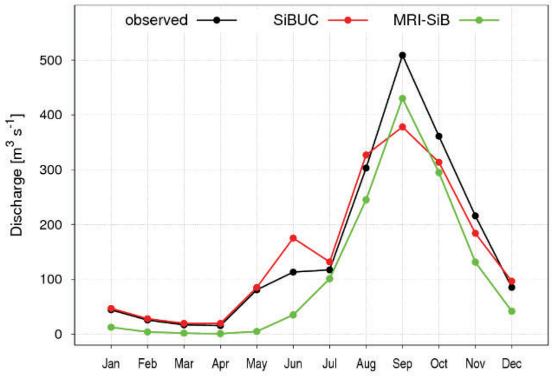


Fig. 6. Comparison of mean monthly streamflow between observed inflow (black line), simulated flow by SiBUC (red line) and MRI-SiB (green line).

by SiBUC tends to be higher than MRI-SiB, owing to higher runoff. The temporal pattern of increase and decrease of the hydrograph by SiBUC show a similar response to the rainfall events. The discharge by SiBUC, particularly in the case of heavy rainfall, was formed mainly through surface runoff. Consequently, it increases soon after the precipitation events. Meanwhile, the streamflow estimated by MRI-SiB does not show a high response, particularly at the beginning of rainfall events in May. As subsurface runoff is the dominant runoff component in MRI-SiB, the effect of catchment wetness is clear. During the transition between dry and wet seasons, the soil is in unsaturated condition. Therefore, the rainwater is first used to increase the soil moisture, and as the wetness of the soil gets higher, the discharge starts to rise.

Next, river flow simulated by runoff from both LSMs is evaluated by comparing climatological mean (20-years-mean) of monthly simulated and observed river flow, as shown in Fig. 6. Streamflow estimated by SiBUC shows a similar time series of observed discharge: low flow in the dry season, slightly high flow in the early rainy season (May to July), and high flow in the late rainy season (August to October). On the other hand, peak discharge by MRI-SiB is closer than SiBUC to the peak observation. However, the discharge by MRI-SiB failed to reproduce the observed discharge, particularly in the early wet season. That is due to the difference in runoff estimation by both LSMs, as mentioned earlier. In terms of volume, simulated streamflow by SiBUC in both wet and dry seasons is close to the observed river flow. Meanwhile, the discharge by MRI-SiB underpredicts the observation throughout the year.

This study has revealed the different runoff estimations by each LSM and how it affects the simulated streamflow.

3 INVESTIGATION OF RUNOFF GENERATION SCHEMES in LSMs

Fig. 7 shows changes in runoff components by adopting MRI-SiB settings in SiBUC. As mentioned previously, both LSMs show a significant difference in the ratio of runoff components: SiBUC tends to estimate higher surface runoff and lower subsurface runoff than MRI-SiB. In contrast, in MRI-SiB, subsurface runoff is the dominant runoff component. That difference is owing to different settings among both LSMs.

First, the impact of land surface parameters is investigated in experiment 1. By adopting MRI-SiB soil parameters in SiBUC, surface runoff significantly increases, while subsurface runoff decreases compared to SiBUC results. That could be due to the shallow soil depth setting in the MRI-SiB. Thinner soil depth could increase the surface runoff since the soil has a lower capacity to store the rainwater.

Next, the impact of incorporating the P_2 scheme is analyzed in experiment 2. As seen, surface runoff decreases and subsurface increases compare to experiment 1. The surface runoff reduces due to an increase of infiltrated rainwater in the soil. As the infiltrated water increases, the subsurface runoff also becomes higher.

Impact of neglecting gravitational drainage in Darcy's Law is shown in experiment 3. Surface runoff is significantly lower compared to experiment 1. Ignoring gravitational drainage might cause lower

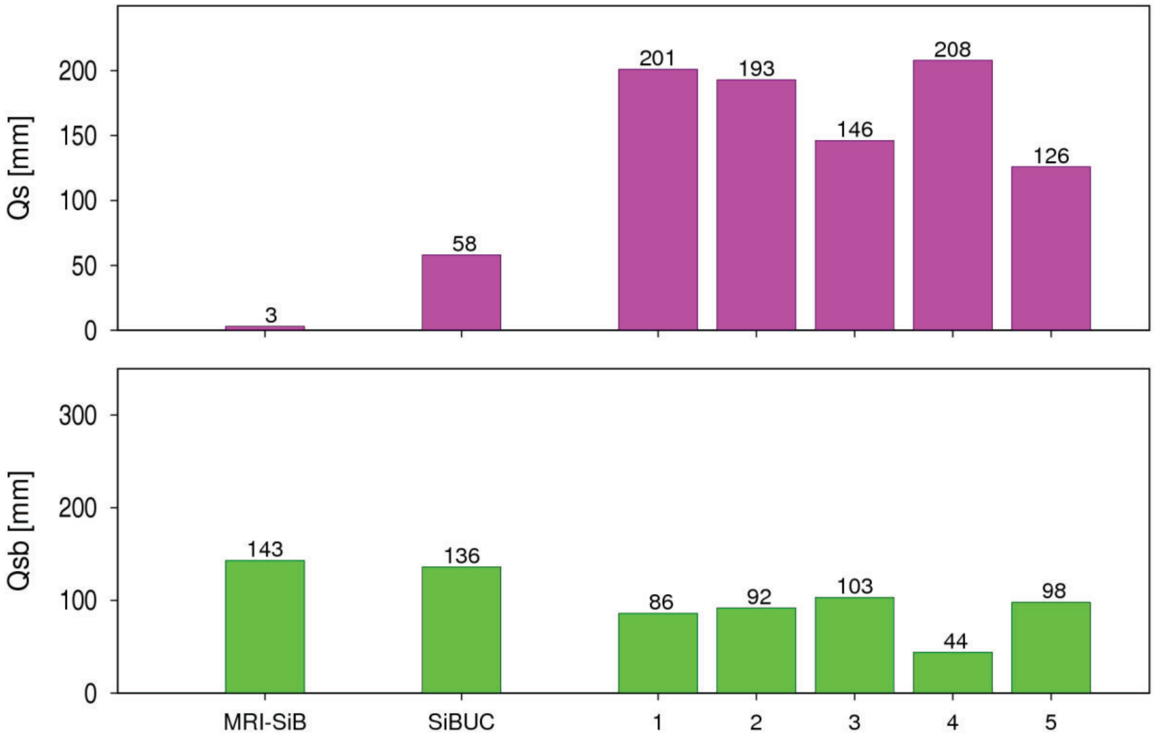


Fig. 7. Results of sensitivity analysis to investigate the impacts of different settings among LSMs. Pink and green bars represent surface runoff (Qs) and subsurface runoff (Qsb), respectively.

soil-water flow. As a result, soil moisture was kept high, resulting in higher evapotranspiration and lower runoff.

Experiment 4 analyzed the impact of considering hydraulic diffusion on subsurface runoff estimation. The increase or decrease of subsurface runoff depends on the soil moisture of the second and third soil layers. If the soil moisture of the second layer is higher than the third layer, subsurface runoff increases; otherwise, it decreases. This analysis shows that considering hydraulic diffusion for subsurface runoff estimation results in the lower subsurface runoff compared to experiment 1.

In experiment 5, all model parameters and structures of MRI-SiB were adopted in SiBUC. Surface runoff is higher, and subsurface runoff is lower than experiment 1, owing to the impact of each setting, as already mentioned earlier.

Even though SiBUC has adopted all MRI-SiB settings, the runoff characteristics of MRI-SiB still could not be well reproduced. Therefore, further investigation is necessary to understand which other settings affect the runoff estimation by LSMs. Throughout this activity, we have demonstrated a framework to identify sources of bias in the runoff generation schemes in the LSMs. This framework can be extended to propose better settings for improving the runoff accuracy by LSMs to reproduce the observed river flow.

4 SUMMARY

This research investigated the applicability of runoff generated by two land surface models (LSMs): SiBUC and MRI-SiB, for streamflow simulation. Atmospheric output from MRI-AGCM 3.2S was used as forcing for both LSMs. Based on water budget analysis, SiBUC tended to estimate higher evapotranspiration and lower runoff than MRI-SiB. Different LSMs also generated different runoff characteristics. SiBUC estimated higher surface runoff and lower subsurface runoff than MRI-SiB. In comparison, the subsurface runoff was the dominant runoff component in MRI-SiB. The different runoff estimation by each LSM has impacts on the simulated streamflow. To determine the reasons for such differences, runoff generation schemes in both LSMs were analyzed in detail. This study has shown some different settings that contribute to the sources of runoff uncertainty in both LSMs. However, further work is necessary to identify which other settings affect the runoff estimation by LSMs.

ACKNOWLEDGMENTS
This study is supported by the Integrated Research Program for Advancing Climate Models (TOUGOU) Theme-C and D supported from MEXT Japan (Grant Number JPMXD0717935561 and JPMXD0717935498).

REFERENCES
(1) IPCC (2021): Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. *Cambridge University Press*. In Press.
(2) Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., and Kanae, S. (2013): Global flood risk under climate change, *Nature Climate Change*, Vol. 3, pp. 816-821.
(3) Nohara, D., Kitoh, A., Hosaka, M., Oki, T. (2006): Impact of Climate Change on River Discharge Projected by Multimodel Ensemble, *J. Hydrometeorol.*, Vol. 7, pp. 1076–1089.
(4) Tanaka, K. (2005): Development of the new land surface scheme SiBUC commonly applicable to basin water management and numerical weather prediction model, *doctoral dissertation*, Kyoto University.
(5) Hirai, M., Sakashita, T., Kitagawa, H., Tsuyuki, T., Hosaka, M., Oh'izumi, M. (2007): Development and Validation of a New Land Surface Model for JMA's Operational Global Model Using the CEOP Observation Dataset, *J. Meteor. Soc. Jpn.*, Vol. 85A, pp. 1-24.
(6) Sellers, P. J., Mintz, Y., Sud, Y. C., and Dalcher, A. (1986): A simple biosphere model (SiB) for use within general circulation models, *J. Atmos. Sci.*, Vol. 43, No. 6, pp. 505-531.
(7) Mizuta, R., Yoshimura, H., Murakami, H., Matsueda, M. Endo, H., Ose, T., Kamiguchi, K., Hosaka, M., Sugi, M. Yukimoto, S., Kusunoki, S.,and Kitoh, A. (2012): Climate simulations using MRI-AGCM 3.2 with 20-km grid, *J. Meteor. Soc. Jpn.*, Vol. 90A, pp. 233-258.
(8) Yorozu, K., Kurosaki, N., Ichikawa, Y., Kim, S., and Tachikawa, Y., (2018): A study on long-term river discharge data generation by distributed hydrologic model and recombination atmospheric data, *J. JSCE*, Ser. B1 (Hydraulic Engineering), Vol. 74, pp. I_127-I_132 (in Japanese).
(9) Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., and Michaelsen, J. (2015): The climate hazards infrared precipitation with stations-a new environmental record for monitoring extremes, *Scientific Data 2*, 150066.
(10) Kyoto University Department of Civil and Earth Resources Engineering Hydrology and Water Resources Research Laboratory: 1K-FRM/1K-DHM, http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html [Access: November 24, 2021].
(11) Tinumbang, A. F. A., Yorozu, K., Tachikawa, Y., Ichikawa, Y., Sasaki, H., Nakaegawa, T. (2019): Analysis of runoff characteristics generated by land surface models and their impacts on river discharge, *J. JSCE*, Ser. B1 (Hydraulic Engineering), Vol. 75, No. 2, pp. I_127-I_276.
(12) Falloon, P., Betts, R., Wiltshire, A., Dankers, R., Mathison, C., McNeall, D., Bates, P., and Trigg, M. (2011): Validation of river flows in HadGEM1 and HadCM3 with the TRIP river flow model, *J. Hydrometeorol.,* Vol. 12, No. 6, pp. 1157-1180.
(13) Tinumbang, A. F. A., Yorozu, K., Tachikawa, Y., Ichikawa, Y., Sasaki, H., Nakaegawa, T. (2020): Impacts of model structures and soil parameters on runoff characteristics in land surface models, *J. JSCE*, Ser. B1 (Hydraulic Engineering), Vol. 76, No. 2, pp. I_217-I_222.

TA-109S

IMPROVING ACCURACY OF GROUNDWATER STORAGE IN THAILAND USING GRACE DATA ASSIMILATION TECHNIQUE

ABSTRACT
Groundwater storage (GWS) is a fundamental component of the terrestrial hydrology and climate system. Accurate GWS measurements are required for a reliable assessment of regional water resource availability and climate variation but obtaining GWS is very challenging due to the sparsity of the groundwater measurement network. To date, the only measurements of large-scale GWS available are gravity data from the Gravity Recovery And Climate Experiment (GRACE) and GRACE follow-on missions. The coarse spatial resolution of GRACE (e.g., 100,000 km^2), on the other hand, limits its application to groundwater research in large river basins, whereas effective communication with the private sector or public stakeholders would necessitate a much higher spatial resolution. Therefore, this study employs data assimilation (DA) techniques to statistically combine the strengths of satellite data and model estimates to improve the spatiotemporal resolution and accuracy of GWS. The analysis is carried out in Thailand's northern Ping River basin, where in situ groundwater data (ground observations) are available to evaluate DA performance. The results reveal that GRACE DA significantly improves GWS estimates by increasing correlation coefficients (relative to the ground truth) by up to 0.53, highlighting the GRACE DA approach as an effective tool for a groundwater monitoring system in Thailand. The proposed algorithm is entirely based on publicly available data, and the approach is easily adaptable to other regions of Thailand.

***Keywords*—** Data assimilation, GRACE, Groundwater, Thailand

1 INTRODUCTION

Groundwater is critical for supporting ecosystems and facilitating human adaptation to climate change, which may exacerbate water accessibility and food security issues [1]. Accurate groundwater data is thus essential for improving the reliability of the country's strategic plan. However, obtaining groundwater data from ground measurements is difficult due to the scarcity of sampling sites, despite providing accurate groundwater information. In some provinces, for instance, there may be only a few available measurement sites. As a result, groundwater information is frequently obtained through a hydrology or land surface model. A strong point of models is their ability to generate spatially distributed estimates and comprehensive environmental variables. The model's limitation is the significant uncertainty surrounding, for example, inaccurate parameter calibrations and underrepresented model physics, and relying solely on model simulation may result in faulty or invalid predictions.

Groundwater data can also be estimated by measuring the Earth's regional gravity fields over time. These have been observed by the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) satellite missions since 2002 [2]. GRACE-FO is a continuous gravity mission to its successor (GRACE), and this study refers to both missions as GRACE. GRACE is a twin satellite tracking system that flies in a near-polar orbit 500 km above the Earth's surface. The K-band ranging system is used to calculate the range (or range rate) deviation between the twin satellites as a result of changes in Earth's gravity. This range measurement is used to derive variations in terrestrial water storage (TWS), which is the sum of soil moisture, groundwater, canopy, snow, and surface water storage. Satellite gravimetry is distinct from other remote sensing techniques in that it can detect total column of mass variations (including groundwater), whereas other techniques are only sensitive to a few centimeters of depth. The disadvantage of GRACE is its limited spatiotemporal resolution, which only provides monthly-average data at a footprint of approximately 100,000 km^2. This limits GRACE applications to a large area, while direct use of GRACE data is unlikely to benefit local farmland or urban planning.

This study employs the data assimilation (DA) technique to combine the strengths of model simulation and GRACE data. In DA, the model states are statistically adjusted using satellite observations, taking into account the uncertainties in the model states and observations [3]. Despite the success of GRACE DA techniques, they have never been used in Thailand. The purpose of this paper is to demonstrate the GRACE DA application in improving groundwater information in Thailand. The development is demonstrated in the northern part of the Ping River Basin, where in situ groundwater measurements are available to evaluate the results (Fig. 1). GRACE data are assimilated into the Community Atmosphere–Biosphere Land Exchange (CABLE) land surface model (LSM) to improve the groundwater storage (GWS) at a resolution of approximately 5x5 km^2. The analysis from this study highlights the relevance of the GRACE DA technique in assisting a groundwater monitoring system in Thailand.

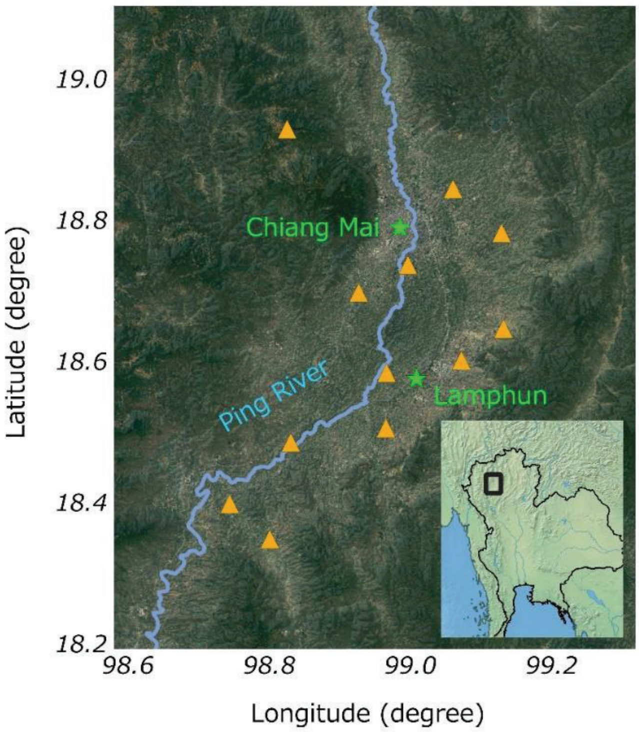


Fig. 1. The northern part of Ping River Basin in Thailand and geolocations of in situ groundwater sites. The inset shows the geolocation of the study area (black rectangle).

2 MODEL SETUP AND DATA

2.1 Model configurations

TWS and GWS estimates are obtained from CABLE LSM simulations, providing comprehensive hydrologic variables at 0.05° (~5 km) resolution [3]. The model was developed by the Commonwealth Scientific and Industrial Research Organization in Australia and has been widely used for global terrestrial hydrology analyses. CABLE TWS includes soil moisture storage (SMS), GWS, snow water equivalent (SWE), canopy storage (CNP), of which SWE and CNP are neglectable in Thailand. Forcing data required for CABLE simulations are precipitation, air temperature, wind speed, humidity, surface pressure, and radiation. Precipitation is obtained from the Climate Hazards Group Infrared Precipitation with Station data [4], while other forcing variables are derived from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 products [5]. To overlay with model spatial resolution, all forcing variables are spatially resampled to 0.05° model grid space using nearest-neighbor interpolation.

2.2 GRACE observations

This study uses the GRACE and GRACE-FO mascon solutions (RL06M.MSCNv02) of the Jet Propulsion Laboratory (JPL), California Institute of Technology, downloaded from http://grace.jpl.nasa.gov. The mascon approach parameterizes Earth's mass variation using mass concentration function, yielding a more accurate TWS estimate than the spherical harmonic basis. From April 2002, the JPL mascon product provides monthly TWS variations and uncertainties at a spatial resolution of about 3° (~300 km). The solutions from April 2002 to December 2020 are used in this study. To obtain TWS variations relative to this study period, the long-term mean computed from all data in time series is removed from each monthly data at each mascon cell.

2.3 In situ groundwater measurements

In situ groundwater is obtained from the Department of Groundwater Resources in Thailand (DRG; http://www.dgr.go.th/th/home). DGR provides groundwater level (H) data on a map-based basis. The data at each site are manually downloaded. Only sites with more than three years of data that do not contain significant data gaps or outliers are used in this study. Because model estimates (GWS) and in situ data (H) are in different domains and cannot be compared directly, the evaluation is only performed in terms of temporal correlation between the two, as specific yield for the conversion from H to GWS is not available.

3 METHODOLOGIES

3.1 Data assimilation

The GRACE-derived TWS variations are assimilated into the CABLE model using the 3-dimensional ensemble Kalman smoother (EnKS 3D). The EnKS 3D accounts for spatial correlations in model and observation errors, given that the latter are highly correlated at neighboring 0.05°×0.05° grid cells (e.g., within 3°×3° observation space). This section provides a high-level overview of the EnKS 3D concept, while more in-depth information can be found in [3]. The EnKS 3D comprises forecast, analysis, and update distribution steps (Fig. 2). The forecast step propagates the ensemble model states forward in time. The analysis step calculates the monthly model state correction using GRACE observations (and uncertainties). The final step reinitializes the initial states and repeats the forecast step with the correction distributed across the month.

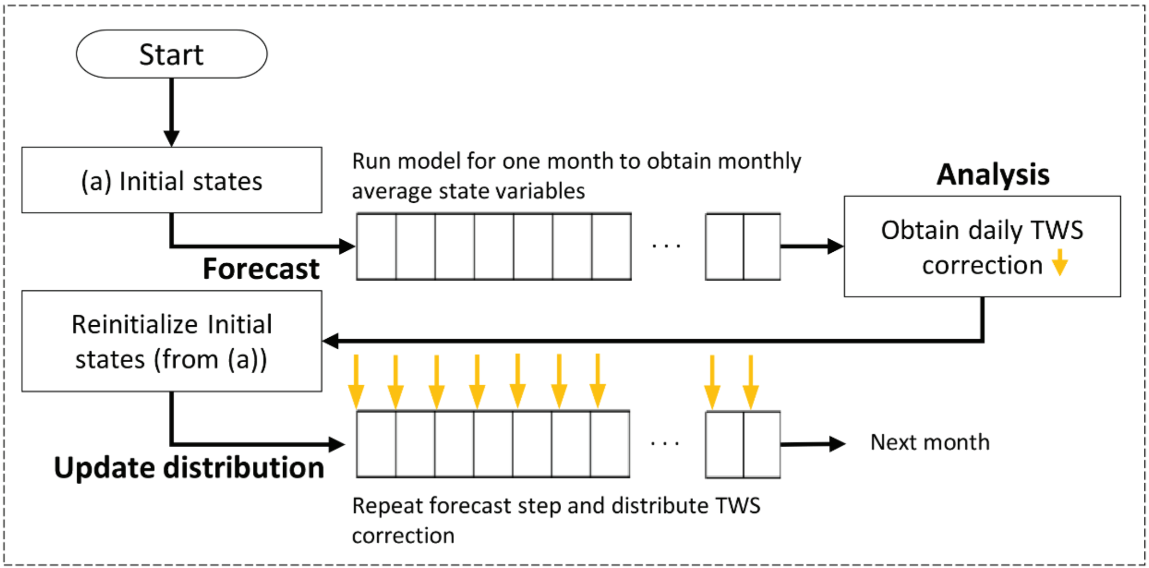


Fig. 2. Data processing diagram of GRACE data assimilation

The formulation of EnKS is as follows. Firstly, the forecast step performs the ensemble model run without data assimilation:

$$\boldsymbol{x}_t^i = \boldsymbol{\mathcal{F}}\left(\boldsymbol{x}_{t-1}^i, \boldsymbol{f}_t^i, \boldsymbol{\alpha}^i\right), \tag{1}$$

where $\boldsymbol{\mathcal{F}}$ is the model operator used to propagate the model states from $t-1$ to t, $\boldsymbol{x}$ is the model state vector (containing SMS and GWS), $\boldsymbol{\alpha}$ represents the model parameters, and $i = 1,2,3,\dots,N$ denotes the index of ensemble member. Note that the ensemble member is generated by adding random noises to the nominal values. The forecast step is run for one month to obtain the monthly average state variables consistent with GRACE temporal resolution. Secondly, the analysis step computes the updated state vector ($\hat{\mathbf{x}}_T$) as follows:

$$\hat{\mathbf{x}}_T^i = \mathbf{x}_T^i + \mathbf{K}\left(\mathbf{y}_T^i - \mathbf{H}\mathbf{x}_T^i\right) = \mathbf{x}_T^i + \Delta\mathbf{x}_T^i, \tag{2}$$

where the subscript T indicates monthly average, $\Delta\mathbf{x}_T$ denotes the monthly correction, $\mathbf{y}_T$ is the observation vector containing GRACE monthly TWS data, $\mathbf{K}$ is the Kalman gain matrix, and $\mathbf{H}$ is the measurement operator relating model state vector to observation. After obtaining the monthly correction $\Delta\mathbf{x}_T$, the daily correction is computed by dividing $\Delta\mathbf{x}_T$ by the number of days in that month. Finally, the update distribution step is carried out by repeating the forecast step but with the daily correction applied to the initial state at the beginning of each day.

3.2 Evaluation metrics

The agreement between the estimated variable and the in situ data is assessed using the Pearson correlation coefficient (*R*) calculated as:

$$R = E[(\boldsymbol{p} - \overline{\boldsymbol{p}})(\boldsymbol{q} - \overline{\boldsymbol{q}})]/(\sigma_{\boldsymbol{p}}\sigma_q), \tag{3}$$

Where the ***p*** vector contains the model estimates, the ***q*** vector contains the validation data (e.g., in situ measurements), $E[\quad]$ is the expectation operator, and $(\overline{\boldsymbol{p}}, \overline{\boldsymbol{q}})$ and $(\sigma_{\boldsymbol{p}}, \sigma_q)$ are the mean and standard derivations of ***p*** and ***q***, respectively.

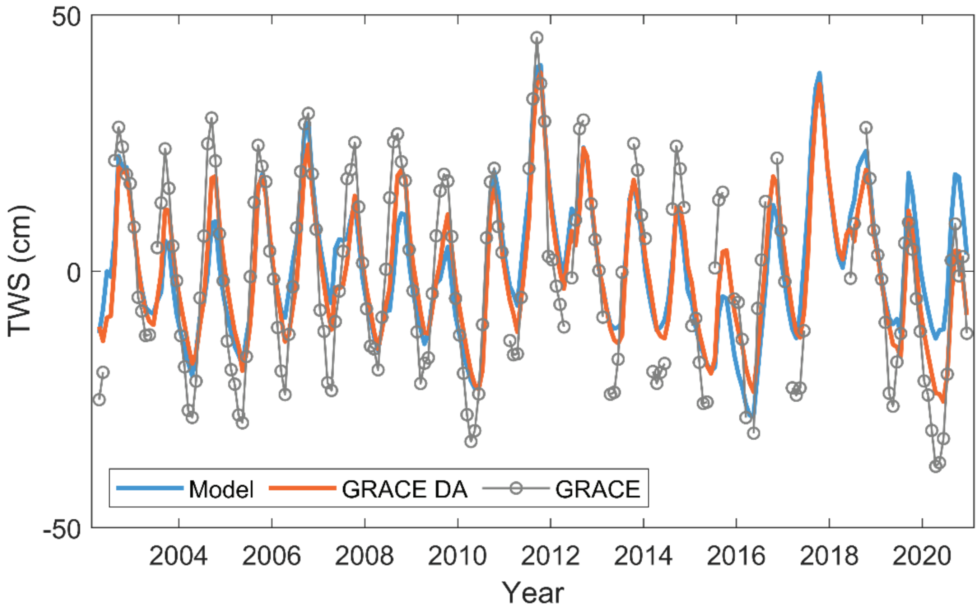


Fig. 3. Basin average TWS variations from CABLE model, GRACE DA, and GRACE observations between 2002 and 2020.

Table 1: Statistical results (correlation and RMSE) calculated from the model and GRACE DA estimates with respect to GRACE data. The long-term trend of all datasets is also shown.

	Model	**GRACE DA**	**GRACE**
Correlation	0.82	0.91	-
RMSE (cm)	10.46	8.45	-
Long-term trend (cm/year)	0.13 ± 0.06	-0.13 ± 0.01	-0.49 ± 0.06

4 RESULTS AND DISCUSSIONS

4.1 Impact of GRACE DA on TWS simulations

The impact of GRACE DA can be apparently seen from the TWS estimates (Fig. 3). To begin with, the CABLE model performs particularly well in northern Thailand, where model TWS estimates show similar TWS variations to GRACE with a slightly underestimated annual amplitude. The Spearman correlation coefficient of 0.8 confirms this significant agreement (Table 1). Implementing GRACE DA brings TWS estimates closer to GRACE observations, improving correlation and root mean square error (RMSE) by 13% (from 0.8 to 0.9) and 24% (from 10.5 cm to 8.5 cm), respectively. It is also seen that GRACE DA provides continuous TWS estimates even when satellite observations are not available. In addition, GRACE DA provides a trend estimate closer to GRACE observations and informs a decreased water storage in the study area by 0.13 cm/year. GRACE DA also improves the model's ability to capture the drought signature in 2019 – 2020. The model, on the other hand, shows increased water storage and underestimates the drought feature. Using such incorrect information (from the model) may result in faulty or invalid water resource assessments.

4.2 Accuracy assessment of groundwater estimates

The evaluation is carried out by comparing the correlation (*R*) of GRACE DA GWS results (with respect to in situ data) with the correlation value of the model estimates. Specifically, the difference is computed by $R_{\text{GRACE DA}} - R_{\text{model}}$, where positive and negative values reflect GRACE DA improving and degrading GWS estimates, respectively. Figure 4 shows that GRACE DA provides a significant improvement in GWS estimations, with higher correlation values of up to 0.53, or by 0.3 on average (Fig. 4a). The low correlation observed in some stations can be attributed to local characteristics of ground observations that may not be fully captured by the 5 km model. It is of particular note that this improvement is substantial in light of the fact that the model estimate is already quite accurate. The positive impact of GRACE DA on GWS is consistent with most GRACE DA research [6,7]. The 2019 – 2020 drought characteristic is found in both GRACE DA GWS estimations and in situ groundwater level (Fig. 4b), similar to TWS (Fig. 3), indicating the sensitivity of the groundwater component to droughts. Model simulations are unable to depict the declining GWS.

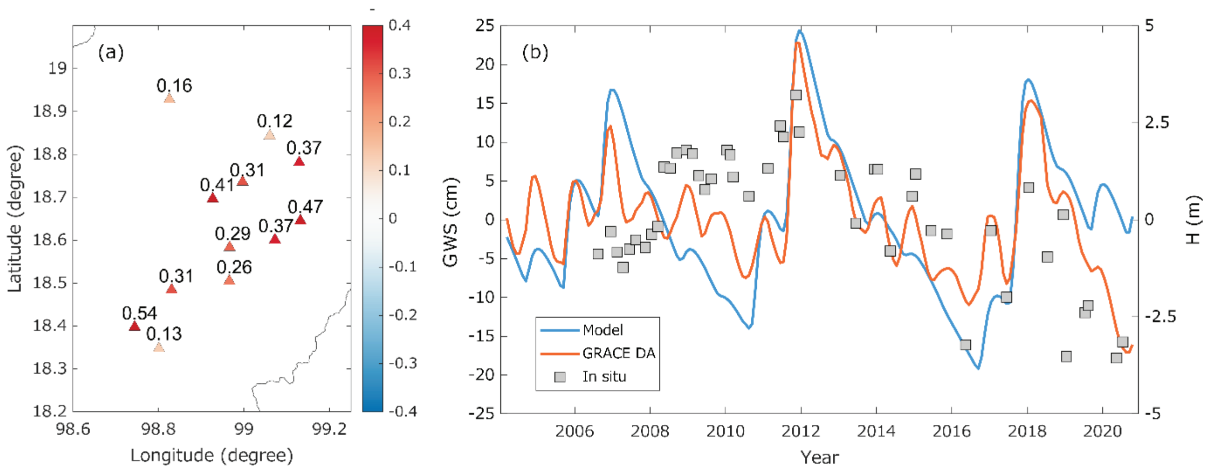


Fig. 4. (a) Differences in correlation between GRACE DA and model estimations (DA minus model). Positive (red) and negative (blue) readings imply that GRACE DA improves or degrades GWS estimates, respectively. The given values are the correlation differences at the measurement sites. (b) The average GWS estimates from model and GRACE DA between 2004 and 2020. The time series from all sites are used in the averaging. The average in situ groundwater level (H) is also shown.

4.3 Future development for improved hydrology analyses in Thailand

The development from this study can be applied to any area in Thailand, given that all data are globally and publicly available. Because the fundamental concept of EnKS remains unchanged, the DA approach described in Sect. 3 is also applicable with other satellite data such as the Soil Moisture Active Passive (SMAP; https://smap.jpl.nasa.gov) and surface reflectance products from the Moderate Resolution Imaging Spectroradiometer (MODIS; e.g., https://modis.gsfc.nasa.gov). This paper demonstrates the success of univariate DA, in which only one or a few state variables are updated with a single satellite data set. A multivariate DA could be used in a future study to incorporate multiple satellite data sets and improve a suite of hydrologic variables simultaneously [8]. The GWS (and other hydrologic variables) can also be developed at ultra-resolution (i.e., near real-time 1 km or higher) over the entire Thailand. Despite the potential utility of data collection across interdisciplinary sectors, the development is still in its early stages. It will necessitate substantial resources and financial support to maintain a public archive for reanalysis and operation purposes.

5 SUMMARIES

The success of using satellite data assimilation to enhance the accuracy of regional groundwater storage in Thailand is demonstrated in this study. The method improves hydrologic variables at the very high spatiotemporal resolution, and spatially/temporally continuous fields can always be produced even where/when satellite observations are absent. These accurate groundwater products may improve the robustness of water resources and climate-related decision-making, including (but not limited to) agriculture and urban planning. Future work aims to increase product resolution and incorporate multiple satellite data into a multivariate data assimilation framework to produce a suite of accurate hydrologic and climate variables for interdisciplinary studies.

REFERENCES

(1) Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J. S., Edmunds, M., Konikow, L., Green, T. R., Chen, J., Taniguchi, M., Bierkens, M. F. P., MacDonald, A., Fan, Y., Maxwell, R. M., Yechieli, Y., Gurdak, J. J., Allen, D. M., Shamsudduha, M., Hiscock, K., Yeh, P. J.-F., Holman, I., and Treidel, H.: Ground water and climate change, Nature Clim Change, 3, 322–329, https://doi.org/10.1038/nclimate1744, 2013.

(2) Tapley, B. D., Bettadpur, S., Ries, J. C., Thompson, P. F., and Watkins, M. M.: GRACE Measurements of Mass Variability in the Earth System, 305, 503–505, https://doi.org/10.1126/science.1099192, 2004.

(3) Tangdamrongsub, N., Jasinski, M. F., and Shellito, P. J.: Development and evaluation of 0.05° terrestrial water storage estimates using Community Atmosphere Biosphere Land Exchange (CABLE) land surface model and assimilation of GRACE data, 25, 4185–4208, https://doi.org/10.5194/hess-25-4185-2021, 2021.

(4) Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelsen, J.: The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes, Sci. Data, 2(1), 1–21, doi:10.1038/sdata.2015.66, 2015.

(5) Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Randles, C. A., Darmenov, A., Bosilovich, M. G., Reichle, R., Wargan, K., Coy, L., Cullather, R., Draper, C., Akella, S., Buchard, V., Conaty, A., da Silva, A. M., Gu, W., Kim, G.-K., Koster, R., Lucchesi, R., Merkova, D., Nielsen, J. E., Partyka, G., Pawson, S., Putman, W., Rienecker, M., Schubert, S. D., Sienkiewicz, M. and Zhao, B.: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), J. Climate, 30(14), 5419–5454, doi:10.1175/JCLI-D-16-0758.1, 2017.

(6) Li, B., Rodell, M., Kumar, S., Beaudoing, H. K., Getirana, A., Zaitchik, B. F., Goncalves, L. G. de, Cossetin, C., Bhanja, S., Mukherjee, A., Tian, S., Tangdamrongsub, N., Long, D., Nanteza, J., Lee, J., Policelli, F., Goni, I. B., Daira, D., Bila, M., Lannoy, G. de, Mocko, D., Steele-Dunne, S. C., Save, H., and Bettadpur, S.: Global GRACE Data Assimilation for Groundwater and Drought Monitoring: Advances and Challenges, 55, 7564–7586, https://doi.org/10.1029/2018WR024618, 2019.

(7) Yin, W., Li, T., Zheng, W., Hu, L., Han, S.-C., Tangdamrongsub, N., Šprlák, M., and Huang, Z.: Improving regional groundwater storage estimates from GRACE and global hydrological models over Tasmania, Australia, Hydrogeol J, https://doi.org/10.1007/s10040-020-02157-3, 2020.

(8) Tangdamrongsub, N., Han, S.-C., Yeo, I.-Y., Dong, J., Steele-Dunne, S. C., Willgoose, G., and Walker, J. P.: Multivariate data assimilation of GRACE, SMOS, SMAP measurements for improved regional soil moisture and groundwater storage estimates, Advances in Water Resources, 135, 103477, https://doi.org/10.1016/j.advwatres.2019.103477, 2020.

TA-112S

Relationship between Soil Moisture Content and Salinity Degree in the Salt-Affected Soils in Khon Kaen, Northeast Thailand

Supranee Sritumboon
Land Development Department Regional Office 5, Land Development Department: LDD
Khon Kaen,Thailand
ssritumboon@yahoo.com, supranee@ldd.go.th
Somsak Sukchan
Land Development Department: LDD
Bangkok, Thailand
Mallika Srisutham
Faculty of Agriculture, Khon Kaen University:KKU
Khon Kaen,Thailand
Koshi Yoshida
Graduate School of Frontier Sciences, The University of Tokyo
Japan
Kazuo Oki
Faculty of Engineering, Kyoto University of Advanced Sciences
Japan
Koki Homma
Graduate School of Agricultural Science, Tohoku University
Japan
Masayasu Maki
Faculty of Food and Agricultural Sciences, Fukushima University
Japan

ABSTRACT

The research was set up in the salt-affected area in Ban Phai and Non Sila district, Khon Kaen Thailand during 2017-2018. The aims were to study on the variation of a salt-affected soil properties as ECe and SAR and explanation the relationship between soil moisture content and salinity degree in the salt-affected soil. The study site was classified in four classes by map of distribution of salt crust on soil surface, created by LDD, there are the class 1(salt crust>50%), class 2(salt crust10-50%), class 3 (salt crust1-10%), and class 4 (salt crust<1%). Soil samples were collected monthly at 0-30 cm depth for analyze Electrical Conductivity of the saturated extract (ECe), Sodium Adsorption Ratio (SAR), Soil Moisture Content (SMC), Permanent Wilting Point (PWP), and Field Capacity (FC) at LDD5 laboratory. The results showed that variation of ECe and SAR is high (CV >35%) at 0-30 cm soil depth. ECe and SAR in class 1 (salt crust >50%) ranged from moderately to very severely salinity and sodic in a dry season. But it was varied from slightly to very severely salinity and non-sodic to sodic in a wet season. While, class 2, 3 and 4 (soil crust <50%),the ECe value pointed out that salinity degree varied from normal to very severely salinity in both a dry season and a wet season. Also, SAR showed range from non-sodic to sodic. According to ECe and SAR, a salinity was higher variability in a wet season than in a dry season. The correlation showed that ECe and SAR is positive relation to SMC in a dry season. Whereas, the relation of salinity properties like as ECe and SAR showed a negative trend with SMC in a wet season. Also, a soil moisture content at PWP and FC had a negative correlation with ECe and SAR in both a wet season and a dry season. Meanwhile, the relation of ECe and SAR with SMC under different soil texture had a positive correlation in a dry season, especially, in a fine-textured soil. But a relation is not clarified in a wet season.

Keywords: salt-affected soils; Electrical Conductivity, SAR, soil moisture content; Northeast Thailand

INTRODUCTION

Salt-affected soils, which is the one significant problem for soil resource that impact on an agricultural system. Soil salinization is the key limiting factors for agricultural development. Due to it has high the saline ion and exchangeable Na in soil solution, that effect on growth and yield of crop. Salt-affected soil is classified into three types including saline soil, sodic soil, and saline-sodic soil. The salinity degree is considered by Electrical conductivity of the saturated extract (ECe), Sodium Adsorption Ratio (SAR), and Exchangeable Sodium Percentage (ESP). Saline soils can be defined as soils have a high enough salt concentration to start affecting plant growth will have an EC greater than 4.0 dS m^{-1}. These soils will have high concentration of several salts (e.g., Ca^{2+}, Mg^{2+}, Cl^{-} , HCO^{3-} , etc.). The sodic soil is dominated by the salt Na^{+} that SAR above 13(1). In generally, the salt-affected soils are in tropical zone and subtropical zone that an evapotranspiration is higher than a precipitation (2).

The agricultural area in Thailand is affected by the salt, where found in Northeast1.84 million ha. Due to is influenced from rock salt is baseline in underground. The central part was flooded and deposited by the sea water that is 8,743 ha. Moreover, the coastal saline soil is found in the coastal where the sea is reached that is about 304,000 ha (3).

Salt-affected soil is influenced by factors that the primary factors are climate, precipitation, and parent material. Also, the secondary factors are manmade, climate change, landform, and rainfall pattern, there can stimulate the higher salinity (4). For a changing of salinity degree is related to many factors. However, the salinity degree is a temporary changing especially 0-30 cm soil depth because it is impacted from a climate such as precipitation, temperature, and drought period (5).

This project aim to study on the variation of a salt-affected soil properties as ECe and SAR and explanation the relationship between soil moisture content and salinity degree in the salt-affected soil.

1.METHODOLOGY

1.1 Study Area

The project was set up in the salt-affected area in Ban Phai and Non Sila district, Khon Kaen, Thailand during 2017-2018. The study site covered four classes, based on the map percentage of salt crust on soil surface (6), shown in Table. 1. The main land use is a rain-fed paddy rice. The annual precipitation is 1,451.97 mm and 1,192.97 mm in 2017 and 2018, respectively (Fig.1 and Fig.2).

TABLE 1 Classification of salinity degree by map percentage of salt crust on soil surface

Class	Description
1: very severely salinity	soil surface covered by salt crust > 50 %
2: severely salinity	soil surface covered by salt crust 10-50%
3: moderately salinity	soil surface covered by salt crust 1-10%
4: slightly salinity	soil surface covered by salt crust <1%

1.2 Soil sampling and analysis

The soil samples were taken monthly at 0-30 cm depth in 4 classes of a salt crust on soil surface based on map percentage of salt crust on soil surface. For class1 and class4, 10 samples for each class were collected. While soil samples in class2 and class3 were gathered 15 samples for each class. Totally 1,200 soil samples were collected (Table 2).

The samples were air-dried naturally indoor and then all soil samples were passed through a 2 mm sieve. Next, soil samples were determined using saturated paste extract, which were prepared by adding deionized water until it reached a condition of complete saturation. The extracts were analyzed for Electrical conductivity of the saturated extract (ECe), and Sodium Adsorption Ratio (SAR). And, soil samples were analyzed for Soil Moisture Content (SMC), Permanent Wilting Point (PWP), and Field Capacity (FC) at Land Development Department Regional 5 (LDD5) laboratory.

1.3 Statistical analysis

The descriptive statistics including mean, minimum, maximum, and_coefficient of variation (CV)were determined for each class separately. The CV was classified as little (CV <15%), moderate (CV =15-35%), and high (CV >35%) variability (7). Also, the linear regression was analyzed.

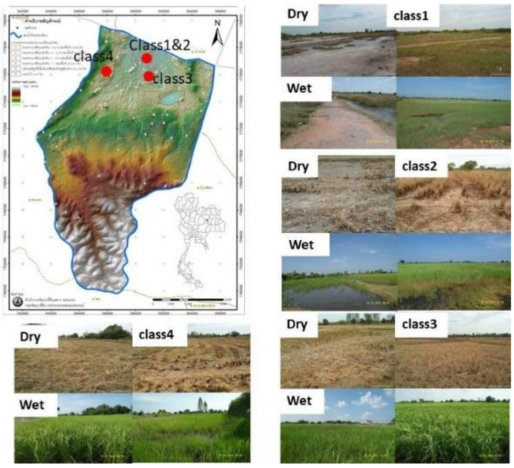


Fig.1. Study area

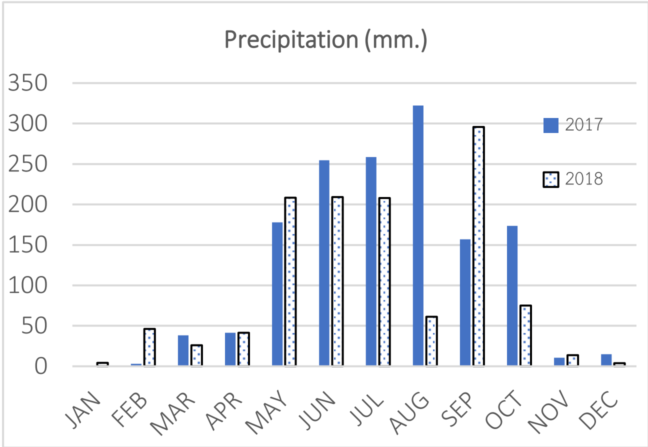


Fig.2. Precipitation in 2017 and 2018

TABLE 2 Classes, soil texture, and Number of soil samples

class	Soil texture	Number of soil samples
1: very severely salinity	Sandy loam, loam, silt loam	240
2: severely salinity	Loam, sandy loam	360
3: moderately salinity	Sandy loam, clay loam, sandy clay loam	360
4: slightly salinity	Sandy loam, loamy sand, clay loam, sandy clay loam	240

2.RESULT AND DISCUSSION

2.1 Variation of ECe and SAR

As seen in Table 3, ECe and SAR were highly varying in area of every class. Regarding to the coefficients of variation, soil ECe and SAR of every class were higher than 35 % that there is high variability. Thus, salinity degree in class 1 was ranged from moderately to very severely salinity and sodic in a dry season. But it was varied from slightly to very severely salinity and non-sodic to sodic in a wet season. While, in class 2and class 3, the ECe value pointed out that salinity degree is ranged from normal to very severely salinity in both dry and wet. Also, SAR showed range from non-sodic to sodic. As class4, ECe indicated that soil is normal to moderately salinity in a dry season. But it was normal to severely salinity in a wet season in 2017. While, in 2018, soil ECe was normal to very severely salinity. SAR variation was ranging from normal to sodic in consideration area. Moreover, the data presented that ECe and SAR are higher variability in a wet season than in a dry season. And, SAR in class4 was the highest variation, compared to others.

The results revealed that salinity degree at 0-30 cm depth are highly variability. Also, the salinity variability in rainy season was higher than in dry season. Similarly, coefficients of variation of the ECe and SAR values was higher than 35% (8). Due to the salinity level changing was related to the water movement through a soil profile. The water upward was moved by capillary force from a subsoil to surface. Meanwhile, the water from a surface soil to a subsoil was moved by a permeability that depends on the hydraulic conductivity (9). During the dry season, there is a lot of groundwater move up to the soil surface. While there is little rainfall, it is not enough to leach the salt into the subsoil. In contrast to the rainy season, although the movement of groundwater to the surface but there is rainfall that can leach salt back into the subsoil outside the root zone. And soil moisture content reduced the movement of groundwater caused by capillary force, which is the pulling force of water in small channels. Therefore, the soil salinity was more changing in the topsoil (10). In addition, salinity level and sodium level were also reported to be spatial and vertical variations. which is a temporary change, especially, at a soil depth of 0-30 cm, that is influenced by rainfall, climate changing, and changing of the seasons (rain/drought) in the year such as length of the dry season. These factors affect soil salinity excess both salt accumulation and salt leaching from the root zone (11). Moreover, the salt leaching was easy in a sand texture and a deep ground water table, resulting in the salt in a 0-30 cm soil depth is leached. However, the salt leaching method may induce the future problem, especially, the area had a ground water table near a surface. Due to the leaching water moved downward to add a groundwater level and water was move to a surface and evaporated (12,13). Comparing the results of the two periods, which soils at 0-30 cm depth in a wet season were affected by rice cultivation resulting in variability of salinity degree. Due to land management such as tillage and fertilizer could alter physical and chemical properties of soil for example bulk density, increased water permeability, and pH, etc. of top soil. But at some depth below the top soil a hard layer was developed, which is characterized by high bulk density and low infiltration rate (14).

TABLE 3 Showing variation of ECe and SAR in 4 study sites using basic statistics

		Dry							
value		class1		class2		class3		class4	
		2017	2018	2017	2018	2017	2018	2017	2018
ECe ($dS\ m^{-1}$)	Min	6.48	5.57	1.00	0.75	0.92	1.07	0.33	0.33
	Max	121.05	165.50	36.41	53.90	16.46	21.10	4.54	7.04
	Mean	41.73	67.94	8.74	12.43	4.90	6.11	1.10	1.31
	CV(%)	65.24	78.16	78.81	105.99	74.39	72.85	66.09	103.95
SAR	Min	18.66	16.64	8.39	3.76	1.22	2.08	0.46	0.38
	Max	196.31	244.57	68.41	103.22	80.98	80.16	10.74	28.47
	Mean	81.17	108.51	28.19	29.39	21.73	19.29	3.98	3.82
	CV(%)	51.99	67.92	51.05	79.15	79.93	76.23	69.76	126.76
TYPES		saline-sodic	saline-sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic
		Wet							
value		class1		class2		class3		class4	
		2017	2018	2017	2018	2017	2018	2017	2018
ECe ($dS\ m^{-1}$)	Min	3.56	3.17	0.58	0.69	0.54	0.50	0.30	0.23
	Max	136.35	157.00	60.95	113.80	35.80	25.73	10.74	28.47
	Mean	42.14	59.61	7.30	11.02	3.83	5.36	3.98	3.82
	CV(%)	84.31	83.44	168.29	165.00	117.21	97.44	69.76	126.76
SAR	Min	11.72	10.42	5.28	3.29	0.48	1.14	0.24	0.25
	Max	195.09	289.09	99.95	169.92	78.65	77.40	14.78	47.26
	Mean	81.69	100.43	21.53	27.48	16.77	18.71	3.37	5.76
	CV(%)	61.57	73.22	90.31	96.93	94.58	73.69	96.18	157.92
TYPES		slightly saline, saline-sodic	slightly saline, saline-sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic	normal, saline, saline-sodic, sodic

2.2 Relation ECe and SAR with soil moisture content

The relation between ECe and SAR to SMC, PWP, and FC were presented in Fig.2. and Fig.3. The results showed that ECe and SAR is positive correlation to SMC in a dry season. While, the relation of salinity properties like as ECe and SAR showed a negative trend with SMC in a wet season. Likewise, a soil moisture content at PWP and FC indicated that it is a negative relation with ECe and SAR in both a wet season and a dry season. Moreover, the relation of ECe and SAR with SMC under a different soil texture pointed out that it is a positive correlation in a dry season, especially, in a fine-textured soil with R^2 value 0.5892 for ECe and 0.7019 for SAR. While, in a wet season is not clarified for both salinity as ECe and SAR, as shown in Fig.5 and Fig.6.

As the correlation result, it explained that quantity of moisture content in soil and soil texture are impact on a salinity alteration. Thus, SMC in a wet season was higher than SMC at saturated condition, resulting in more water can wash a salt into a subsoil. Also, SMC at FC point could leach a salt due to soil moisture content at FC almost reach to a saturated moisture content. Meanwhile, SMC at PWP point was too dry that can not carry a salt into a root zone (0-30 cm). In contrast, SMC in a dry season was between PWP and FC, thus soil has enough soil moisture can move up a salt to an upper soil horizon. Additionally, the fine-textured soils showed a significant relation in a dry season. Due to salinity was affected by rainfall, soil moisture, and soil texture, which influencing salt deposition in the soil cross-section. Due to soil texture was related to hydraulic conductivity and soil pore. In generally, soil was more different texture between each soil horizon. Which, different soil texture and their distributions influence the water conductivity and solute distribution in the face (15). Additionally, a water absorbed in the hardpan layer, it may be a source of water for plants or may increase the risk of saline soil formation (16). Moreover, soil profile complicated by the discontinuity of the soil texture. That, it was a very important factor in the permeability of saturated soil and the water permeability in the unsaturated soil water retention and air pressure values which related to salt accumulation (17).

The salt leaching process was more affected by soil structure fractures, and scattering of small soil particles resulted in fragmentation, especially, in saline soils with high clay particles such as montmorillonite (18). Which, the amount of salt accumulation in the root zone was depended on the leaching process and the process of upward movement of groundwater by capillary force which is in the opposite direction (19). The moist soil would have the expansion of the soil ped, resulting in a macro pore being compressed, causing the hydraulic conductivity decreased. It has been shown that saline soil was affected by both water conductivity and soil water retention (20, 21).

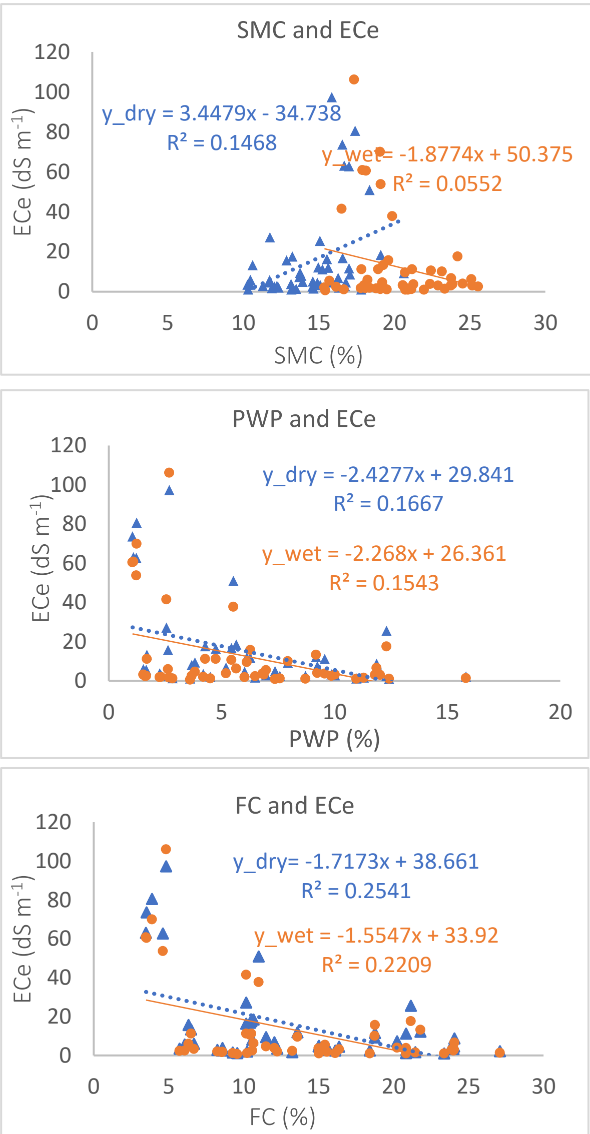


Fig. 3. Relation soil moisture content and ECe

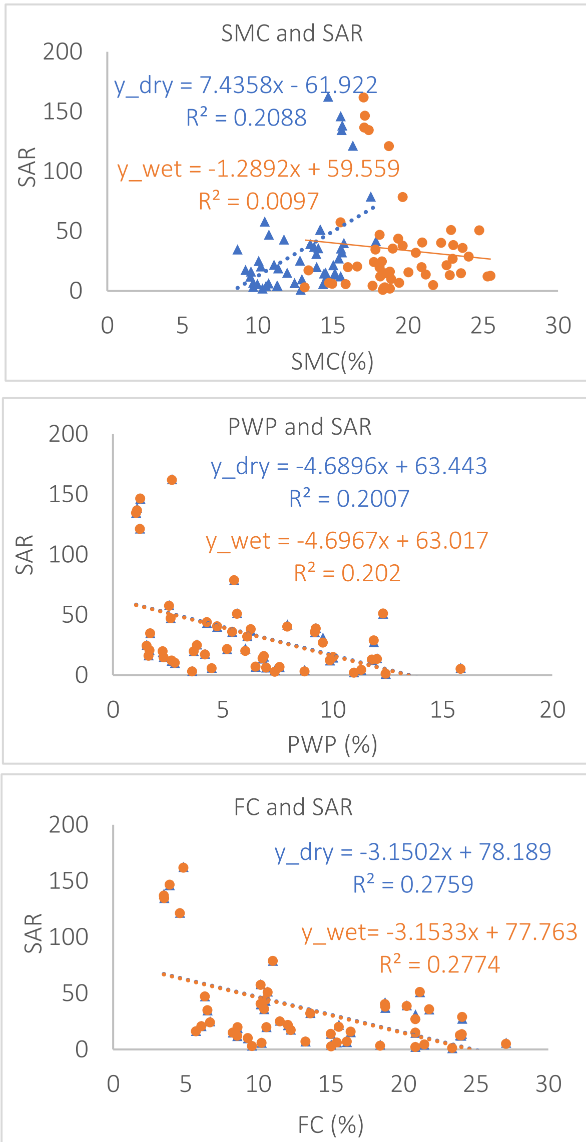


Fig. 4. Relation soil moisture content and SAR

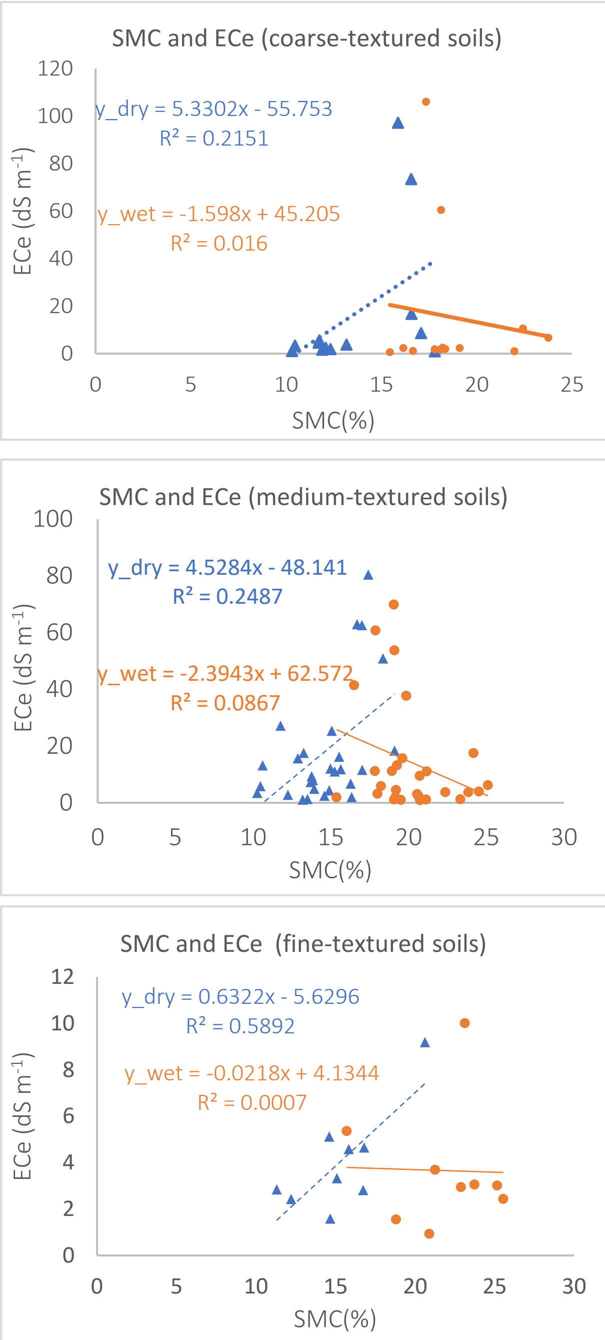


Fig.5. Relation soil moisture content and ECe

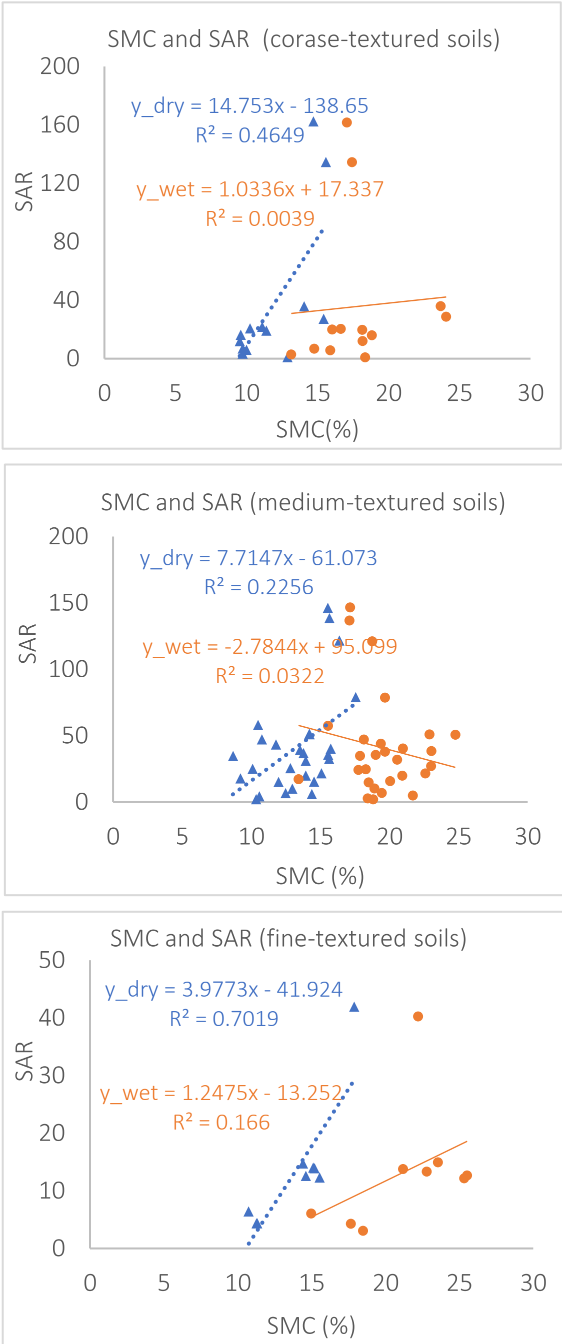


Fig.6. Relation soil moisture content and SAR

3. SUMMARY

The research results showed that variation of ECe and SAR is high (C.V >35%) at 0-30 cm. soil depth. Soil ECe and SAR in class 1 (salt crust on surface >50%) was ranged from moderately to very severely salinity and sodic in dry season. But it was varied from slightly to very severely salinity and non-sodic to sodic in wet season. While, in class 2,3 and 4 (salt crust on surface <50%), thus, ECe data pointed out that salinity degree is ranged from normal to very severely salinity in both dry and wet. Also, SAR variation was ranging from non-sodic to sodic for every class in consideration area. Moreover, the data presented that ECe and SAR are higher variability in wet season than dry season. The correlation showed that ECe and SAR is positive relation to SMC in a dry season. While, the relation of salinity properties like as ECe and SAR showed a negative trend with SMC in a wet season. Likewise, a soil moisture content at PWP and FC showed a negative correlation with ECe and SAR in both a wet season and a dry season. Moreover, the results pointed out that it is a positive correlation between a salinity and soil moisture content under different soil texture in a dry season, especially, in a fine-textured soil. While, in a wet season was not clarified for both salinity as ECe and SAR.

In future research, the long-term continuing study will provide a better understanding of salt variation in the soil profile. Thus, it is significant to understand changes and spatial responses, climate, and the water cycle. Also, the irrigation research will be more study to expose how much of suit water for crop and leaching salt from the root zone and how to manage a salt-affected soil under the climate change situation.

4. ACKNOWLEDGMENTS

This research is financially supported by the JICA/JST, Japan under the Advancing Co-Design of integrated strategies with Adaptation to climate change in Thailand (ADAP-T) project.

REFERENCES

(1) George, E., Horst W. J.and Neumann E. (2012), Chapter 17 - Adaptation of plants to adverse chemical soil condition, Marschner's Mineral Nutrition of Higher Plants (Third Edition), pp. 409-472.
(2) http://www.fao.org/ag/agl/agll/spush.
(3) https://www.ldd.go.th/Web_Soil/salty.htm
(4) Rengasamy, P.(2006),World salinization with emphasis on Australia, J. Exp. Bot, Vol.57, pp. 1,017–1,023.
(5) Zaman, M., Shahid S. A. and Heng L.(2018), Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques (Springer, 2018).
(6) Land Development Department (2004), Map of distribution of salt crust on soil surface, Khon Kaen Province.
(7) Wilding, L.P. 1(985), Spatial variability: its documentation, accommodation and implication to soil surveys, pp. 166-194, *In* D.R. Nielsen and J. Bouma (eds.), Soil Spatial Variability.Pudoc, Wageningen:Netherland.
(8) Jansom, S., Katawatin R. and Pannangpetch K. (2012), Variability of electrical conductivity, sodium adsorption ratio, and soil reaction in salt-affected areas in Northeast Thailand, Proceedings: 1stASEAN PLUS THREE GRADUATE RESEARCH CONGRESS, 1-2 March 2012, Chaing Mai, Thailand.
(9) Faculty of the Department of Soil Science (2001), Foundation of soil science, Faculty of Agriculture, Kasetsart University.
(10) Chamaki, S., Taghvaeian S., Zhang H. and Warren J.G. (2019), Soil salinity variations in an irrigation scheme during a period of extreme dry and wet cycles, Soil System, Vol. 3, No. 35.
(11) Hassani, A., Azapagic A. and Shokri N.(2020), Predicting long-term dynamics of soil salinity and sodicity on a global scale, PNAS, Vol. 117, No. 52.
(12) Gelaye, K. K., Zehetner F., Loiskandl W. and Klik A. (2019), Effects of soil texture and groundwater level on leaching of salt from saline fields in Kesem irrigation scheme, Ethiopia, Soil and Water Research, Vol. 14, No.4, pp. 221–228.
(13) Ayars, J.E., Hoffman G.J. and Corwin D.L. (2011), Leaching and rootzone salinity control, Chapter 12, In: Wallender W.W., Tanji K.K. (eds.): Agricultural Salinity Assessment and Management. 2nd Ed, Reston. ASCE, pp. 371–403.
(14) Ji, B., Zhao, Y., Mu, X., Liu, K. and Li, C.(2013), Effects of tillage on soil physical properties and root growth of maize in loam and clay in central China, Plant Soil Environ., vol.59, No. 7. pp.295-302, DOI: 10.17221/57/2013—PSE.
(15) Zhao, Y., Feng Q. and Yang H.(2016), Soil salinity distribution and its relationship with soil particle size in the lower reaches of Heihe River, Northwestern China, Environmental Earth Sciences, Vol. 75, No.810.
(16) Li, X., Chang S. X. and Salifu K. F. (2013), Soil texture and layering effects on water and salt dynamics in the presence of a water table: a review, Environ. Rev., Vol. 21, pp. 1–10, doi.org/10.1139/er-2013-0035.
(17) Wösten, J.H.M., Pachepsky Y.A. and Rawls W.J. (2001), Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulic characteristics, J. Hydrol, Vol. 251, No.3–4, pp. 123–150, doi:10.1016/S0022-1694(01)00464-4.

(18) Cucci, G., Lacolla G., Pallara M. and Laviano R.(2012), Reclamation of saline and saline-sodic soils using gypsum and leaching water, African Journal of Agricultural Research, Vol.7, No. 6, pp.508–514.

(19) van der Zee, S. E. A. T. M., Shah S. H. H. and Vervoort R. W.(2014), Root zone salinity and sodicity under seasonal rainfall due to feedback of decreasing hydraulic conductivity, Water Resour.Res, Vol. 50, No.9, pp. 9,432–9,446, doi:10.1002/2013WR015208.

(20) Halliwell, D. J., Barlow K. M. and Nash D. M.(2001), A review of the effects of wastewater sodium on soil physical properties and their implications for irrigation systems, Aust. J. Soil Res,Vol.39, No. 1, pp.259–1,267.

(21) Ezlit, Y. D. (2009), Modelling the change in conductivity of soil associated with the application of saline-sodic water, PhD thesis, Fac. of Eng. and Surv., Univ. of South Queensland, Toowoomba, Queensland, Australia.

TA-115S

Flood simulation of the 2021 Thailand flood in the upstream area of Chi River basin

Multi-resolution flood modeling for a specific area in Chaiyaphum City, Chaiyaphum Province

Kwanchai Pakoksung, D. Eng
International Research Institute of Disaster Science (IRIDeS)
Tohoku University
Sendai, Japan
pakoksung@irides.tohoku.ac.jp

Cherdsakul Torsakul, M. Eng
Megatech Consultant Co Ltd.
Bangkok, Thailand

ABSTRACT
Thailand has received a devastating flood disaster in 2021. In the upstream area of the Chi River basin, large-scale riverine and flash floods caused damage to approximately 240 square kilometers in the Chaiyaphum Province. This study aims to simulate the flood in the upstream area of the Chi River basin with two-dimensional shallow water equations on the geographic coordinate system. The model is combined into 2 regions, large region (basin-scale) and small region (specific area), with the nesting grid method, as the multi-resolution modeling. The simulation results presented an inundation map for large-scale riverine flooding and specific area in Chiyaphum City. In addition, the simulation showed flood-affected areas based on the maximum flood depth, the arrival time of maximum depth, the average flood depth, the flood arrival time, and the flood duration time. Finally, this study can be useful data for large-scale flooding and small-scale flooding to provide information to disaster management.

***Keywords*—**Flood model, Shallow water equation, Multi-resolution flood modeling

1 INTRODUCTION

Floods are one kind of natural disaster causing human life and economic losses. Approximately 66% of water-related disasters in the world flood (**WMO, 2014**). At this moment, the impacts of floods are increasing because of population growth, decreasing of floods plain, and climate change (**Pakoksung and Takagi, 2016**). Flood modeling is the important thing used to estimate the spatial and temporal variation over a river basin surface (**Singh and Woolhiser, 2002**).

Thailand has received a devastating flood disaster in 2021. In the upstream area of the Chi River basin, large-scale riverine and flash floods caused damage to approximately 240 square kilometers in the Chaiyaphum Province. This study aims to simulate the flood in the upstream area of the Chi River basin with two-dimensional shallow water equations on the geographic coordinate system. The model is combined into 2 regions, large region (basin-scale) and small region (specific area), with the nesting grid method. The simulation results presented an inundation map for large-scale riverine flooding and specific area in Chiyaphum City.

The information of the study area is described in Sect. 2. Section 3 presents the methodology; governing equation and data for the flood model. The results are shown in Sect. 4 with flood map, while conclusions and discussion of the study are reported in Sect. 5.

2 STUDY AREA

Chi River Basin in the upper part area is an important area for the northeastern region of Thailand where the largest area. **Figure 1a** shows the study river basin area locates in the northeastern region of Thailand with a total catchment area of 49,480 sq. km. The river originates from Nong Bua Deang District, Chiyaphum Province. The topography levels mention in the Mean Sea Level (MSL) vary from 70 to 1200 m. The mean annual rainfall is 1080 mm. According to the aim of this study, it suggests 2 scales of flood simulation, the river basin area, and the local area. **Figure 1b** shows the location of the Chi river basin that the local area as the specific area in the Chiyaphum Province was shown in **Figure 2c**. The local area is used to detail the flood characteristic with a higher resolution than the river basin scale where is located in the upstream area of the Chi river basin.

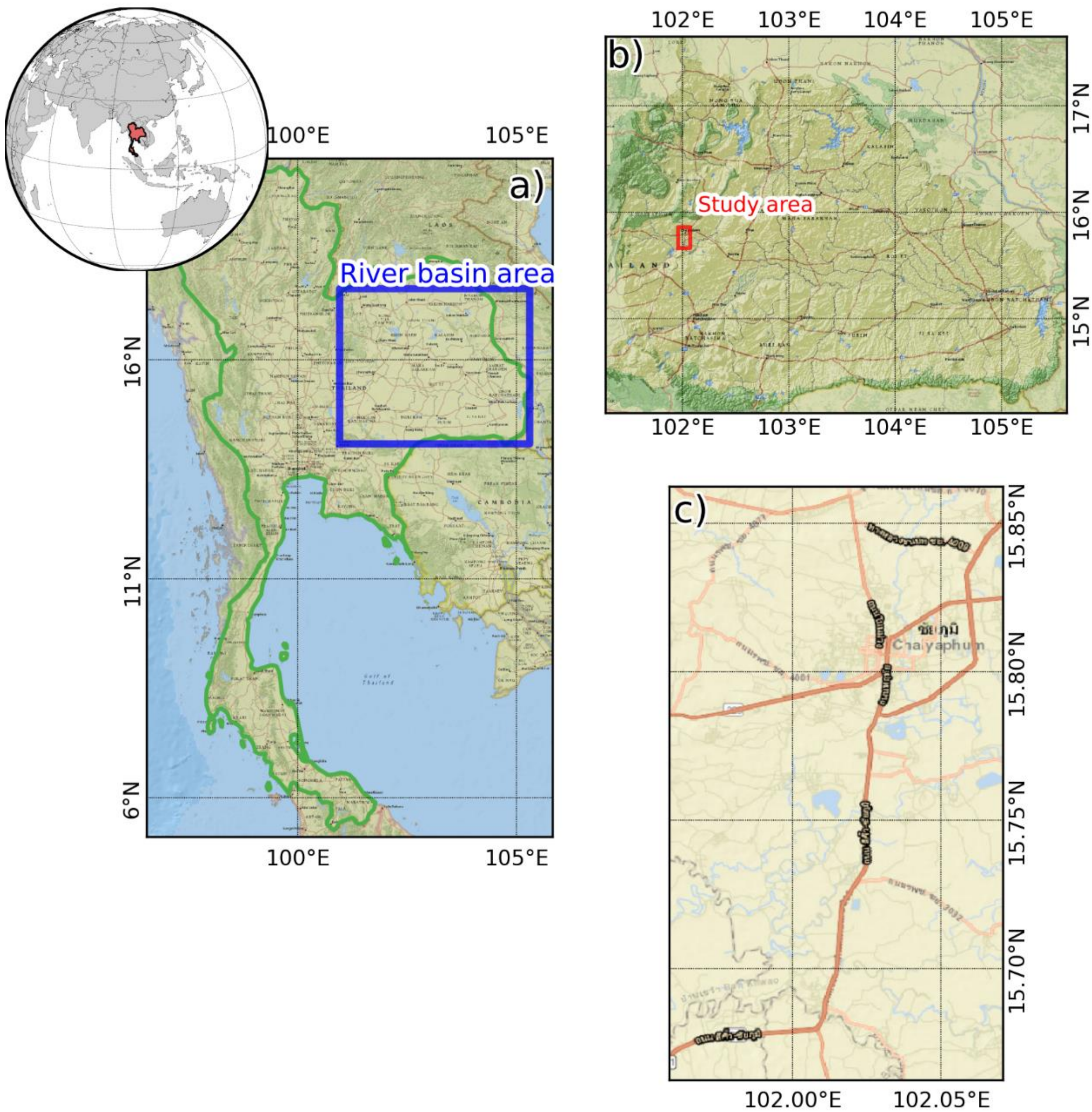


Fig. 1. Study area, a) the location of the Chi river basin in Thailand is the blue box, b) the area of the blue box as the river basin scale modeling that the study area as the detailed modeling is the red box and c) the area of the red box is in the upstream area of the Chi river basin, including Chaiyaphum City.

3 METHODOLOGY

3.1 Flood modeling

In the numerical modeling of the flood, it is general to use the staggered leap-frog method for the discretization of the governing equation. The Staggered method is a grid system to set variables in the spatial domain staggeringly (**Pakoksung et al., 2020**). In general, the scalar variable as the water depth is set on the center of a grid, while the vector variable as the discharge is on the side, as shown in **Figure 2a**. The numerical scheme for the flood modeling in the shallow water equation is mentioned for the conservation of mass in Equations (1) and the conservation of momentum in X and Y in Equations (2), and (3), respectively. **Figure 2b** indicates the staggered leap-frog method for this problem. The finite-difference equation for solving Equation (1) is shown in Equation (4), while the momentum is described in Equation (5). The bottom friction term described in the last term of Equation (5) is implemented by the implicit scheme to keep the numerical stability, as presented by Equations (6) and (7), for X and Y, respectively.

According to the aim of this study to simulate flood with 2 scale resolution, **Figure 2c** shows the concept of connecting between large and small resolution. The method is done by collecting the discharge from the large-scale resolution input to the small-scale resolution to estimate the flood depth in the small region model (**Pakoksung et al., 2018**) as the originality of this study to apply this method for flood simulation.

$$\frac{\partial D}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = R + I \tag{1}$$

$$\frac{\partial Q_x}{\partial t} + gD\frac{\partial Z}{\partial x} + \frac{gn^2}{D^{7/3}} Q_x \sqrt{{Q_x}^2 + {Q_y}^2} = 0 \tag{2}$$

$$\frac{\partial Q_y}{\partial t} + gD\frac{\partial Z}{\partial y} + \frac{gn^2}{D^{7/3}} Q_y \sqrt{{Q_x}^2 + {Q_y}^2} = 0 \tag{3}$$

$$D_{i,j}^{t+1} = D_{i,j}^{t} - \frac{\Delta t}{\Delta x}\left[Q_{x\left(i+\frac{1}{2},j\right)}^{t+\frac{1}{2}} - Q_{x\left(i-\frac{1}{2},j\right)}^{t+\frac{1}{2}}\right] - \frac{\Delta t}{\Delta y}\left[Q_{y\left(i,j+\frac{1}{2}\right)}^{t+\frac{1}{2}} - Q_{y\left(i,j-\frac{1}{2}\right)}^{t+\frac{1}{2}}\right] + R_{i,j} + I_{i,j} \tag{4}$$

$$\frac{Q_{x(i+\frac{1}{2},j)}^{t+\frac{1}{2}} - Q_{x(i+\frac{1}{2},j)}^{t-\frac{1}{2}}}{\Delta t} + gD_{i+\frac{1}{2},j}^{t}\frac{Z_{i+1,j}^{t} - Z_{i,j}^{t}}{\Delta x} + \frac{gn^2}{\left(D_{i+\frac{1}{2},j}^{t-\frac{1}{2}}\right)^{7/3}} \frac{Q_{x(i+\frac{1}{2},j)}^{t+\frac{1}{2}} + Q_{x(i+\frac{1}{2},j)}^{t-\frac{1}{2}}}{2} \sqrt{\left(Q_{x(i+\frac{1}{2},j)}^{t-\frac{1}{2}}\right)^2 + \left(Q_{y(i+\frac{1}{2},j)}^{t-\frac{1}{2}}\right)^2} = 0 \tag{5}$$

$$Q_{x(i+\frac{1}{2},j)}^{t+\frac{1}{2}} = \frac{1}{1 + F_{i+\frac{1}{2},j}^{t-\frac{1}{2}}}\left[\left(1 - F_{i+\frac{1}{2},j}^{t-\frac{1}{2}}\right) - gD_{i+\frac{1}{2},j}^{t}\frac{\Delta t}{\Delta x}\left(Z_{i+1,j}^{t} - Z_{i,j}^{t}\right)\right] \tag{6}$$

$$Q_{y(i,j+\frac{1}{2})}^{t+\frac{1}{2}} = \frac{1}{1 + G_{i,j+\frac{1}{2}}^{t-\frac{1}{2}}}\left[\left(1 - G_{i,j+\frac{1}{2}}^{t-\frac{1}{2}}\right) - gD_{i,j+\frac{1}{2}}^{t}\frac{\Delta t}{\Delta x}\left(Z_{i,j+1}^{t} - Z_{i,j}^{t}\right)\right] \tag{7}$$

$$F_{i+\frac{1}{2},j}^{t-\frac{1}{2}} = \frac{\Delta t}{2}\frac{gn^2}{\left(D_{i+\frac{1}{2},j}^{t-\frac{1}{2}}\right)^{7/3}}\sqrt{\left(Q_{x(i+\frac{1}{2},j)}^{t-\frac{1}{2}}\right)^2 + \left(Q_{y(i+\frac{1}{2},j)}^{t-\frac{1}{2}}\right)^2} \tag{8}$$

$$G_{i,j+\frac{1}{2}}^{t-\frac{1}{2}} = \frac{\Delta t}{2}\frac{gn^2}{\left(D_{i,j+\frac{1}{2}}^{t-\frac{1}{2}}\right)^{7/3}}\sqrt{\left(Q_{x(i,j+\frac{1}{2})}^{t-\frac{1}{2}}\right)^2 + \left(Q_{y(i,j+\frac{1}{2})}^{t-\frac{1}{2}}\right)^2} \tag{9}$$

$$Z_{i,j}^{t} = H_{i,j} + D_{i,j}^{t} \tag{10}$$

where $D(x, y, t)$ is the flood depth at each point (x, y) at time t, $Q(x, y, t)$ is the vertically integrated discharge in the x and y direction at time t, $Z(x, y, t)$ is the water surface elevation at each point (x, y) at time t, $H_{i,j}$ is the topography elevation at each point (x, y), g is the gravitational acceleration, n is the Manning's roughness coefficient, and Δt is the time step.

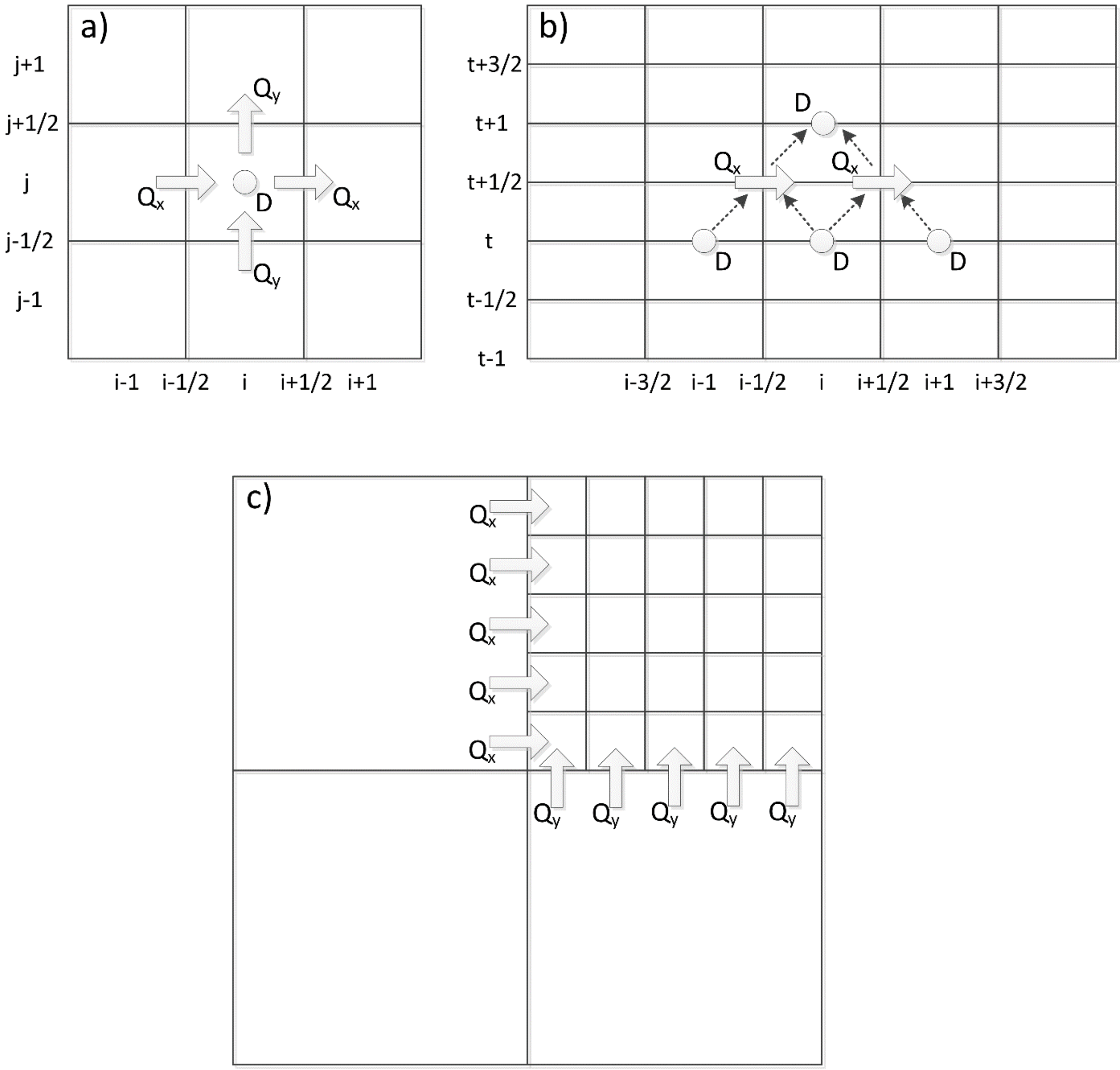


Fig. 2. Conceptual of flood modeling, a) The spatial geometry of the Staggered grid, b) The Staggered grid in the time domain, and c) The linkage modeling between large and small resolution model.

3.2 Dataset

Input data for the model consists of rainfall, topography information on the study area. Satellite-based rainfall data, the Global Satellite Mapping of Precipitation (GSMaP), (**Okamoto et al., 2005**), was used to simulate the 2021 flood. The storm event is selected from September to October 2021. Topography data on the Chi Basin was prepared using the Digital Elevation Model (DEM) from the Hydrological data and maps based on Shuttle elevation derivatives on multiple scales (HydroSHEDS) (**USGS, 2008**) provided by the U.S. Geological Survey (USGS), in which a resolution of 15×15 arc-seconds was used. The DEM, flow direction and flow accumulation for flood modeling are presented in **Figs. 3a**, **3b**, and **3c**, respectively. For the small region as the high-resolution model, it is done by the DEM from the Shuttle Radar Topography Mission (SRTM), (**CGIAR-CSI, 2008**) with a resolution of 3x3 arc-second was used.

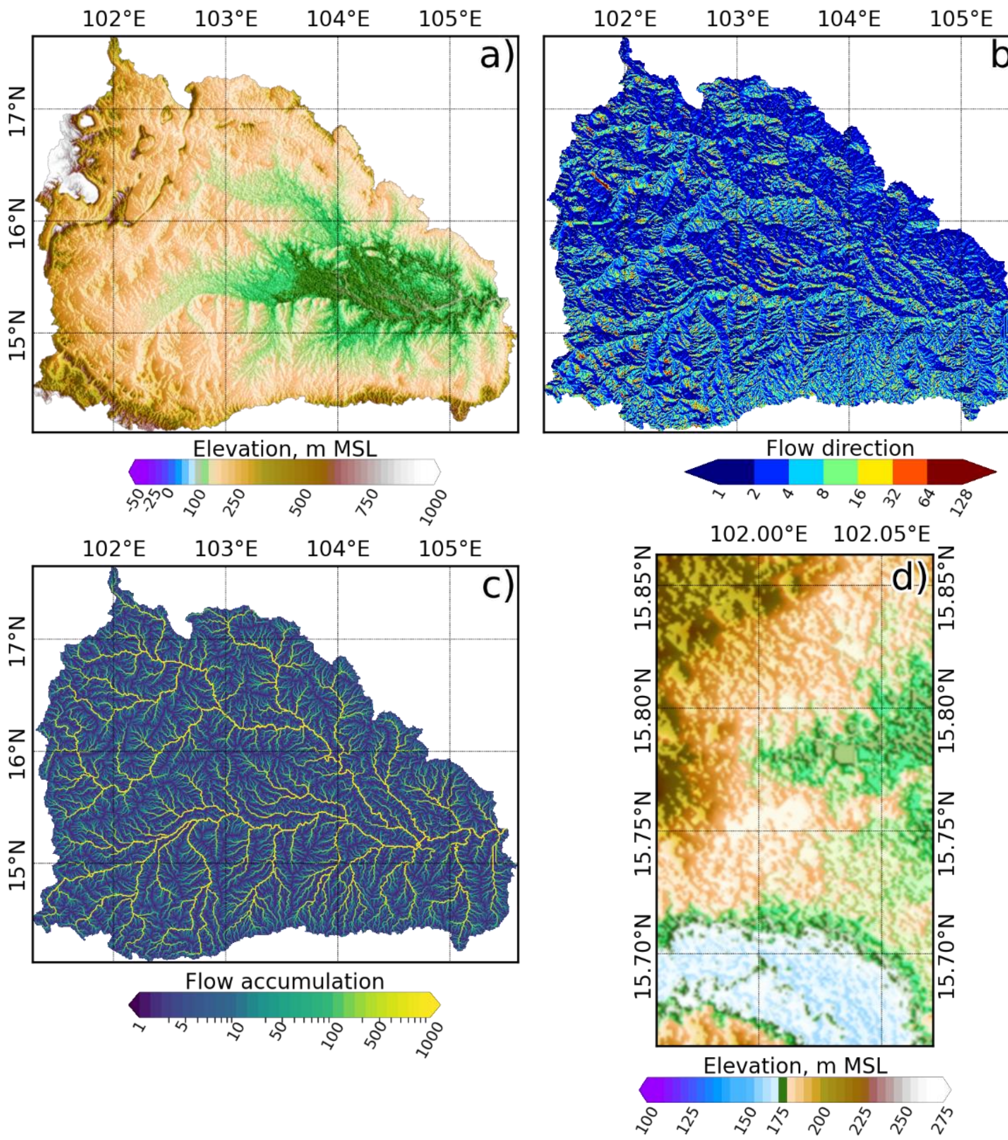


Fig. 3. Dataset for flood modeling in the basin and small region, a) DEM, b) flow direction and c) flow accumulation, for the flood river basin model, while d) DEM for the small flood area mode as the higher resolution modeling.

4 RESULTS

4.1 Flood generation

Flood generation was based on the rainfall from September to October 2021, topography characteristics, and shallow water equation mentioned in section 3.1. The distribution of the flood depth was identified as a flow that was generated with Equations (6) and (7). Figure 4 presents the flood generation in the study area for large river basins and small specific areas the distribution is shown at different times, namely, September 28 at 2:00, October 4 at 9:00, and October 31 at 0:00. The small region as high-resolution results was shown in the first column, while the flood in the river basin area was presented in the second column. The lowest flood depth (0–1 m) is shown in blue, whereas the highest depth (7–8 m) is shown in red.

4.2 Flood characteristic

Figure 5 presents the flood characteristic of the storm event from September to October 2021 in Chaiyaphum City such as the maximum flood depth, the arrival time of maximum depth, the average flood depth during the event, arrival time of flood depth as the flood beginning, and flood duration time. The maximum flood depth in the small region as the high-resolution result was shown in **Figure 5a**. The results reveal that the water depth from the middle to the top of the small region is

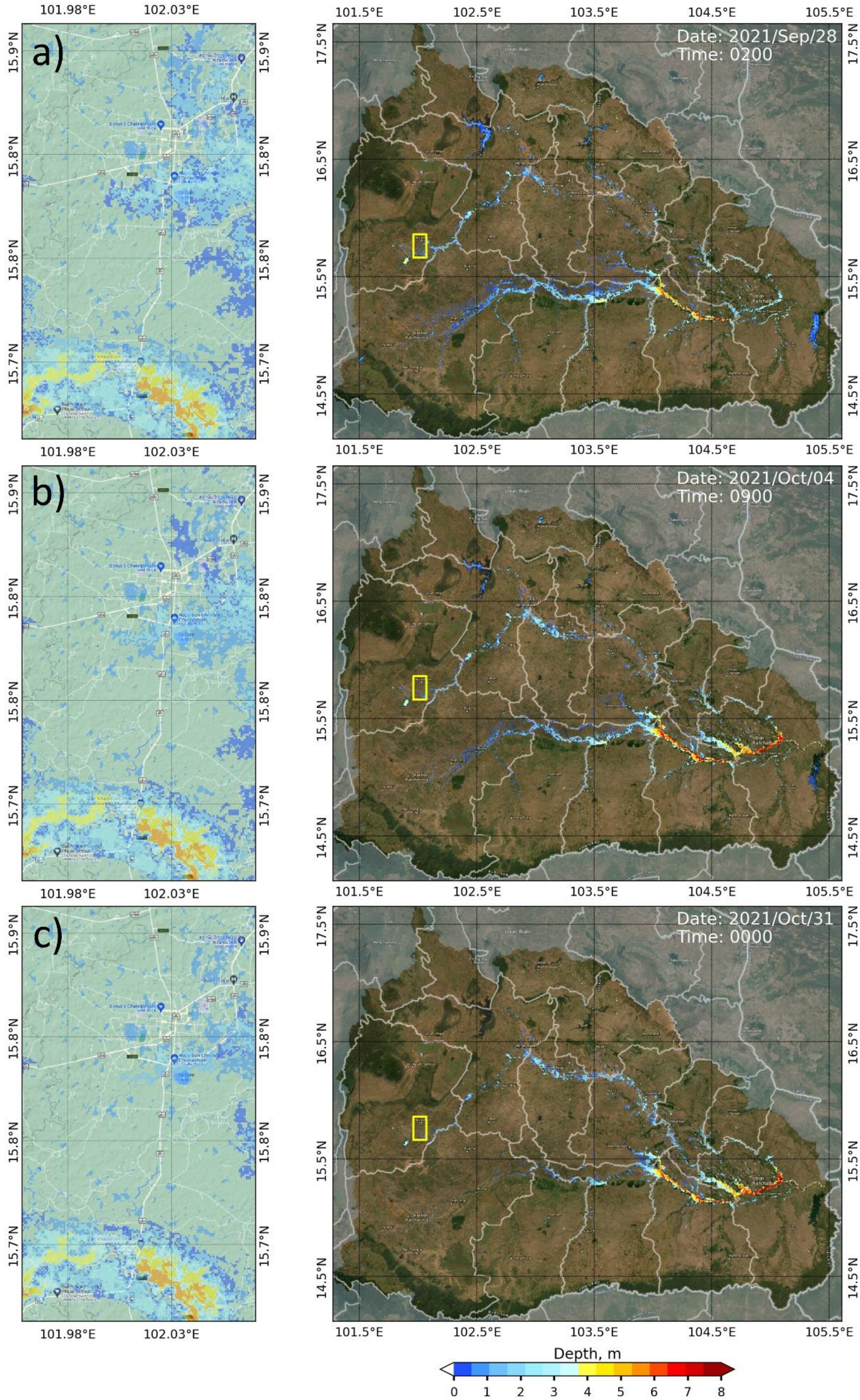


Fig. 4. Flood generation: September 28 at 2:00, October 4 at 9:00, and October 31 at 0:00.

approximately 1–3 m, and in the bottom area is approximately 3–8 m. The different values of the maximum flood depth are come from that the top area of the small region is a process of the overland flow mechanism, while the bottom area is the floodplain area of the Chi River. Figure 5b presents the arrival time of maximum flood depth that The lowest (0–15 days) is shown in blue, whereas the highest

(30–40 days) is shown in red. The overland flow area has an arrival time of approximately 15-30 days, while the floodplain area is approximately 30–40 days. The average flood depth during the selected event was shown in Figure 5c that the overland flow area was represented by the flood depth of approximately 0.1–2 m, while 3–5 m was in the floodplain area. The beginning of the flood for this event was presented by **Figure 5d** with varying from 0.1–20 days. The overland flow area represented the time of approximately 0.1–10 days due to the local flood, while the time of approximately 5–20 days is in the floodplain area. **Figure 5e** presented flood duration from September to October 2021 that an average time of approximately 45 days. The overland flow area varied by approximately 50–60 days, while the time of approximately 35–50 days is in the floodplain area. The overland flow area has a longer duration time than the flood plain area due to the obstruction of drainages such as infrastructure, building, and channel network.

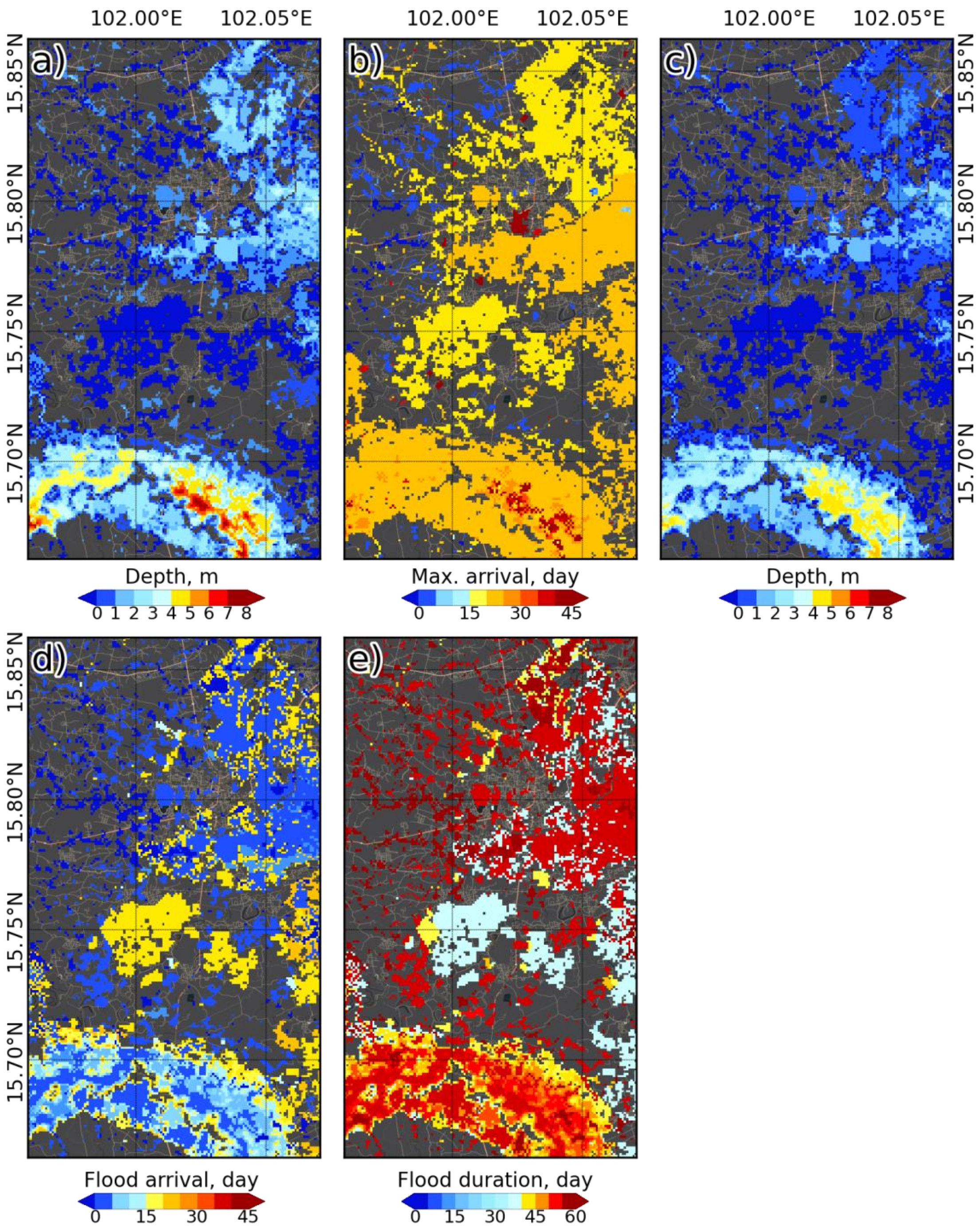


Fig. 5. Flood characteristics during the selected event in the small region, a) the maximum flood depth, b) the arrival time of maximum depth, c) the average flood depth during the event, d) arrival time of flood depth as the flood beginning and e) flood duration time.

5 CONCLUSIONS AND DISCUSSION

Flood event in 2021 Thailand in the upstream area of the Chi River basin, large-scale riverine, and flash floods caused damage to approximately 240 square kilometers in the Chaiyaphum Province. This study applied the 2D shallow water equation to simulate this event with the model is combined into 2 regions, large region (basin-scale) and small region (specific area), with the nesting grid method, as the multi-resolution modeling. The multi-resolution flood modeling could be presented by the originality of this study to apply the nesting grid method for flood simulation. The results presented an inundation map for large-scale riverine flooding and specific region in Chiyaphum City. In the specific region, the 5 flood characteristics, the maximum flood depth, the arrival time of maximum depth, the average flood depth during the event, the arrival time of flood depth as the flood beginning, and flood duration time, were analyzed. It can be useful data for large-scale flooding and small-scale flooding to provide information to disaster management.

For the future work of this study, it is required to calibrate the model results with surveyed data such as flow hydrograph at the observation station, flood depth at surveyed spot height, and flood area.

6 ACKNOWLEDGMENTS

In this study, QGIS software and Python were used to illustrate the spatial results.

REFERENCES

(1) WMO (2014) Atlas of mortality and economic losses from weather, climate, and water extremes (1970-2012). World Meteorological Organization (WMO) Publication: WMO-No. 1123.
(2) Pakoksung, K, Takagi, M (2016) Effect of satellite-based rainfall products on river basin responses of runoff simulation on flood event. Model. Earth Syst. Environ. 2, 143. https://doi.org/10.1007/s40808-016-0200-0
(3) Singh, V P, Woolhiser, D A (2002) Mathematical modeling of watershed hydrology, Journal of Hydrologic Engineering, 7(4), 270-292.
(4) Pakoksung, K, Suppasri, A, Muhari, A et al. (2020) Global optimization of a numerical two-layer model using observed data: a case study of the 2018 Sunda Strait tsunami. Geosci. Lett. 7, 15. https://doi.org/10.1186/s40562-020-00165-5
(5) Pakoksung, K, Suppasri, A, Imamura, F (2018) Systematic Evaluation of Different Infrastructure Systems for Tsunami Defense in Sendai City. Geosciences. 8(5):173. https://doi.org/10.3390/geosciences8050173
(6) Okamoto, K, Iguchi, T, Takahashi, N, Iwanami, K, Ushio, T (2005) The Global Satellite Mapping of Precipitation (GSMaP) project. In: 25th IGARSS Proceeding, pp 3414–3416.
(7) United State Geological Survey, (2008) Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales (Hy1droSHEDS), Available: http://hydrosheds.cr.usgs.gov/index .php [accessed January 31, 2008].
(8) The CGIAR Consortium for Spatial Information, (2008) Shuttle Radar Topographic Mission (SRTM), Available: http://srtm.csi.cgiar.org/ [accessed August 19, 2008].

TA-116L

ASSESSING CLIMTE CHANGE IMPACT ON FLOOD PEAK DISCHARGES OF ALL THE CLASS-A RIVERS IN JAPAN

Tomohiro Tanaka[*1], Keita Kobayashi[2], Yasuto Tachikawa[2]
[1] Graduate School of Global Environmental Studies, Kyoto University
[2] Graduate School of Engineering, Kyoto University

1. Objectives

Climate change is expected to significantly increase flood risk in many parts of the world. In Japan, we have experienced several heavy storm events causing devastating flood damage in this decade. For example, Hagibis, a strong typhoon hit Japan in September 2019. The heavy rainfall resulted in dike break has occurred in major six rivers out of 109 class-A rivers, updating the highest insurance payment for water-related disaster (MLIT, 2019). Because the frequency of such devastating floods is low at the present climate, large ensembles are required to detect its future changes by climate change. In 2017, a large ensemble climate simulation data d4PDF was developed, it has been widely applied to assessing climate change impacts mainly on extreme events (Ishii and Mori, 2020). So far, the authors have addressed future changes of flood peak discharges in all the 109 class-A river basins and its simultaneous occurrence probability using d4PDF (Kobayashi et al., 2020; Tanaka et al., 2020; Tanaka et al., 2021). We present the summary of a series of these research works.

2. Study area and methods

To achieve the impact assessment on flood peak discharge over Japan, we took the following four steps in class-A river basins: 1) bias detection and correction of Annual Maximum Basin Rainfall (AMBR) in d4PDF, 2) rainfall-runoff modelling of each river basin, 3) rainfall-runoff simulations of d4PDF annual maximum storm events and 4) flood frequency analysis of single river basin and statistical test of the number of flooded rivers. River basins in Japan are classified into classes A and B depending on social/economic importance. As class-A river basins covers a large proportion of population (63.5 %) and area (63.7 %) with all major economic zones, this study targeted all 109 class-A river basins. d4PDF is a dataset of large ensemble climate projections under four climate scenarios, i.e. the pre-industrial and the past climates and the climates 2K and 4K warmer than the pre-industrial climate (https://www.miroc-gcm.jp/d4PDF/index_en.html). This study used the past and the 4K warmer climate experiments (hereinafter, historical and 4K experiments). The past experiment consists of 50 ensembles in which the past 60-year climate from 1951 to 2010 was reproduced with different initial and boundary conditions, producing 3000-year samples. The 4K experiment consists of 6 ensembles of future Sea Surface Temperature (SST) patterns in which 60-year stationary climate were simulated with 15 different initial conditions.

The bias of extreme rainfall intensity in d4PDF was identified for AMBR. Observed rainfall was Radar AMeDAS Rainfall (RAR) that is a radar observation rainfall adjusted with gauged rainfall data by Japan Meteorological Agency. The empirical cumulative distributions between RAR (29 samples from 1988 to 2016) and d4PDF were compared using the two sample Kolmogorov-Smirnov test at a 5 % significance level. For the rejected, i.e. largely biased, river basins, mainly in southern Japan, the bias was corrected using a quantile mapping method. To extrapolate the tail of the distribution in RAR, the Generalized Extreme Value (GEV) distribution and Gumbel distribution were fitted. Due to the small number of samples in RAR, the shape parameter of the GEV distribution might be extreme in some river basins; therefore, a typical range of the shape parameter was examined using d4PDF in all the 109 river basins, which was identified to range from -0.043 to 0.222. In the model selection between the GEV and Gumbel distribution, the Gumbel distribution was employed if the shape parameter of the fit GEV distribution was in the outside of the range. Then, the bias correction factor of AMBR was identified as the rate of the quantile between d4PDF and a parametric distribution of RAR and multiplied to hourly rainfall intensity of annual maximum storms. To translate rainfall to flood peak discharge, a kinematic wave-based distributed hydrological model (Tanaka and Tachikawa) was constructed in each basin.

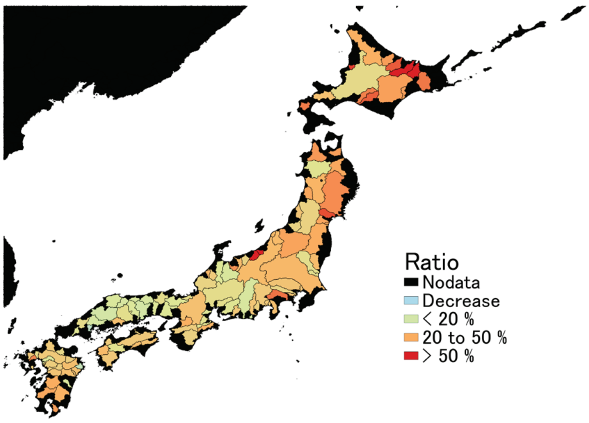


Fig. 1. Increase ratio of 100-year discharge between the past and 4K experiments in all the 109 class-A river system, Japan (Kobayashi et al., 2020). Flood peak discharge in the 4K experiment is the mean value of six SST ensembles.

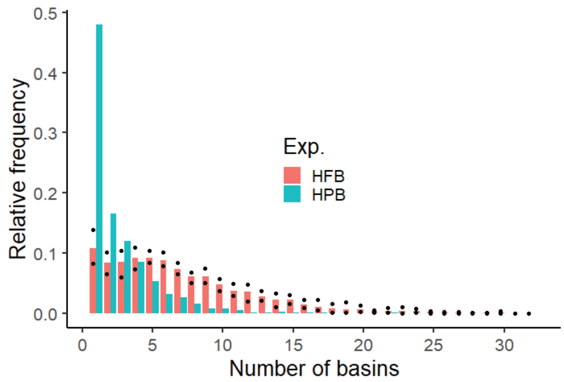


Fig. 2. The number of river systems where annual maximum flood peak discharge exceeded its design level in the same year in the past (HPB) and 4K (HFB) experiment (Tanaka et al., 2021). In this analysis, all the SST ensembles were merged to one sample.

3. Results

The increase ratio of the 100-year discharge (discharge at the non-exceedance probability of 99 %) between the past and 4K experiments of all the river basins are shown as a colored basin map in **Fig. 1**. In the 4K-warmer climate, all the river basins will experience 100-year flood more frequently than the past climate in the end of 20th century. The increase ratio is larger in the Pacific Ocean side, Kyushu and northern Japan. As the result, the return period of the present design flood peak is projected to decrease to 15 to 60 years. **Figure 2.** shows the number of river systems where annual maximum flood peak discharge exceeded the present design level in the same year, indicating the simultaneous floods in a single year. Compared to the past climate (HPB), the 4K-warmer climate (HFB) will increase the number of rivers in the same year, e.g. five river basins may be flooded in the same year at the same frequency as no flooding. The difference of the two histogram is statistically different at 1% significance level according to the one-side binominal distribution test.

References

Ishii, M. and Mori, N. 2020. d4PDF: large-ensemble and high-resolution climate simulations for global warming risk assessment. Progress in Earth and Planetary Science, 7(1), 1-22.

Kobayashi, K., Tanaka, T., Shinohara, M. and Tachikawa Y. 2020. Analyzing future changes of extreme river discharge in Japan using d4PDF, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), 76(1), 140-152.

MLIT 2019a Economic damage by Typhoon Hagibis, 2019 (50th report) (available at: www.mlit.go.jp/common/001319108.pdf) (Accessed 25 October 2021)

Tanaka, T., Kobayashi, K. and Tachikawa, Y. 2020. Analyzing return period of number of flooded rivers by typhoon Hagibis and its future change, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), 76(1), 159-165.

Tanaka, T., Kobayashi, K. and Tachikawa, Y. 2021. Simultaneous flood risk analysis and its future change among all the 109 class-A river basins in Japan using a large ensemble climate simulation database d4PDF, Environmental Research Letters, 16, 074059.

Keywords: climate change, d4PDF, Japan

Graduate School of Global Environmental Studies, Kyoto University.
Kyotodaigaku-katsura, Nishikyo-ku, Kyoto, Kyoto 615-8540, Japan.
E-mail tanaka.tomohiro.7c@kyoto-u.ac.jp

TA-118L

Projected Change in Seasonal Monsoon Precipitation over Southeast Asia under CMIP6 Climate Model

S. Rojpratak
Graduate student: Civil Engineering Department, Rangsit University Pathumthani 12000, Thailand
sawitree.r61@rsu.ac.th

S. Supharatid
Director: Climate Change and Disaster Center, Rangsit University Pathumthani 12000, Thailand
seree.s@rsu.ac.th

ABSTRACT

The present study applies the statistical bias-correction to analyze the changes in mean temperature and precipitation of the latest 18 Couple Model Intercomparison Project phase 6 (CMIP6) models simulation over Southeast Asia (SEA). The models are employed to assess future mean precipitation change for 3 periods (Near-future: 2015-2039, Mid-future: 2040-2069, and far-future: 2070-2099) derived from the climate projections under the medium-emission (SSP2-4.5) and high-emission (SSP5-8.5) scenarios. The bias-correction is employed by using the "Variance scaling" method for the temperature and the "Empirical quantile mapping" method for the precipitation. Higher annual-mean precipitation is observed over the Maritime Continent than the mainland SEA. The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increases in Southwest and Northeast monsoon rainfall (SWMR and NEMR) along the timeline of the 21st century with larger values found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display greater increases during the boreal summer than boreal winter.

Keywords— CMIP6; Shared socioeconomic pathway; Monsoon precipitation

1 INTRODUCTION

Southeast Asia (SEA) is considered to be most vulnerable to climate extremes as a result of its high population density, long coastline with exposure to tropical cyclones, low-lying area, more than 20,000 islands and significant rainfall variability. Manton et al. 2001 analysed climate extreme indices for historical period over the SEA and South Pacific. Regional studies across the Asia–Pacific (Griffiths et al. 2005) have shown significant increases in occurrences of annual number of hot days and warm nights and decreases in incidences of annual number of cool days and cold nights over the past few decades. The projected changes in precipitation characteristics during the east Asian summer rainy season was investigated by Kitoh et al. (2009). They found an increase in the frequency of heavy precipitation in the near future and by the end of 21st century. Caesar et al. (2011) made an assessment of the changing climate extremes in the Indo-Pacific region using available data from 13 countries between 1971-2005. They discovered that the warm extremes are increasing and cold extremes are decreasing. Trends in precipitation extremes are less spatially consistent across the region.

Studies investigating the consequences of climate change over SEA are limited. The majority of SEA is influenced by the Asian–Australian monsoon and several regions within it are affected by extreme weather events, particularly tropical cyclones, droughts, and floods (Chang et al., 2005). The warm extremes increased while the cold extremes decreased over the Indo-Pacific region during 1971–2005 (Caesar et al., 2011). Most studies of the projected changes in SEA climate are embedded in global-scale domain carried out using global climate models (GCM) (Chadwick et al., 2016). The projected changes in mean and extreme precipitation (using the NASA Earth Exchange Global Daily Downscaled

Projection, NEX- GDDP dataset) over several parts of SEA show substantial increases in the 21st century (Mandapaka and Lo, 2018). Suppari et al. (2020) found significant changes in consecutive dry day (CDD) and a decrease in total wet day precipitation (PRCPTOT) over most regions in SEA by using eight ensemble members of CORDEX-SEA simulations for RCP4.5 and RCP8.5 scenarios. A marked amplification in extreme precipitation over the Indochina Peninsula and the Maritime Continent were found under 1.5 °C and 2 °C global warming levels (Ge et al., 2019). Recently, Tangang et al. (2020) examined the projected rainfall changes in Southeast Asia in the 21st century based on seven regional climate models (RCMs) members of archived CORDEX-SEA simulations.

To our knowledge, few studies have analyzed the CMIP6 datasets to examine the future climate, especially in SEA. Grose et al (2020) evaluated CMIP6 models and its future climate projects over Australia compared to CMIP5 models. Almazroui et al (2020) examined the projected changes in temperature and precipitation over 6 South Asian countries during the 21st century using the latest Coupled Model Intercomparison Project phase 6 (CMIP6) dataset. They found an increase in annual-mean precipitation under all scenarios with considerable variations among countries. Ukkola et al (2020) revealed larger projected drought changes and more consistent in CMIP6 compared to CMIP5 models. Very recently Supharatid et al (2021) assessed changes in climate variables (mean temperature and precipitation) over SEA by using 18 CMIP6 models. They found robust increases in rainfall during the Southwest Monsoon.

The present study analyses the changes in mean temperature and precipitation using the latest Couple Model Intercomparison Project phase 6 (CMIP6; Eyring et al. 2015) model simulation dataset over SEA. It has yet to be thoroughly understood how the latest CMIP6 models can effectively simulate the climate response to anthropogenic forcing over SEA. The goal of this work is to assess the long-term changes of the temperature and precipitation in different areas of SEA, especially, the seasonal monsoon precipitation in the near-future, mid-future, and far-future periods. This is an initial step required to find appropriate level of adaptation measures in response to the impacts of projected climate extreme events.

2 Data and methodology

2.1 Study region

Our region of interest is the Southeast Asia domain as display in Fig. 1. The climate of SEA is mainly tropical–hot and humid most part of the year and is characterized by two distinct sub-monsoon seasons: wet and dry. The southwest monsoon (SWM) typically begins from early June to late September, causing heavy rainfall over the mainland SEA between May to October. The northeast monsoon (NEM) is characterized by cold air from the Himalayas, causing heavy rain from December to early March over the southern parts of SEA while the northern parts experience drier weather. Majority of the Southeast Asia region is affected by extreme weather events, particularly tropical cyclones, droughts and floods.

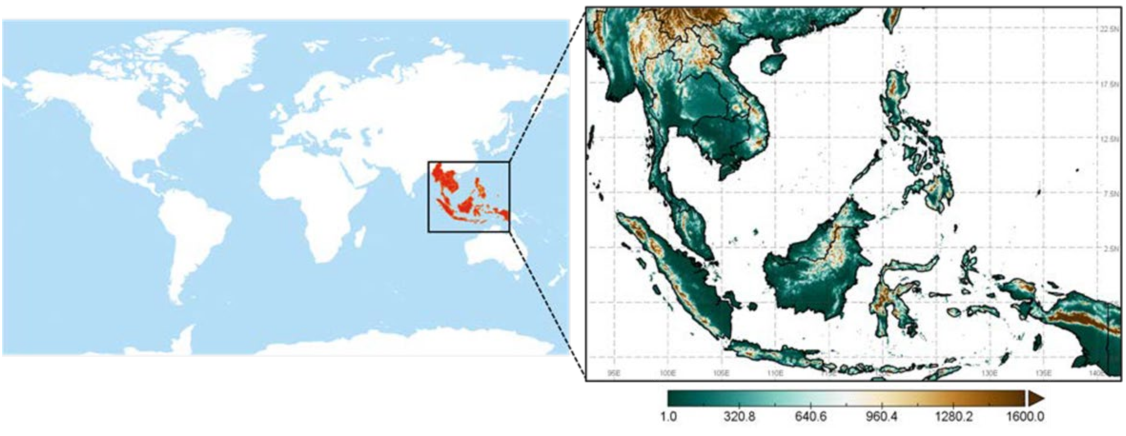


Fig. 1 Study area SEA (Southeast Asia)

2.2 Observation and model datasets

In this study, we use SA-OBS as observation dataset. SA-OBS is a daily high-resolution land-gridded observational dataset for the minimum, mean and maximum temperature and precipitation covering SEA region. This data set is delivered in 0.25° by 0.25° and a 0.5° by 0.5° regular latitude-longitude grid during the period of 1981– 2016 (Van Den Besselaar et al., 2016).

For model datasets, we examine 18 CMIP6 models (see Table 1) obtained from the CMIP6 database website (https://esgf-node.llnl.gov/search/cmip6) . The new generation of CMIP6 models differs from those of CMIP5 in a new set of specifications for concentration, emission, and land-use scenarios (Gidden et al. 2019) as well as a new start year for the future scenarios. The CMIP6 is based on community scenarios (Van Vuuren et al., 2014) by integrating across different research disciplines including societal development, known as Shared Socioeconomic Pathways (SSPs). The SSPs are based on 5 narratives that describe different levels of socioeconomic development (Riahi et al. 2017): sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4), and fossil fuel-driven development (SSP5). Detailed descriptions of the SSPs are available in O'Neill et al. (2016)

Table 1 List of CMIP6 models used in this study

GCM	Research Center	Resolution
ACCESS-CM2	Australian Community Climate and Earth System Simulator	1.88×1.25
ACCESS-ESM1-5	Australian Community Climate and Earth System Simulator	1.88×1.25
BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration, Beijing, China	1.12×1.11
CanESM5	Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Canada	2.81×2.77
CNRM-CM6-1	National Center for Meteorological Research, France	1.41×1.39
CNRM-ESM2-1	National Center for Meteorological Research, France	1.41×1.39
EC-Earth3	EC-Earth Consortium (EC-Earth)	0.70×0.70
FGOALS-g3	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, China	0.70×0.70
GFDL-ESM4	NOAA Geophysical Fluid Dynamics Laboratory, USA	1.25×1.00
INM-CM4-8	Institute for Numerical Mathematics, Russia	2.00×1.50
INM-CM5-0	Institute for Numerical Mathematics, Russia	2.00×1.50
IPSL-CM6A-LR	The Institut Pierre Simon Laplace, France	2.50×1.27
MIROC6	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Japan), AORI (Atmosphere and Ocean Research Institute, The University of Tokyo), NIES (National Institute for Environmental Studies), and R-CCS (RIKEN Center for Computational Science), Japan	1.41×1.39
MIROC-ES2L	JAMSTEC, AORI, NIES, and R-CCS, Japan	2.81×2.77
MPI-ESM1-2-LR	Max Planck Institute for Meteorology, Germany	1.88×1.85
MRI-ESM2-0	Meteorological Research Institute, Japan	1.12×1.11
NESM3	Nanjing University of Information Science and Technology, China	1.88×1.85
NorESM2-LM	NorESM Climate modeling Consortium consisting of CICERO (Center for International Climate and Environmental Research), MET-Norway (Norwegian Meteorological Institute), NERSC (Nansen Environmental and Remote Sensing Center, Bergen), NILU (Norwegian Institute for Air Research), UiB (University of Bergen, Bergen), UiO (University of Oslo) and UNI (Uni Research), Norway	2.50×1.89

2.3 Bias correction

Bias correction is widely used in climate impact modelling. The aim is to adjust selected statistics (mean, variance and/or quantile) of a climate model simulation to better match observed statistics during a reference period. Many bias correction methods have been employed in previous studies (Teutschbein and Seibert, 2012; Chen et al. 2013; Supharatid, 2016; Navarro-Racines et al. 2020) with a critical review by Maraun (2016). In this study, we use the "Variance scaling" method for the temperature and the "Empirical quantile mapping" method for the precipitation.

3. Results and Discussion

3.1 Model performance

The CMIP6 model performance was evaluated in terms of correlation coefficient (R), center root mean-square difference (RMSD) and standard deviations (SD) by the Taylor Diagram (Taylor 2001) during the reference period (see Fig. 2). The center root mean-square difference and the standard deviation are normalized by their corresponding observations of SA-OBS. The observation datasets are represented by black symbol and the CMIP6 models are represented by other colors. Most temperature datasets show high R (> 0.9) to SA-OBS. Most CMIP6 models give R in a range 0.8-0.9 and more spread SD are found than R and RMSD. For precipitation, all datasets are found to give also high R (> 0.8) but lower than ones of temperature. We observe distinctly different magnitudes of SD but similar RMSD. The CMIP6 models display more widespread with lower R compared to Tmean. Most CMIP6 model correlation coefficients lie between 0.4 to 0.7 by which MIROC-ES2L gives the highest R and smallest RMSD. NorESM2 shows highest SD and also RMSD. The MME model is found to give best results (Highest R and lowest RMSD) among CMIP6 models.

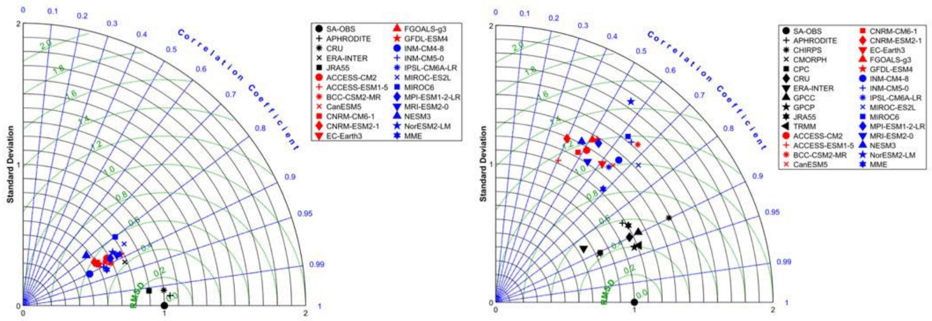


Fig. 2 Taylor diagram of temperature and precipitation for CMIP6 models during the reference period

3.2 Projected Changes in annual-mean precipitation

The annual-mean precipitation changes show significant regional difference (see Fig. 3). Overall, the projected annual-mean precipitation shows small reductions (< 10%) over northern SEA and Indonesia (Java) for the near-future period and, then increases towards the far-future periods. For the near-future period, the projected precipitation shows an increase of 3.04 % and 3.64 % under SSP2-4.5 and SSP5-8.5, respectively as compared to the present climate. For the mid-future period, the projected precipitation shows an increase of 7.10 % and 8.51 % under SSP2-4.5 and SSP5-8.5, respectively. And for the far-future period, precipitation is projected to increase by 9.62 % and 15.19 % under SSP2-4.5 and SSP5-8.5, respectively. Under the high-emission SSP5-8.5 scenario, most areas in SEA exhibits a significant and robust increase in precipitation (except in Java) relative to the present climate. Mandapaka and Lo (2018) also found similar results from the NEX-GDDP dataset under RCP4.5 and RCP8.5 scenarios. The larger increases in precipitation are projected over northern and central Vietnam, northern Thailand, northern Myanmar, northern Laos, Cambodia, Kalimantan, Sulawesi, and east Papua. These findings are generally consistent with Tangang et al. (2019, 2020) who used 7 RCMs in CORDEX-SEA domain and 11 driving CMIP5 GCMs and found robust increases in the 21st century over northern Vietnam, Cambodia, Laos, and northern Thailand.

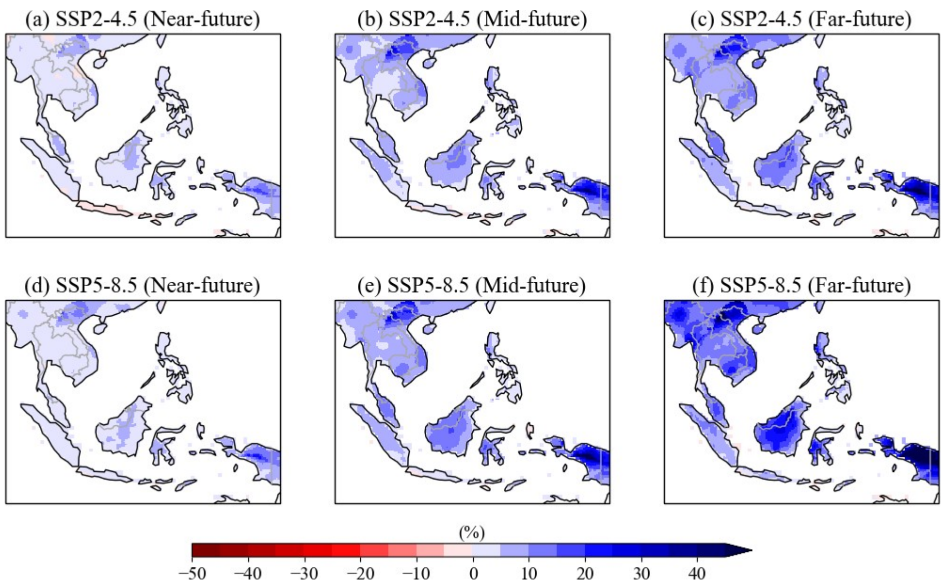


Fig. 3 Spatial distribution of future changes in mean Precipitation

3.3 Projected Changes in seasonal monsoon rainfall

The area-averaged mean seasonal monsoon precipitation over SEA is shown for MME model in Fig. 4. The 1st, 2nd,3rd, and 4th columns represent values for the historical, near-future, mid-future, and far-future periods, respectively. The projection in each column is displayed under both SSP2-4.5 and SSP5-8.5 scenarios. The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increasing of SWMR, NEMR along the timeline to the 21st century with larger increases are found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display larger increases during the boreal summer than boreal winter.

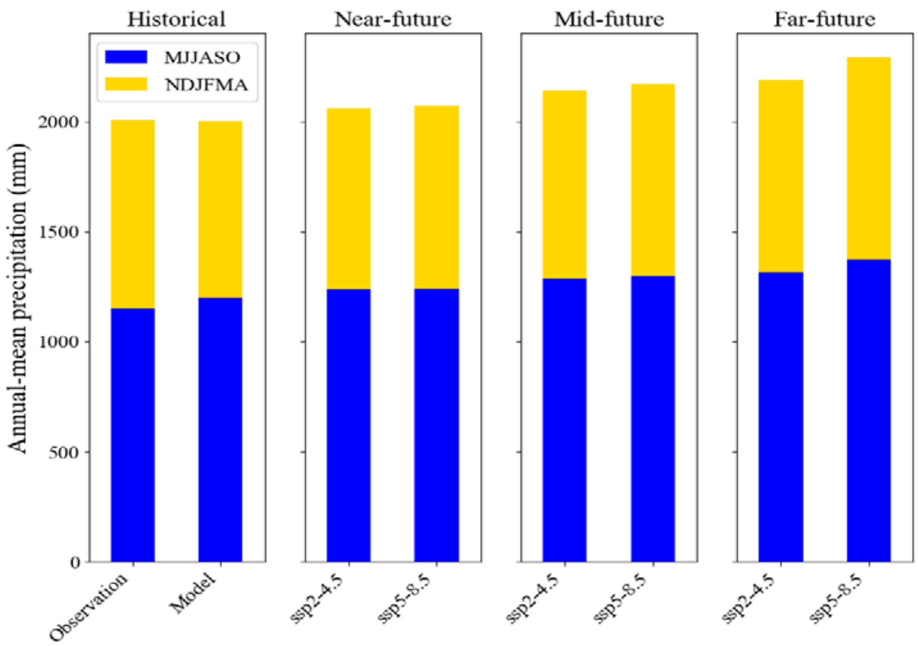


Fig. 4 Mean seasonal monsoon precipitation

4. Conclusions

The present study applies the statistical bias-correction ("Variance scaling" method for the temperature and the "Empirical quantile mapping" method for the precipitation) to analyze the changes in mean temperature and precipitation of the latest Couple Model Intercomparison Project phase 6 (CMIP6) model simulation over SEA. The CMIP6 is based on community scenarios known as Shared Socioeconomic Pathways which differ from CMIP3 and CMIP5 in a different start year of the future scenarios, as well as a new set of specifications on emission and land-use scenarios. In this study, Eighteen CMIP6 models are employed to assess future mean climate change for 3 periods (Near-future: 2015-2039, Mid-future: 2040-2069, and far-future: 2070-2099) derived from the climate projections under the medium-emission (SSP2-4.5) and high-emission (SSP5- 8.5) scenarios.
The spatial distributions in annual-mean temperature and precipitation of CMIP6 models generally produce similar pattern to SA-OBS. Higher annual-mean precipitation is observed over the Maritime Continent than the mainland SEA. The annual-mean temperature under SSP2-4.5 (SSP5-8.5) is projected to increase by 1.1 ^{o} C (1.41^{o} C) in 2050 and 1.99 ^{o}C (4.29^{o} C) in 2100. The annual-mean precipitation is projected to increase by 6.21 % (8.11 %) in 2050 and 9.62 % (18.43 %) in 2100 under SSP2-4.5 (SSP5-8.5).
The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increases in Southwest and Northeast monsoon rainfall (SWMR and NEMR) along the timeline of the 21st century with larger values found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display greater increases during the boreal summer than boreal winter.

Acknowledgement We would like to thank the anonymous reviewers. The author gratefully acknowledges the assistance of the Thailand Research Fund (The Royal Golden Jubilee Ph.D. Program) for supporting full scholarship under grant number PHD/0203/2560. The authors also thank the Earth System Grid Federation (ESGF) for archiving and providing access to the CMIP6 dataset, including all observation dataset providers cited in the manuscript.

REFERENCES

(1) Almazroui, M, Saeed S, Saeed F, Islam MN, Ismail M (2020), Projections of Precipitation and Temperature over the South Asian Countries in CMIP6, Earth Systems and Environment, Vol. 4, No. 2, pp. 297-320.
(2) Caesar, J, Alexander LV, Trewin B, Tse-ring K, Sorany L, Vuniyayawa V, Keosavang N, Shimana A, Htay MM, Karmacharya J, Jayasinghearachchi DA, Sakkamart J, Soares E, Hung LT, Thuong LT, Hue CT, Dung NTT, Hung PV, Cuong HD, Cuong NM, Sirabaha S (2011), Changes in temperature and precipitation extremes over the Indo-Pacific region from 1971 to 2005, International Journal of Climatology, Vol. 31, No. 6, pp. 791–801.
(3) Chadwick, R, Good P, Martin G, Rowell DP. (2016), Large rainfall changes consistently projected over substantial areas of tropical land, Nature Climate Change, Vol. 6, No. 2, pp. 177–181.
(4) Chang, CP, Wang Z, McBride J, Liu CH (2005), Annual cycle of Southeast Asia—Maritime Continent rainfall and the asymmetric monsoon transition, Journal of climate Vol. 18, No. 2, pp. 287-301.
(5) Chen, J, Brissette FP, Chaumont D, Braun M (2013), Finding appropriate bias correction methods in downscaling precipitation for hydrologic impact studies over North America, Water Resources Research, Vol. 49, No. 7, pp. 4187-4205.
(6) Eyring, V, Bony S, Meehl GA, Senior C, Stevens B, Stou er RJ, Taylor KE (2015), Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geoscientic Model Development Discussions, Vol. 8, pp. 10539-10583.
(7) Ge, F, Zhu S, Peng T, Zhao Y, Sielmann F, Fraedrich K, Zhi X, Liu X, Tang W, Ji L (2019), Risks of

precipitation extremes over Southeast Asia: does 1.5 °C or 2 °C global warming make a difference?, Environmental Research Letters, Vol. 14, No. 4, 044015. https://doi.org/10.1088/ 1748-9326/aaff7e.

(8) Gidden, MJ, Riahi K, Smith SJ, Fujimori S, Luderer G, Kriegler E, Takahashi K (2019), Global emissions pathways under different socio- economic scenarios for use in CMIP6: a dataset of harmonized emissions trajectories through the end of the century, Geoscientific model development, Vol. 12, No.4, pp. 1443-1475.

(9) Griffiths, GM, Chambers LE, Haylocketal MR, Manton MJ, Nicholls N, Baek HJ, Choi Y, Della-Marta PM, Gosai A, Iga N, Lata R, Laurent V, Maitrepierre L, Nakamigawa H, Ouprasitwong N, Solofa D, Tahani L, Thuy DT, Tibig L, Trewin B, Vediapan K, Zhai P (2005), Changing mean temperature as a predictor of extreme temperature change in the Asia-Pacific region, International Journal of Climatology: A Journal of the Royal Meteorological Society, Vol. 25, No. 10, pp. 1301–1330.

(10) Grose, MR, Narsey S, Delage FP, Dowdy AJ, Bador M, Boschat G, Chung C, Kajtar JB, Rauniyar S, Freund MB, Lyu K, Rashid H, Zhang X, Wales S, Trenham C, Holbrook NJ, Cowan T, Alexander L, Arblaster JM, Power S (2020), Insights from CMIP6 for Australia's future climate, Earth's Future, Vol. 8, No.5, e2019EF001469.

(11) Kitoh, A, Ose T, Kurihara K, Kusunoki S, Sugi M (2009), Projection of changes in future weather extremes using super-high-resolution global and regional atmospheric models in the KAKUSHIN Program: Results of preliminary experiments, Hydrological Research Letters, Vol. 3, pp. 49-53.

(12) Mandapaka, PV, Lo EYM (2018), Assessment of future changes in Southeast Asian precipitation using the NASA Earth Exchange global daily downscaled projections data set, International Journal of Climatology, Vol. 38, No. 14, pp. 5231-5244.

(13) Manton, MJ, Della-Marta PM, Haylock MR, Hennessy KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D, Inape K, Isobe H, Kestin TS, Lefale P, Leyuk CH, Lwin T, Maitrepierre L, Ouprasitworng N, Page CM, Pahalad J, Plummer N, Salinger MJ, Suppiah R, Tran VL, Trewin B, Tibig I, Yee D (2001), Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998, International Journal of Climatology, Vol. 21, No. 3, pp. 269-284.

(14) Maraun, D (2016), Bias correcting climate change simulation-a critical review, Current Climate Change Reports, Vol. 2, No. 4, pp. 211-220.

(15) Navarro-Racines, C, Tarapues J, Thornton P, Jarvis A, Ramirez-Villegas J (2020), High-resolution and bias-corrected CMIP5 projections for climate change impact assessments, Scientific Data, Vol. 7, No. 1, pp. 1-14.

(16) O'Neill, BC, Kriegler E, Ebi KL, Kemp-Benedict E, Riahi K, Rothman D, van Ruijven B, van Vuuren DP, Birkmann J, Kok K, Levy M, Solecki W (2016), The roads ahead: narratives for Shared Socioeconomic Pathways describing world futures in the 21st century, Global environmental change, Vol. 42, pp. 169-180.

(17) Riahi, K, Van Vuuren DP, Kriegler E, Edmonds J, O'neill BC, Fujimori S, Bauer N, Calvin K, Dellink R, Fricko O, Lutz W, Popp A, Cuaresma JC, Samir KC, Leimbach M, Jiang L, Kram T, Rao S, Emmerling J, Ebi K, Hasegawa T, Havlik P, Humpenoder F, Aleluia Da Silva L, Smith S, Stehfest E, Bosetti V, Eom J, Gernaat D, Masui T, Rogelj J, Strefler J, Drouet L, Krey V, Luderer G, Harmsen M, Takahashi K, Baumstark L, Doelman JC, Kainuma M, Klimont Z, Marangoni G, Lotze-Campen H, Obersteiner M, Tabeau A, Tavoni M (2017), The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global environmental change, Vol. 42, pp. 153-168.

(18) Supharatid, S (2016), Skill of precipitation projection in the Chao Phraya river Basin by multi-model ensemble CMIP3-CMIP5. Weather and climate extremes, Vol. 12, pp 1-14.

(19) Supharatid, S, Nafung J, Aribarg T (2021), Projected changes in temperature and precipitation over mainland southeast Asia by CMIP6 models, Journal of Water and Climate Change, https://doi.org/ 10.2166/wcc.2021.015.

(20) Suppari, Tangang F, Juneng L, Cruz F, Chung JX, Ngai ST, Salimun E, Mohd MSF, Santisirisomboon J, Singhruck P, PhanVan T, Ngo-Duc T, Narisma G, Aldrian E, Gunawan D,

Sopaheluwakan A (2020), Multi-model projections of precipitation extremes in Southeast Asia based on CORDEX-Southeast Asia simulations, Environmental Research, Vol. 184, 109350. https://doi.org/10.1016/j.envres. 2020.109350

(21) Tangang, F, Santisirisomboon J, Juneng L, Salimun E, Chung J, Supari S, Cruz F, Ngai ST, Ngo-Duc T, Singhruck P, Narisma G, Santisirisomboon J, Wongsaree W, Promjirapawat K, Sukamongkol Y, Srisawadwong R, Setsirichok D, Phan-Van T, Aldrian E, Gunawan D, Nikulin G, Yang H (2019), Projected future changes in mean precipitation over Thailand based on multi-model regional climate simulations of CORDEX Southeast Asia, International Journal of Climatology, Vol. 39, No. 14, pp. 5413-5436.

(22) Tangang, F, Chung JX, Juneng L, Salimun E, Ngai ST, Jamaluddin AF, Mohd MSF, Cruz F, Narisma G, Santisirisomboon J, Ngo-Duc T, Van Tan P, Singhruck P, Gunawan D, Aldrian E, Sopaheluwakan A, Grigory N, Remedio ARC, Sein DV, Hein-Griggs D, McGregor JL, Yang H, Sasak H, Kumar P (2020), Projected future changes in rainfall in Southeast Asia based on CORDEX–SEA multi-model simulations, Climate Dynamics, Vol. 55, pp. 1247-1267.

(23) Taylor, KE (2001), Summarizing multiple aspects of model performance in a single diagram, Journal of Geophysical Research: Atmospheres, Vol. 106, pp. 7183–7192.

(24) Teutschbein, C, Seibert J (2012) Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods, Journal of hydrology, Vol. 456, pp. 12–29.

(25) Ukkola, A, De Kauwe MG, Roderick ML, Abramowitz G, Pitman AJ (2020), Robust Future Changes in Meteorological Drought in CMIP6 Projections Despite Uncertainty in Precipitation, Geophysical Research Letters, Vol. 47, No. 11, e2020GL087820. DOI: 10.1029/2020GL087820.

(26) Van den Besselaar, EJ, Van der Schrier G, Cornes RC, Iqbal AS, Tank AMK (2017), SA-OBS: a daily gridded surface temperature and precipitation dataset for Southeast Asia, Journal of Climate, Vol. 30, No. 14, pp. 5151-5165.

(27) Van Vuuren, DP, Kriegler E, O'Neill BC, Ebi KL, Riahi K, Carter TR, Edmonds J, Hallegatte S, Kram T, Mathur R, Winkler H (2014), A new scenario framework for climate change research: scenario matrix architecture, Climatic Change, Vol. 122, No. 3, pp. 373-386.

TA-119L

EXPLORING BIAS CORRECTIONS OF RIVER DISCHARGE UNDER DAM OPERATION USING d4PDF IN THE CHAO PHRAYA RIVER BASIN, THAILAND

Background

Climate change and variability impact has resulted in many devastating water-related hazards affecting economies and livelihood and flooding is one of the costliest natural disasters that disrupt the counties economy especially in developing countries more than developed countries. Due to its frequency, intensity, and vulnerability, it has been focused on several studies past decades mainly in environment and water resources communities. Meteorological hazards are the root cause of various disasters like storm surges, floods, landslides, high-intensity winds, etc. (Mori & Takemi, 2016). Hydro-meteorological extreme events are likely to increase both in magnitude and frequency due to climate change (IPCC, 2012). Different climate models have studied the various impact of climate change in the future so as to prepare, adapt and mitigate its severeness.

The d4PDF data is used because it has a long time series period, which has a high advantage in flood prediction and risk assessment (Mizuta et al., 2017). It employs 100 sets of 60 years of data for past climate and 6 Sea Surface Temperatures (SST) models each consisting of 15 sets of 60 years of data which amount to 90 ensemble future climate data. The d4PDF data consists of climates 2K and 4K warmer than the pre-industrial climate, which is simulated for 3240 and 5400 years, respectively, to see the effect of global warming. In this study, we adopt only the 4K warmer scenario Global Circulation Models (GCMs) at a resolution of 60 km (Ishii & Mori, 2020). These global models have to be bias corrected in order to remove the uncertainty. A Quantile-Quantile Mapping (QQM) bias correction is used which is based on the assumption that the equivalent level in the simulated projection can be corrected from the sorted historical simulation or observation data (Bennett et al., 2014).

The objective of this study is to analyze the bias correction techniques for large ensemble climate data for future projection in big basins such as the Chao Phraya River Basin (CPRB). When we consider large basins, there may not be a similar bias-correction factors throughout the basin. Some parts of the basin may be overestimated whereas some may be underestimated which creates a large uncertainty in the study. Therefore, to rule out the effect of bias in a substantially large basins we divide the basin to two parts according to the topography and perform bias correction for the upper part of the basin and lower part of the basin.

Study Area

CPRB is one of the vulnerable basins with respect to fluvial and pluvial flooding as it is situated in a low-slung area with a highly built-up urban dimension (Visessri et al., 2020). Ranked as one of the expensive disastrous events in the history of the world, the 2011 Great Thailand Flood was a huge calamity that claimed hundreds of lives and massive economic damage (The World Bank, 2012). Disturbing the nation’s economy, Thailand had not experienced such catastrophic floods in the last half-century with the huge inundated areas. Coping with various stress such as social loss, economic damage due to the impact of climate change on extreme events, many government and non-government institutions are actively participating to bring up the country’s economy.

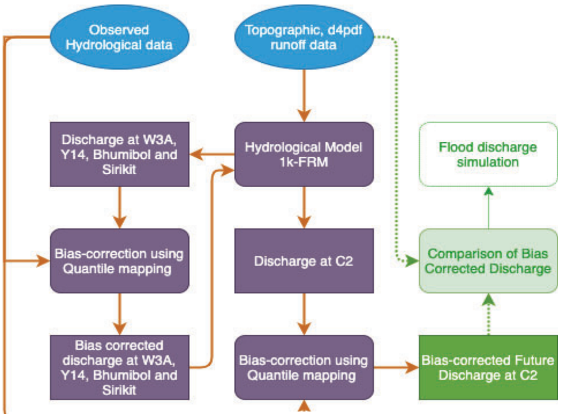


Figure 1: Framework of the study

Overall Methodology

K-FRM, developed by the Hydrology and Water Resource Research Laboratory of Kyoto University, was chosen for this study (Hunukumbura & Tachikawa, 2012). This model is used for runoff-to-discharge simulation in the study basin. QQM is used for the bias correction of the discharge at the Bhumibol, Sirikit dam as well as the Nakhon Sawan (C2) which is the outlet of the basin. CC, GF, HA, MI, MP, MR are the 6 GCMs (Ishii & Mori, 2020) selected. The past climate period is from 1951-2020 where as the future climate time period is from 2051 – 2110.

Results and Discussion

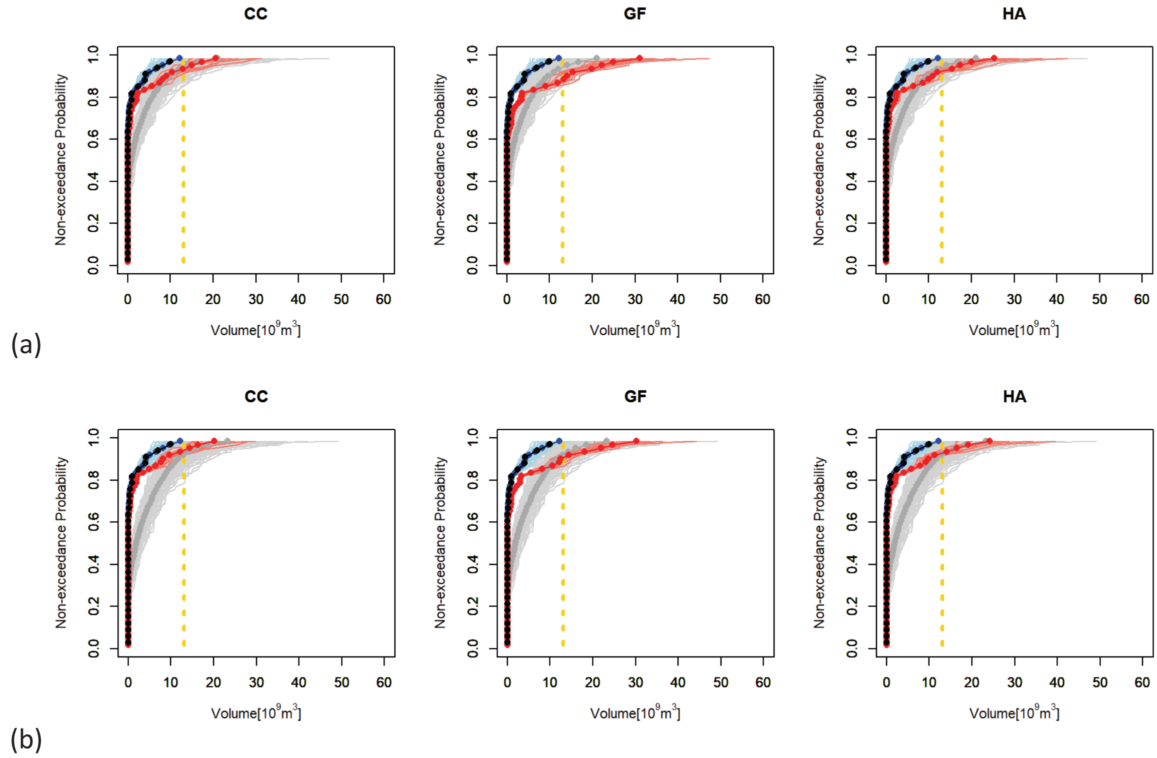


Figure 2: Non-exceedance probability curve between Observed, Present and Future Climate at the outlet (a)Without bias correction at dams (b) With bias correction at dams.

One of the methods is bias correction of the d4PDF data sets at the outlet of the basin in C2. The other method is we bias correct the river discharge firstly at the two dams (i.e., Bhumibol and Sirikit) and then with its results simulate the model and bias correct the river discharge again at C2. The main objective of this study is to compare the results to make the river discharge simulation more robust and remove the uncertainty in large basins. Three out of six model results of the two cases are shown in Figure 2 (a) and (b). We can observe that both the bias correction methods show a similar trend in future scenarios for all ensembles. There is not much difference between the results in two different cases for Chao Phraya Basin and hence, we can proceed without bias correction at dams.

Keywords: Bias correction; Dam Inflow; Quantile-Quantile Mapping; Chao Phraya River Basin

Reference:

Bennett, J. C., Grose, M. R., Corney, S. P., White, C. J., Holz, G. K., Katzfey, J. J., Post, D. A., & Bindoff, N. L. (2014). Performance of an empirical bias-correction of a high-resolution climate dataset: EMPIRICAL BIAS-CORRECTION OF A HIGH-RESOLUTION CLIMATE DATASET. *International Journal of Climatology*, *34*(7), 2189–2204. https://doi.org/10.1002/joc.3830

Hunukumbura, P. B., & Tachikawa, Y. (2012). River Discharge Projection under Climate Change in the Chao Phraya River Basin, Thailand, Using the MRI-GCM3.1S Dataset. *Journal of the Meteorological Society of Japan. Ser. II*, *90A*(0), 137–150. https://doi.org/10.2151/jmsj.2012-A07

IPCC. (2012). *IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX)*.

Ishii, M., & Mori, N. (2020). d4PDF: Large-ensemble and high-resolution climate simulations for global warming risk assessment. *Progress in Earth and Planetary Science*, *7*(1), 58. https://doi.org/10.1186/s40645-020-00367-7

Mizuta, R., Murata, A., Ishii, M., Shiogama, H., Hibino, K., Mori, N., Arakawa, O., Imada, Y., Yoshida, K., Aoyagi, T., Kawase, H., Mori, M., Okada, Y., Shimura, T., Nagatomo, T., Ikeda, M., Endo, H., Nosaka, M., Arai, M., … Kimoto, M. (2017). Over 5,000 Years of Ensemble Future Climate Simulations by 60-km Global and 20-km Regional Atmospheric Models. *Bulletin of the American Meteorological Society*, *98*(7), 1383–1398. https://doi.org/10.1175/BAMS-D-16-0099.1

Mori, N., & Takemi, T. (2016). Impact assessment of coastal hazards due to future changes of tropical cyclones in the North Pacific Ocean. *Weather and Climate Extremes*, *11*, 53–69. https://doi.org/10.1016/j.wace.2015.09.002

The World Bank. (2012). *Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning*. www.worldbank.org/th

Visessri, S., Ekkawatpanit, C., Department of Water Resources Engineering and Disaster and Risk Management Information Systems Research Group, Faculty of Engineering, Chulalongkorn University Phayathai Road Pathumwan, Bangkok 10330, Thailand, & Department of Civil Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand. (2020). Flood Management in the Context of Climate and Land-Use Changes and Adaptation Within the Chao Phraya River Basin. *Journal of Disaster Research*, *15*(5), 579–587. https://doi.org/10.20965/jdr.2020.p0579

TA-120L

ANALYSIS OF FUTURE PRECIPITATION CHANGES IN TAIWAN USING ENSEMBLE CLIMATE CHANGE SCENERIO DATABASE, D4PDF.

Chang, JuiChe*, Yasuto Tachikawa,
Graduate School of Engineering
Kyoto University
Kyoto, Japan
chang.juiche.25m@st.kyoto-u.ac.jp

Tomohiro Tanaka
Graduate School of Global Environmental Studies
Kyoto University
Kyoto, Japan

Keywords-Ensemble climate simulation dataset (d4PDF), Future extreme rainfall analyzation, Climate change

ABSTRACT

Global warming, a world-discussed issue in recent years, increase temperature, being the main factor of climate change. The latest climate assessment report in 2021—IPCC AR6 has shown that, due to global temperature increases, the future climate must become more complicated and challenging. Extreme events, such as heavy rainfall, drought, and heatwave, will more frequently and severely occur than before; consequently, damage to human beings and organisms on the earth. Disasters induced by extreme events can directly damage a country on its human activities or foundation facilities, further, impact on the economy. Therefore, prevention and mitigation work have no doubt should be urgent. However, existing research may not enough for us to encounter the highly uncertain future climate. We still need more research to predict and understand future climate situations.

Fl Flooding, a classic type of disaster which usually accompanies an enormous impact on society and the economy. Most significant capitals and megacities are built along the river or in the delta areas; usually, exposed to higher flood risk. Climate change have had obviously changed the precipitation pattern, especially in Asia. A high intensity within short duration rainfall will occur frequently than before, further increasing the flooding risk. Taiwan, which is located in monsoon and typhoons attacked area. Integrate with geographic factors, Taiwan has suffered from flood attacks during the wet season for years. Under climate change, studies had shown that flood risk has increased; further, brings high potential flood risk to our society and economy. However, in Taiwan, future flooding research is still lacking since a shortage of robust future climate datasets. Therefore, developing and optimizing the climate dataset could progress on future flooding research.

Rainfall design is an essential part of flooding research. Traditionally, rainfall design usually gives rainfall based on different return periods. Generating high-intensity rainfall events usually relies on a long period of observation. However, acquiring numbers of observation data usually being difficult and challenging, making rainfall settings owing a huge uncertainty to utilize. For future flooding research, a robust and precise rainfall dataset would be necessary. In recent years, climate simulation data show a high potential to be utilized in various research to assess the climate change impact. Utilizing more precise and reliable data for future flooding research, we can assess future flooding more comprehensively. In Taiwan, simulation climate datasets are still lacking and immature; therefore, introducing a simulation climate dataset could provide a great opportunity to progress future flood research. Database

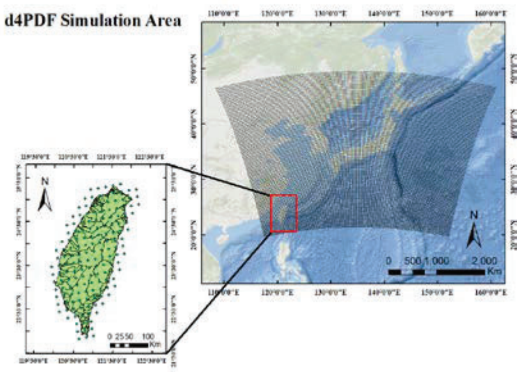


Fig. 1. d4PDF Simulation Area

for policy decision making for future climate change (d4PDF) Awhich produced by the Japan Meteorological Agency, which contains thousands of years of datasets of historic climate, 2K and 4K temperature raise conditions (Mizuta et al., 2017). For the use of +4K simulation, six CMIP5 models are selected to provide the sea surface temperature (SST) increase. Each scenario is conducted by setting different initial conditions and different SSTs change. Through ensemble simulation, d4PDF provides robust projection data for future climate studies using (Mizuta et al., 2014). Shown as **Fig. 1.**, Taiwan is located in the southwest part of the simulated scope of d4PDF; in other words, Taiwan owing a high potential could utilize the d4PDF dataset. In this study, the main target is to clarify the possibility of introducing d4PDF in the Taiwan region.

In this study, we extracted 20 km regional climate model simulation data of target catchments from d4PDF datasets and analyze the precipitation data by calculating the catchment average rainfall. Further, we extract 24, 48, and 72-hour annual maximum rainfall of each catchment to catch the extreme event for each year. Weibull Plotting Position Formulas was employed for statistical analysis; the statistical results were plotted on the Gumbel paper for presenting the relationship between non-exceedance probability, rainfall intensity, and return period. Comparing with the observation data and the historic data from d4PDF, and executing bias correction for specific catchments, we could indicate the agreement between both data of each catchment. Shown as **Fig. 2.** When observation data have a high agreement with d4PDF historic data, we could further confirm the reliability of d4PDF 4K temperature increase simulation data and import the simulation climate data into Taiwan flood research. In conclusion, this study presents the demonstration of d4PDF possesses the capability to employ in Taiwan or even countries out of Japan within the cover area, which have no doubt can provide benefit to those countries for progressing their climate change research; further, implementing the research results into society, such as disasters prevention, risk assessment, or even solving human security problem, to reduce the impact from climate change to human. Ultimately, by using simulation data and learning techniques for other countries, hope to stimulate the government to understand the importance of climate change research and develop a more suitable database for our countries policy decisions for future climate.

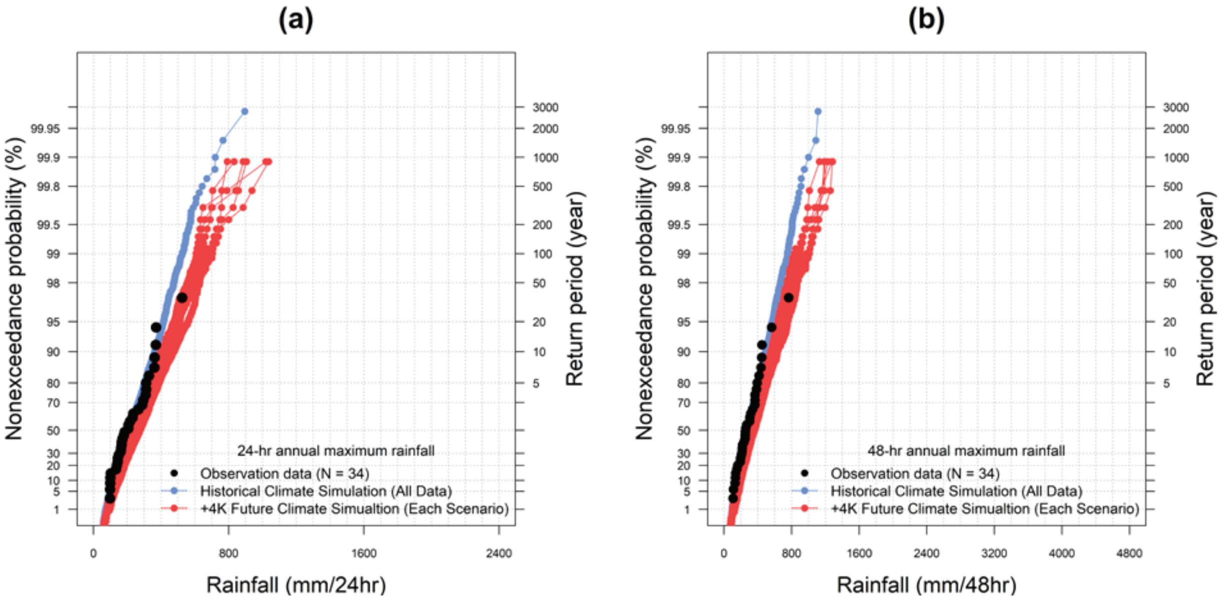


Fig. 2. T hour annual maximum rainfall for observation data, historical climate simulation, and +4K future climate simulation in Tamsui river basin (a) T = 24 (b) T = 48

REFERENCE

(1) Mizuta, R., et al., 2017. Over 5,000 years of ensemble future climate simulations by 60-Km global and 20-Km regional atmospheric models. B Am. Meteorol. Soc. 98 (7), 1383–1398.

TA-121L

REAL-TIME FLOOD FORECASTING USING ECMWF ENSEMBLE PRECIPITATION FORECAST IN THE UPPER NAN RIVER BASIN, THAILAND

Thatkiat Meema* and Yasuto Tachikawa

Department of Civil and Earth Resources Engineering, Kyoto University, C1, Nishikyo-ku, Kyoto 615-8540, Japan.
E-mail: thatkiat.meema@gmail.com

Introduction

The upper part of the Nan River Basin frequently experiences heavy rainfall events influenced mainly by tropical storms. Combined with the steep slope condition of the topography, the basin is vulnerable to flash flood disasters. To mitigate the extensive damage and disruption to societies caused by the disaster, flash floods need to be predicted over a wide range with a long forecasting lead time. Incorporating weather forecasts may improve the efficiency of decision-making. However, the forecast has limitations in accuracy (forecast uncertainty) with increasing forecast lead time. Instead of deterministic forecasting, probabilistic forecasting with Ensemble Prediction System (EPS) has advanced in the last decade. In this study, the medium-range ensemble precipitation forecast conducted by the European Centre for Medium Range Weather Forecasts (ECMWF) was employed with a hydrological model to predict the real-time river discharge of the study basin which locates in a tropical climate with a distinct wet and dry season. The objective of this study is to evaluate the performances of the forecast scheme during the case study of the severe flood event in 2017 (the tropical storm Talas) by comparing the forecast results with the observation.

Methodology

Using the forecast information with the hydrological model is a well-known approach for a long-lead-time of flood forecasting. For this study, the ECMWF (51 precipitation forecast members) was used with the improved 1K-DHM (Meema and Tachikawa, 2020). However, using medium-range ensemble precipitation forecast with a distributed hydrological model to predict the real-time river flow in a tropical climate basin with a distinct wet and dry season, the initial conditions of the model largely influenced the forecast results (Meema *et al*., 2020). For this purpose, the assimilation approach has been adopted to determine the initial states of the model before performing the flow forecasting. Ensemble Kalman Filter (EnKF) considering spatial correlation that improves the flood prediction (Kaniya *et al*., 2020) was applied. Not only adopting forecast rainfall during the forecast period, the observed rainfall was also utilized considering as a perfect rainfall forecast for evaluating the performances of the real-time forecast scheme. The scheme was applied to the case study in the tropical storm event in 2017 (Talas) with 20 continuous times of the initial forecast regarding each updated 12-hour of ECMWF with 15 days of forecast lead time. The real-time flood forecast scheme started the simulation from 11 July 2017 00:00 UTC (7 days before the peak of flood) to 20 July 2017 12:00 UTC. The forecast scheme has been evaluated the performance by using the Root Mean Square Error (RMSE) that represent the error between the forecast ensembles and the observation for each lead time of forecast.

Result and discussions

Fig. 1 presented the result of the 15-day (360 hours) in advance forecast flood hydrograph for the initial forecast time of 15 July 2017 12:00 UTC (3 days before the peak of flood) at the N.1 station of the Nan River. The box plot showed the distribution among the flood forecast members. For this initial forecast time, the flood discharge forecasts have a large distribution among the members due to a large difference among the precipitation forecast members. On the other hand, between the 25th and 75th percentile of forecast members could represent satisfaction in the possibility of severe storm and flood occurrence compared to observation. **Fig. 2** presented the comparison of RMSE among all forecast members, 25th, 50th, 75th percentile, and the use of observed precipitation (perfect forecast) for different 20 forecast initial times. The results showed the large uncertainties in flood forecasting compared to the use of observed rainfall, especially during the high rainfall intensity. This indicated the high challenges in precipitation forecast with long-lead time for the severe storm events. On the other hand, considering the ensemble precipitation forecasts could represent the possibility of flood in advance.

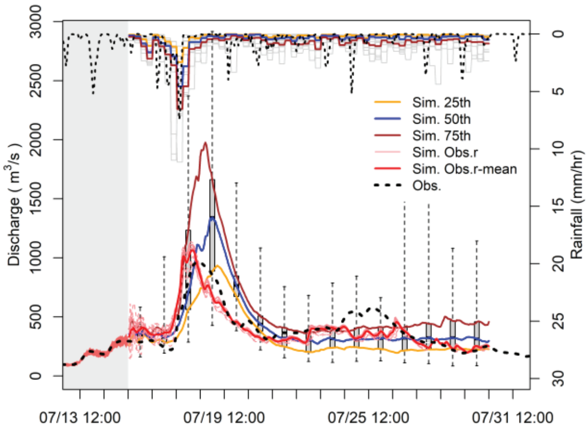


Fig. 1 The 15-day in advance forecast hydrograph for the initial forecast time of 15 July 2017 12:00 UTC (Obs.; observation and Sim. Obs.r; forecast simulation using observed rainfall).

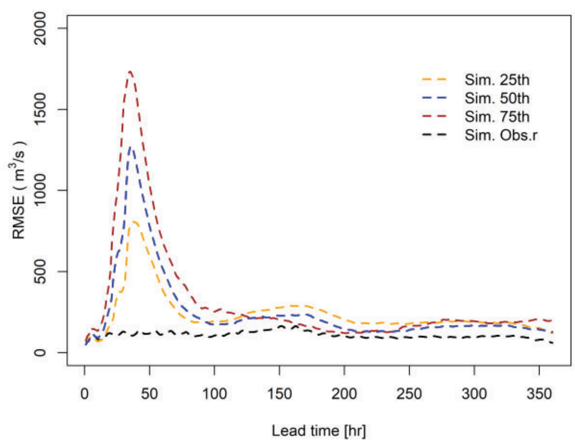


Fig. 2 The comparison of RMSE between forecast results and observation for each lead time of flood forecasting for 20 different initial forecast times between 11 July 2017 and 20 July 2017.

Conclusions

This study demonstrated that the use of ensemble forecast technique in the real-time flood forecasting scheme could predict the occurrence probability of the flood events during the severe storm in advance. This information will be useful for the decision-making on mitigation responses against flood events, which may be adapted to other basins in the study region.

References

Khaniya, M., Tachikawa, Y., Ichikawa, Y., Yorozu, K., 2020. Impact of system noise specification on Ensemble Kalman Filter performance in a distributed hydrological model. J. Japan Soc. Civ. Eng. Ser. B1 (Hydraulic Eng.). 67, I_361-I_366.

Meema, T., Tachikawa, Y., 2020. Structural improvement of a kinematic wave-based distributed hydrologic model to estimate long-term river discharge in a tropical climate basin. Hydrol. Res. Lett. 14, 104–110. 10.3178/hrl.14.104.

Meema, T., Tachikawa, Y., Ichikawa, Y., Yorozu, K., 2021. Real-time optimization of a large-scale reservoir operation in Thailand using adaptive inflow prediction with medium-range ensemble precipitation forecasts. J. Hydrol. Reg. Stud. 38, 100939. 10.1016/j.ejrh.2021.100939.

Keywords: real-time flood forecast, ensemble forecast, data assimilation, distributed hydrological model

TA-123L

FUTURE CHANGES OF FLOOD CONTROL EFFECTS OF DAMS IN CLASS-A RIVERS IN JAPAN USING d4PDF

Keiichiro Kitaguchi*, Tomohiro Tanaka, Yasuto Tachikawa, Yutaka Ichikawa , Kim Summin and Kazuaki Yorozu

1.Objective

In order to discuss the effectiveness of existing dams against severer flood disasters in a changing climate, it is necessary to evaluate the effects that existing dams may have under the future climate and regional trends. In this study, we analyzed the effect of dams on the control of peak flood flows at downstream reference stations by using the rainfall-runoff model over class-A river basins of Japan and bias-corrected d4PDF annual maximum rainfall data developed by Kobayashi et al. [1].

2.Methods

2.1 Bias correction for large-scale ensemble climate prediction database “d4PDF”

Kobayashi et al. [1] corrected the bias of the annual maximum basin-averaged rainfall in the past climate simulation of a regional climate experiment of database for Policy Decision making for Future climate change (d4PDF). In this study, this rainfall data was used.

2.2 Overview of the target basin and rainfall-runoff model

In this study, we used the distributed rainfall-runoff model 1K-DHM [2] developed by Kobayashi et al. [1] in order to calculate the discharge. Dams which are developed in the runoff model have a catchment area of more than 5% of the basin area. A constant-volume discharge system was assumed for each dam.

2.3 Evaluation index for flood control effects of dams

To evaluate the impacts of climate change on the flood control effects of dams, the following indicators are used: 1) the rate of flood peak discharge at the reference station simulated with the model with/without the dam operation scheme (Hereinafter referred to as peak flow ratio.) and 2) equivalent rainfall to dam storage.

The peak flow ratio is calculated by dividing the maximum annual peak flow considering the dam operation by Kobayashi et al [1] into the maximum annual peak flow of a model assuming no dams exist in the basin. This flow is obtained from rainfall-runoff calculations without the dam model, assuming there is no dam in the basin. The closer the value of the peak flow rate ratio is to 1, the less the difference between the peak flow rates with and without the dam is, and the less the flood control effect is considered to be expressed. The equivalent rainfall to dam storage was obtained by dividing the effective flood control capacity of the dam by the catchment area. In the case of multiple dams in the system, the sum of the equivalent rainfall of each dam divided by the average of the catchment areas of each dam is used.

3.Results

3.1 Relationship between peak flow ratio and flood control effect of dams

The peak flow rate ratios were calculated for all cases of annual maximum rainfall in the past experiments and the 4-degree rise experiments and plotted against the flood peak discharge with the model without the dam operation schemes. The results for the Kitakami River basin, as an example, are shown in Figure 1. The larger the flood size and the larger the difference between the inflow rate of each dam in the basin and the starting flow rate of flood control, the smaller the peak flow ratio becomes and the more effective the flood control becomes. As a result, the graph of the peak flow ratio is a convex curve with a clear minimum value. Comparing the past experiment (blue line) and the 4-degree rise experiment (red line), the storage is used up before the peak time and the effect of dams are lost in a shorter return period on the 4-degree rise experiment. On the other hand, there are some basins that continue to exhibit flood control effects, with no clear minimum value even for the largest floods in the 4-degree rise experiment.

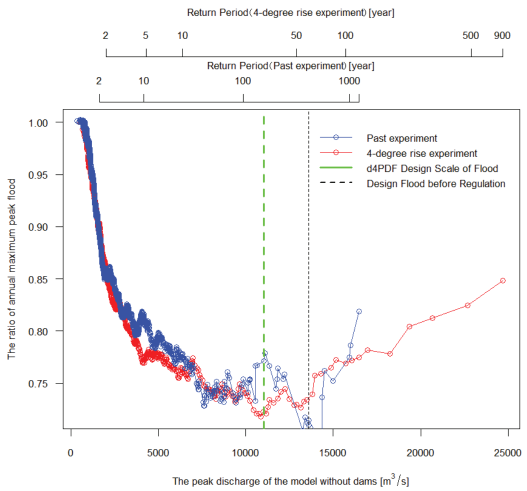


Figure 1 The relationship between the peak flow ratio and the peak discharge of the model without dams

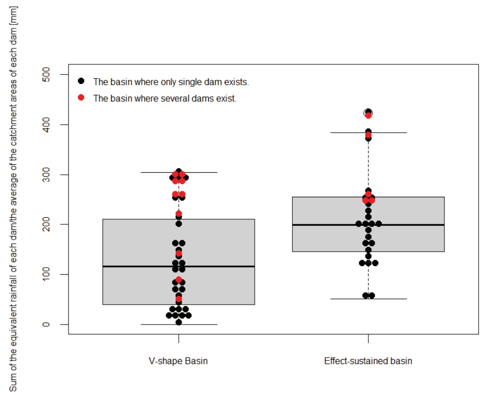


Figure2 Equivalent rainfall to dam storage of V-shape basins and effect-sustained basin.

The presence or absence of an inflection point on the peak flow ratio graph was visually determined for all basins. The basin with a clear minimum value was classified as a V-shape basin, and the basin without a clear minimum value was classified as a effect-sustained basin. The equivalent rainfall to dam storage of the V-shaped basins and the effect-sustained basins were calculated and compared (Figure 2). There is a clear difference in the equivalent rainfall.
The two-sample Kolmogorov-Smirnov test showed that the distributions were significantly different at the 1% level of significance. The results show that the flood control effect of dams is strongly related to the total equivalent rainfall of dams in the system. In addition, Figure 2 shows that in both types of water systems, the water system whose equivalent rainfall is located above the box whiskers often has multiple dams. This indicates that the flood control effect of dams is not greatly affected by the number of dams in a basin even in the 4- degree warmer climate.

Reference
1.Keita Kobayashi, Tomohiro Tanaka, Mizuki Shinohara, Yasuto Tachikawa: Analysis of Future Changes in Extreme Flow Rates in Japan's First-Class basins Using d4PDF. Journal of JSCE B1, vol76, No1, pp.140-152,2020.

2. Yasuto Tachikawa, Tomohiro Tanaka: http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/document/1K-DHM-event-ver410.pdf

Keywords: climate change, d4PDF, Japan

Keiichiro Kitaguchi
Kyoto University Graduate School of Engineering Department of Civil and Earth Resources Engineering Hydrology and Water Resources Laboratory
Mail: Kitaguchi.keiichirou.84x@st.kyoto-u.ac.jp

TA-124L

ASSESSING FLOOD INUNDATION IN THE LOWER PREK THNOT RIVER BASIN UNDER CLIMATE CHANGE USING RRI MODEL COUPLED WITH SWAT

Sophea Rom Phy[1], Sophal Try[2], Ty Sok[1,3,*], Ilan Ich[1], Chantha Oeurng[1]

[1] Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia

[2] Disaster Prevention Research Institute, Kyoto University

[3] Research and Innovation Center, Institute of Technology of Cambodia, Phnom Penh, Cambodia
*Corresponding author: E-mail: sokty@itc.edu.kh

Keywords: Climate change, Flood inundation, Lower Prek Thnot River Basin

Introduction

Flooding has become more frequent and intense due to climate change (CC), in which changes in precipitation, hydrology, and flooding attributes are inevitable. Investigation of flooding under certain scenarios is by and large done through hydrodynamic modelling. Yet, the integration between the Soil and Water Assessment Tool (SWAT) model (Neitsch et al., 2011) and the Rainfall-Runoff-Inundation (RRI) model (Sayama et al., 2015) has not been explored yet. Thus, the study seeks to combine both models and determine percentage changes in extreme discharge and flood inundation of a possible flood event in the 2030s (2021-2040) and 2060s (2051-2070) under RCP2.6 and RCP8.5 in the lower Prek Thnot River Basin (Fig 1), where much attention is given due to its high vulnerability to flash flooding during the high rainfall events in October, average annual rate of which is 1,225 mm. The basin has so far incurred maximum flood discharges up to 1,371 m^3/s.

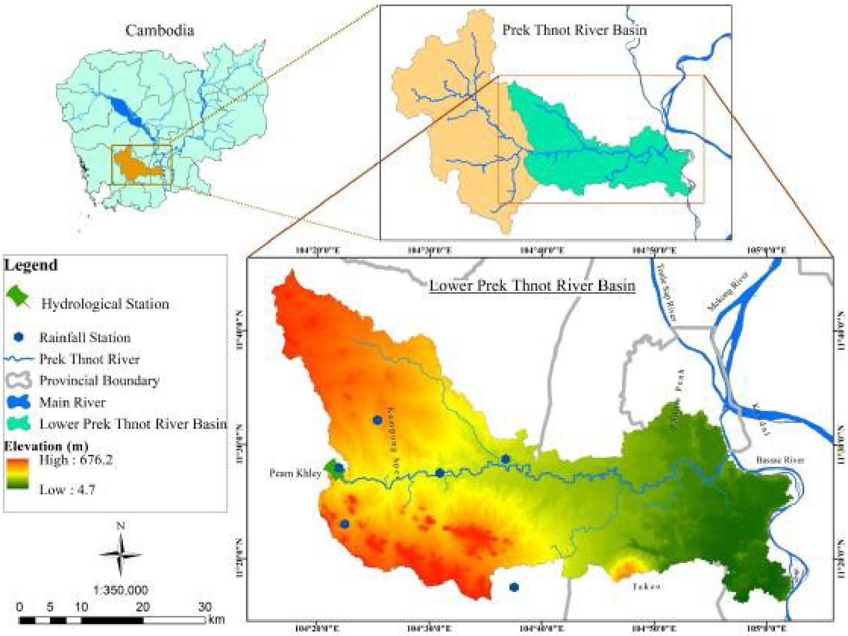


Fig 1. Map of the lower Prek Thnot River Basin

Method

The RRI model, a two-dimensional fully distributed hydrodynamic model, was deployed and set up at spatial resolution of 500 m at a daily time-step from September to November. The simulated baseline and CC daily discharges from SWAT run over the Prek Thnot River Basin were extracted at Peam Khley station to be inputted as the inflow boundary condition for the lower basin using RRI. The worst and peak flood event in 2000 was selected as the baseline. Before running the CC scenarios, the model accuracy was conducted in which 2000, 2001 and 2010 flood events were calibrated and validated. Observed and simulated discharge and flood maps were compared and all deemed acceptable, using the performance indices (NSE, PIBIAS, RSR, R^2 for discharge; True Ratio, Hit Ratio for flood map).

The CC's rainfall was derived from downscaled monthly 'change factors' acquired from the Mekong River Commission Climate Change and Adaptation Initiative (MRC, 2018). The MRC's recommended three General Circulation Models (GCMs), namely the wetter overall GFDL-CM3, the drier overall GISS-E2-R-CC, and the increased seasonal variability IPSL-CM5A-MR, were used.

Results and Discussion

Table 1. Changes (%) of Qm and Q5 under CC

	GCMs	Scenarios	*Qm (%)	**Q5 (%)
2030s	GFDL-CM3	RCP2.6	4.5	3.9
		RCP8.5	11.3	8.4
	GISS-E2-R-CC	RCP2.6	-7.5	-8.4
		RCP8.5	-34.8	-21.4
	IPSL-CM5A-MR	RCP2.6	0.4	1.7
		RCP8.5	-10.6	4.2
2060s	GFDL-CM3	RCP2.6	3.4	3.1
		RCP8.5	19.7	13.5
	GISS-E2-R-CC	RCP2.6	-5.4	-6.4
		RCP8.5	-45.2	-39.3
	IPSL-CM5A-MR	RCP2.6	0.8	1.3
		RCP8.5	-13.9	-1.6

*Baseline Qm = 86.5 m^3/s **Baseline Q5 = 675.5 m^3/s

Overall, the mean discharges (Qm) were bound to change more drastically under RCP8.5, the highest change of which occurred in the 2060s, using the GFDL and GISS scenarios (Table 1). The river flow exceeding 5% of the time (Q5) would change modestly in the 2030s and twice as much in the 2060s, especially under RCP8.5, compare with the baseline. The highest changes in Q5 were over 13.5% and -39.3%, respectively in the 2060s. Increases in Q5 imply intensifying flooding.

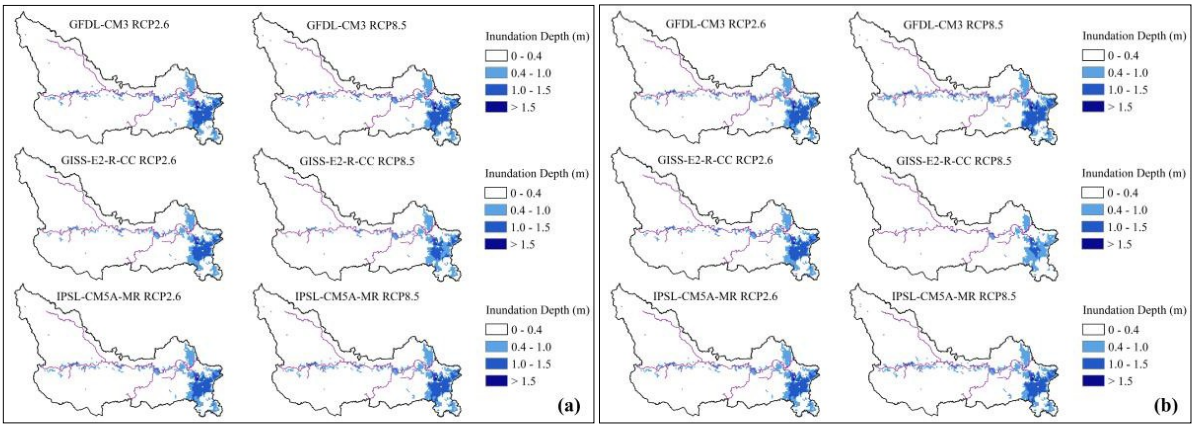


Fig 2. Flood Extent and Depth for All GCMs in the (a) 2030s and (b) 2060s

Table 2. Magnitude and Percentage Change of Inundated Areas in the (a) 2030s and (b) 2060s

	GCMs	Scenarios	Inundated Areas*
2030s	GFDL-CM3	RCP2.6	201 *(+2.3%)*
		RCP8.5	207.75 *(+4.7%)*
	GISS-E2-R-CC	RCP2.6	186 (-5.3%)
		RCP8.5	173 *(-12%)*
	IPSL-CM5A-MR	RCP2.6	198.25 *(+0.9%)*
		RCP8.5	211 *(+7.4%)*
2060s	GFDL-CM3	RCP2.6	200 *(+1.8%)*
		RCP8.5	237.25 *(+20.7%)*
	GISS-E2-R-CC	RCP2.6	186.75 *(-5%)*
		RCP8.5	134.75 *(-31.4%)*
	IPSL-CM5A-MR	RCP2.6	197.75 *(+0.6%)*
		RCP8.5	221.5 *(+12.7%)*

*Baseline inundated areas: 196.5 km^2

Floods would be severer given a larger extent with depth > 1 m as predicted by the GFDL scenario under RCP8.5-2060s (Fig 2). Changes in flooded areas for all models were marginal under RCP2.6 (Table 2). Under RCP8.5-2060s, the changes were significant (20.7% and -31.4%, as per the GFDL and GISS scenarios, respectively). On top of that, flood depth > 1 m would cover the largest areas of 82 km^2 (about +30%) under the GFDL scenario under RCP8.5-2060s (Fig 3).

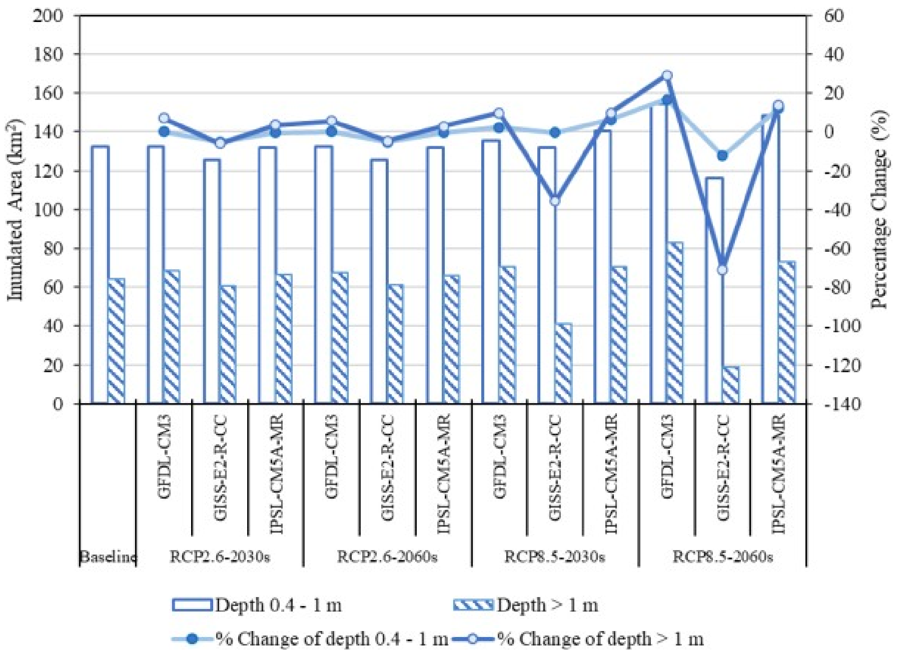


Fig 3. Magnitude and Percentage Change in Inundated Area with Classified Flood Depth

Overall, the volatility of change in discharge and flood magnitude stemmed from the difference of GCMs, scenarios, and time horizons. Moreover, if the climate mitigation strategies are not stringent enough, the outputs under RCP8.5, in which changes are large and significant, should be considered, and vice versa for RCP2.6.

Conclusions

Climate change impacts on flooding were examined through the model integration. The extreme flow and flooding will be intensified using the GFDL and IPSL, and less severe using the GISS scenarios, particularly under RCP8.5 during both periods. These outputs can be used to assist in future forecasting and watershed management.

Acknowledgements
This study was funded by the Cambodia Higher Education Improvement Project (Credit No. 6221-KH).

References

MRC, 2018. Basin-Wide Assessment of Climate Change Impacts on Hydropower Production.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams,J.R., 2011. Soil and water assessment tool theoretical documentation version 2009.

Sayama, T., Tatebe, Y., Iwami, Y., Tanaka, S., 2015. Hydrologic sensitivity of flood runoff and inundation: 2011 Thailand floods in the Chao Phraya River basin. Nat. Hazards Earth Syst. Sci. 15, 1617–1630. https://doi.org/10.5194/nhess-15-1617- 2015

TA-125L

IMPACTS OF CLIMATE CHANGE AND DAM CONSTRUCTION ON RICE DAMAGES IN THE CAMBODIAN FLOODPLAIN OF THE MEKONG RIVER BASIN

Sophal Try[a,b*], Takahiro Sayama[a], Ty Sok[b], Steven Ly[c], Chantha Oeurng[b]
[a]Disaster Prevention Research Institute, Kyoto University
[b]Faculty of Hydrology and Water Resources Engineering, Insitute of Technology of Cambodia
[c]Graduate School Engineering, Kyoto University
*Corresponding author: E-mail: trysophal001@gmail.com

Keywords – flooding; rice damages; Cambodian floodplain; climate change; dam construction

ABSTRACT

Introduction and Objective

The Mekong River Basin (MRB) is one of the large-scale river basins in mainland southeast Asia, travelling across six countries including China, Myanmar, Thailand, Lao PDR, Cambodia, and Vietnam. This area is one of the vulnerable zones to be severely affected by climate change. Climate change has become a global environmental and socioeconomic issue that has a potential impact on changing the river hydrology and flood characteristics. Hydropower dam construction in the upper basin of the Mekong River is an essential driving factor affecting the flooding in the MRB. The study of flood-related damages under climate change impact and dam construction in this river was not yet carried out.

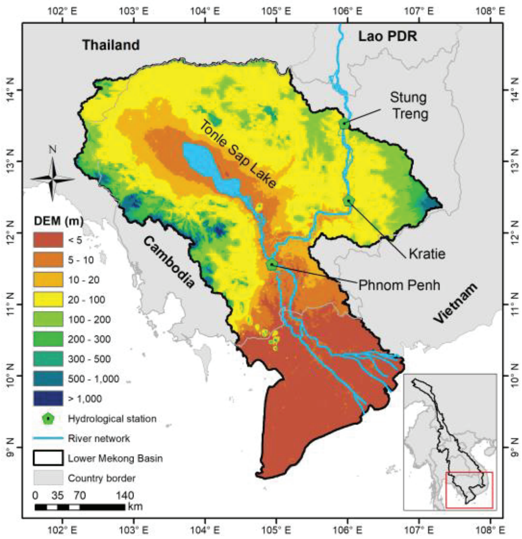


Fig. 1 Location of Cambodian floodplain

This study aims to investigate the potential impacts from future climate change and dam construction on agricultural damages on extreme flood events in the Cambodian floodplain (Fig. 1) in the Lower Mekong Basin (LMB).

Method

This study used a fully distributed rainfall-runoff-inundation (RRI, Sayama et al., 2015) model to simulate flood hazards. The RRI model was set up with a spatial resolution of 2.5 arc-minutes (approximately 4,613 m) for the whole MRB for river discharge simulation and 60 arc-seconds (approximately 1,832 m) for simulation of flood inundation in the LMB considering discharge as boundary condition input. We used a calibrated and validated RRI model by previous studies (Try et al., 2020a, 2020b).

This study used the climate change dataset from a large ensemble Database for Policy Decision-Making for Future Climate Change (d4PDF) which consists of 100-ensemble for present climate (1950-2010) and 90-ensembles for future projections (2051-2110) under increasing of 4°C. Moreover, this study investigated the impact of dam construction from 126 dams in the whole MRB (all six countries), and their operation rule is considered as hydropower generation. The calculation of agricultural economic damage during the growing period (September-November) was performed using the following equation:

Economic Damage Value = Rice Yield × Damage Area × Yield Loss (eq. 1)

Results and Discussions

The results of agricultural flood damages in the Cambodian floodplain was summarized in Table 1. The extreme flood events in the LMB were investigated from the d4PDF dataset as input into the RRI model. The flood extent of 10-year, 50-year, and 100-year return periods (see more detail in Try et al., (2020a)) showed an increase of 12%, 14%, 17% for under climate change impact; and 7%, 10%, 14% under integrated impact from climate change and dam construction. The estimated agricultural damages in the Cambodian floodplain for the present climate were approximately 160, 210, and 240 million US$ for 10-, 50-, and 100-year return periods, respectively. Under climate change effect alone, the change in agricultural damages would increase by 32%, 38%, and 39%. In comparison, the integrated impacts from climate change and dam construction would reduce these rates to 17%, 24%, and 31% for flood event in 10-, 50-, and 100-year, respectively. Fig. 2 illustrated the spatial distribution of rice damages for 50-year return period.

TABLE 1. Estimated agricultural damages in present, climate change, and dam scenarios

Extreme event	Climate scenario	Agricultural damage [M US$]
10-year	HPB	160.35
	HFB (CC)	211.15 *(+32%)*
	HFB (CC+dam)	188.05 *(+17%)*
50-year	HPB	210.26
	HFB (CC)	289.25 *(+38%)*
	HFB (CC+dam)	260.77 *(+24%)*
100-year	HPB	239.69
	HFB (CC)	332.21 *(+39%)*
	HFB (CC+dam)	314.87 *(+31%)*

Conclusions

In conclusion, the results from this study indicated a potential increase in agricultural damages in the Cambodian floodplain of the MRB under the effect of future climate change dam construction. Therefore, appropriate activities and countermeasures should be prepared for response and adaptation to these severe flood events.

Acknowledgement

This research was supported by JSPS Kakenhi Grant-in-Aid: 21F21071 and Cambodian HEIP-ITC-SGA#19.

References

(1) Sayama Takahiro, Tatebe Yuya, Iwami Yoichi, Tanaka Shigenobu (2015), Hydrologic sensitivity of flood runoff and inundation: 2011 Thailand floods in the Chao Phraya River basin. Natural Hazards and Earth System Sciences, vol 15, pp 1617–1630.

(2) Try Sophal, Tanaka Shigenobu, Tanaka Kenji, Sayama Takahiro, Hu Maochuan, Sok Ty, Oeurng Chantha (2020a), Projection of extreme flood inundation in the Mekong River basin under 4K increasing scenario using large ensemble climate data. Hydrological Processes vol 34, pp 4350–4364.

(3) Try Sophal, Tanaka Shigenobu, Tanaka Kenji, Sayama Takahiro, Lee Giha, Oeurng Chantha (2020b), Assessing the effects of climate change on flood inundation in the lower Mekong Basin using high-resolution AGCM outputs. Progress in Earth and Planetary Science, vol 7(34).

TA-126L

POTENTIAL OF ENSEMBLE OPTIMAL INTERPOLATION IN TACKLING PARAMETER BIAS

Manoj Khaniya*, Yasuto Tachikawa, Takahiro Sayama

Keywords: data assimilation, ensemble optimal interpolation, parameter bias

Introduction

Uncertainties in the input data, model structure and model parameters among others render the hydrological predictions imprecise[1)]. Data assimilation algorithms such as the ensemble Kalman filter (EnKF) which provide a framework to represent and subsequently reduce these uncertainties by merging observations into the model continue to receive significant attention in the field of hydrological forecasting. While the evidence of the effectiveness of EnKF is abundant in the literature, its use in operational forecasting may be limited by its high computational demand as it requires multiple runs of the model to characterize the uncertainties. On the other hand, the ensemble optimal interpolation (EnOI) algorithm, unlike the EnKF, contains a single model run akin to the deterministic simulation except for the correction from the observations. While it does not provide any information about the uncertainty in the model predictions, the reduced computational cost of this approach makes it an attractive option for real-time implementation. However, the efficacy of the EnOI in hydrological data assimilation is not yet completely understood and as such, this study aims to investigate the suitability of this computationally inexpensive assimilation algorithm in reducing the parameter bias present in a distributed hydrological model. The experiments conducted are of synthetic in nature and are applied to a small-scale river basin in Japan.

Synthetic observation generation and EnKF implementation

True water level data were first obtained by feeding an assumed true precipitation input to the rainfall-runoff-inundation model[2)] characterized by a spatially uniform true model parameter set. These "true" water stages were then perturbed by a predefined noise model to generate the synthetic water level observations. Uncertainty in the model was limited to the model parameters and was represented by uniformly distributed samples in the parameter space. The EnKF was able to correctly approximate the two model parameters (i.e. the manning's roughness coefficient for the river channel and the soil hydraulic conductivity) at the end of the assimilation period as the assimilated variable i.e. the river stage was found to be more sensitive to these two parameters. This tendency was found to be consistent across different initial parameter uncertainty representations and for the two flood events (from 2013 and 2018) tested.

EnOI implementation

While the covariance matrix needed for parameter update is calculated based on the ensemble anomalies in the EnKF, such estimation is not possible in EnOI as only a single model is integrated forward. As such, background ensembles have to be predefined in order to calculate the errors and allow for the updates of the state variables (and/or the parameters) with the EnOI. This study used the background ensembles from different time steps of the EnKF implementation to calculate the covariance matrices and fixed them for the entirety of the assimilation period of the EnOI implementation. At the start of the assimilation, the model parameters were randomly generated which were then subsequently corrected by using the pre-specified background and observation error covariance matrices. Since a single parameter value was generated for each of the model parameters, this was essentially a deterministic model run with the update to the parameters at each assimilation step.

*Department of Civil and Earth Resources Engineering, Kyoto University
khaniya.manoj.73c@st.kyoto-u.ac.jp

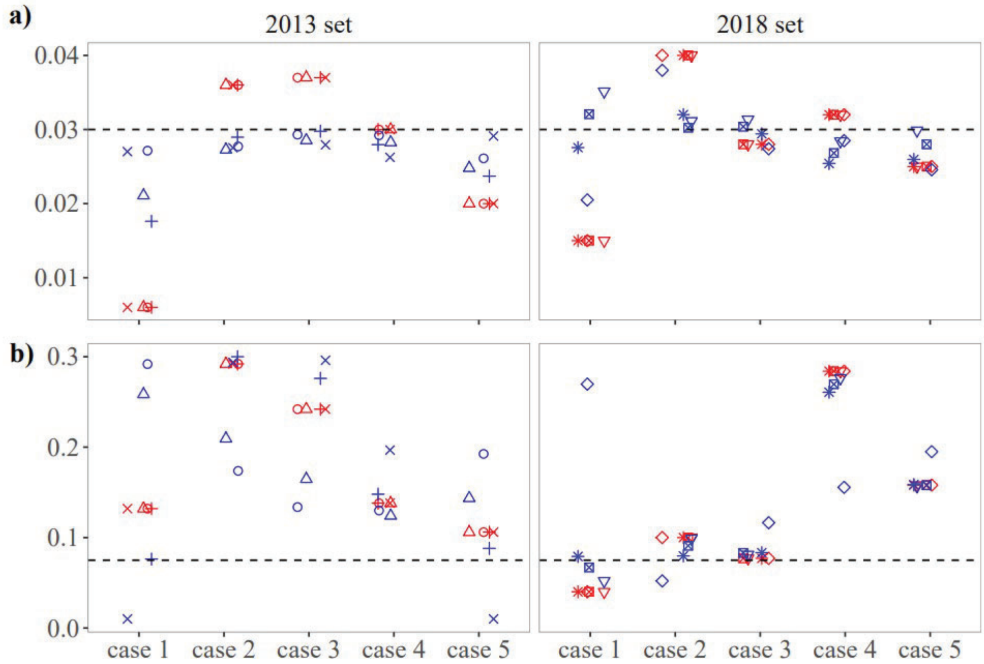


Fig. 1: Model parameters (a) manning's n for river channel and (b) soil hydraulic conductivity (m/s) at the beginning (red) and end (blue) of the assimilation period for the 2018 flood. Dotted lines indicate the true parameter values and the cases represent different initial values of the parameters. Different point shapes represent different covariance matrices (only the results for a select few matrices are shown). The two columns "2013 set" and "2018 set" indicate the flood event from which the covariance matrices are taken.

EnOI was able to reduce the bias in the model parameters to an extent for those matrices which had small covariances between the state variables at the observation locations and the model parameters. When large gains were allowed by the update, parameters became unstable leading to unreasonable water level estimations. In general, EnOI was able to better approximate the channel roughness coefficient (also see Fig. 1) likely because of the high sensitivity of the assimilated variable to this parameter. Encouragingly, covariance matrices from a previous flood event were also found to be effective in a latter flood ("2013 set" in Fig. 1 for 2018 flood). Future works will extend the study to other events and model uncertainties including experiments with real data.

Conclusions

This study investigated the efficacy of a computationally inexpensive assimilation algorithm i.e. the ensemble optimal interpolation in reducing the biases in the model parameters by using synthetic river stage observations for assimilation. Ensemble Kalman filter was first applied to two flood events to yield a set of covariance matrices (both background and observation error) which were then utilized to update the model parameters of the deterministic model runs. While large magnitudes of covariances led to oscillations in the parameters, gradual nudging through small gains led the parameters - especially the manning's n for river - to be close to the truth at the end of the assimilation period.

References

1) Liu, Y., Gupta, H.V., 2007. Uncertainty in hydrologic modeling: Toward an integrated data assimilation framework. Water Resources Research 43. https://doi.org/10.1029/2006WR005756
2) Sayama, T., Ozawa, G., Kawakami, T., Nabesaka, S., Fukami, K., 2012. Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin. Hydrological Sciences Journal 57, 298–312. https://doi.org/10.1080/02626667.2011.644245

TA-127L

DEVELOPMENT OF ULTRA-HIGH RESOLUTION DISTRIBUTED RAINFALL RUNOFF MODEL TO FORECAST FLASH FLOOD IN UNGAUGED URBAN CATCHMENTS

S. Feng*, Y. Tachikawa, Graduate School of Engineering, Kyoto University

Background

Under the impact of Climate Change, occurrence of serious hydrological events showed an increasing tendency in recent years. According to World Water Development Report 2020 (WWDR), global floods and extreme rainfall events have surged by more than 50% this decade and are now occurring at a rate 4 times higher than in 1980. Distributed Hydrological Model (DHM) based on topography and precipitation data has been widely used in river discharge predictions. 1K-DHM-event, as one of the distributed hydrological models based on kinematic wave equations, showed reliable performances focused on large-scale catchments in Japan and other regions according to previous research.

However, as population growth and urbanization rapidly increasing, floods happened frequently in relatively small-scale urban catchments. In 2012 and 2013, two floods happened in Midajiro river with a catchment area of 1.44km^2 and Hata river with a catchment area of 1.52km^2 in Kyoto Prefecture. Both of the two catchments are extremely small without observation devices but caused inundation, house damage and economic loss.

Research Purpose

This research is purposed to develop a discharge prediction method integrated 1K-DHM-event with high-resolution rainfall data in ungauged urban area.

Research Method

To make rainfall-runoff simulations by applying 1K-DHM-event model, three necessary input data and comparison discharge data should be prepared. 1) For topographic data, 1s resolution Digital Elevation Model (DEM) data was used, which also contributes to generate 34 catchments as our target area in Osaka Area. 2) High-resolution radar data X-RAIN with 1min interval was chosen as input precipitation data. 3) 5 hydrological parameters in 1K-DHM may vary from different types of land use were taken into consideration which refers to Manning's coefficient of river (Nr), Manning's coefficient of slope (Ns), Hydraulic conductivity (Ka), Soil depth (Da) and Capillary soil depth (Dm). 4) Finally, water level data with rating curves were supposed as discharge observation data for comparison.

Though we can easily get the first 2 input data for 1K-DHM, to identify suitable hydrological parameters for different land use is still a remained question. This question divided the research into 3 parts which leads to parameters identification, parameters calibration and parameters validation.

First of all, Yamada River Basin (Figure 1), which locates in the north part of Osaka and contains 14 types of different land use was selected for parameters identification. Rainfall event in 2014 from 23th August to 26th August and Rational Method results with different land use runoff coefficients (f) were chosen as rainfall pattern and discharge references. Secondly, In Northern Osaka, rainfall event in 2015 from 16th July to 19th July was chosen for parameters calibration in 12 catchments. While rainfall event in 2017 from 1st October to 24th October was chosen for that in 22 catchments which locate in Southern Osaka Area. Finally, rainfall event in 2018 from 4th July to 6th July will be applied to validate the performance of parameters in whole Osaka Area.

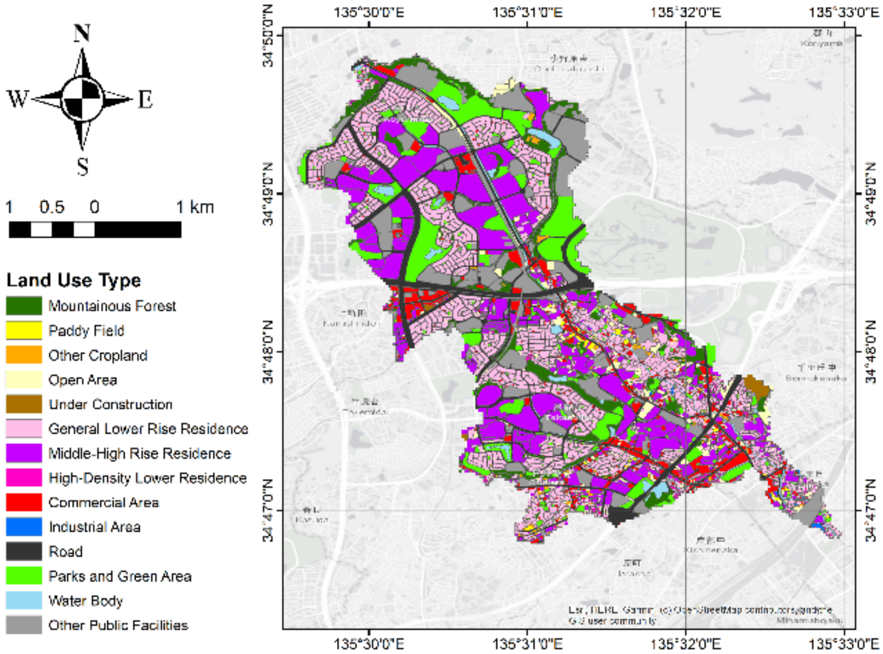


Figure 1 Land use distribution of Yamada River Basin

Current Results

1) Catchment extraction

34 catchments distributed in Osaka Area were extracted with land use information named by the first letter of the district name and following with a number such as I1, I2, I3, etc.

2) Parameter identification

Table 1 Identified hydrological parameters

Land Use Type	f	Ns	Ka[m/s]	Da[m]
Mountainous Forest	0.5	0.6	0.002	0.1
Paddy Field	0.7	0.7	0.002	0
Other Cropland	0.45	0.3	0.002	0.13
Open Space	0.2	0.3	0.002	0.245
Under Construction	0.2	0.3	0.002	0.245
General Lower Rise Residence	0.8	0.03	0.002	0.114
Middle-High Rise Residence	0.8	0.03	0.002	0.114
High-Density Lower Residence	0.8	0.03	0.002	0.114
Commercial Area	0.8	0.03	0.002	0.114
Industrial Area	0.8	0.03	0.002	0.114
Road	0.9	0.03	0.002	0.099
Parks and Green Area	0.65	0.3	0.002	0.234
Public Facilities	0.21	0.03	0.002	0.132
Water Body	1	0.027	0	0
Others	0.65	0.03	0.002	0.132

Besides the parameters above in Table 1, Ns is 0.027 for all kinds of land use types.

3) Parameter performance

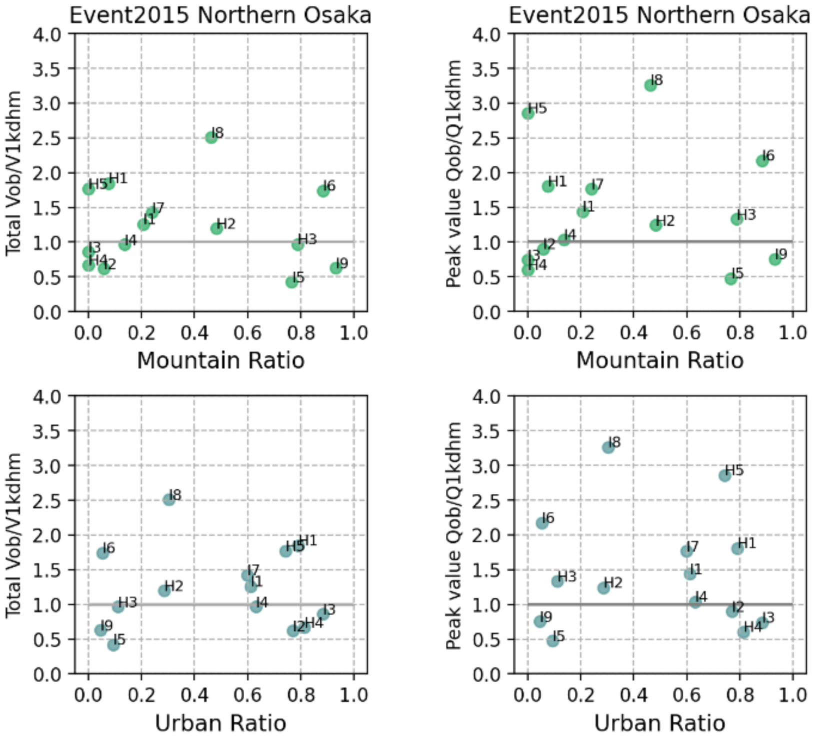


Figure 2 Total discharge comparison in Northern Osaka Area according to mountainous forest ratio and urbanized area ratio

Figure 3 Peak discharge comparison in Northern Osaka Area according to mountainous forest ratio and urbanized area ratio

For the 12 catchments located in Northern Osaka, discharge simulation performances differ from catchment to catchment. To analyze how the current parameters identified affect simulation performances, the comparison between simulation discharge applied by 1K-DHM and observation discharge according to mountainous area ratio and urbanized area ratio were carried out as Figure 2 and Figure 3.

Conclusions

Generally, for the current parameter performance showed in Northern Osaka Area, both the total discharges and peak discharges were under estimated as mountainous ratio increases. Meanwhile they were both over estimated as urban ratio is increasing. The results provide us an indication that perhaps Da should be smaller in mountainous area while Da should be larger in urbanized area for the future research.

Keywords: discharge forecast, distributed rainfall-runoff model, ungauged urban catchments

TA-129L

Development of the landslide-integrated SWAT model

Lu, Chih-Mei[1] and Chiang, Li-Chi[1]*

[1]National Taiwan University, Department of Bioenvironmental Systems Engineering No.1, Sec.4, Roosevelt Rd., Taipei 10617, Taiwan
*Corresponding author: lchiang@ntu.edu.tw

With the steep topography and fragile geology, Taiwan often encounters with natural disturbance, e.g., typhoons and earthquakes, leading disasters in landslide-prone areas. During storm and typhoon events, landslide contributes the majority of the sediment loads in the watersheds of Taiwan. The sediment from landslide might change the stream morphology, hydrologic processes, sediment transportation, and in-stream water quality. Therefore, it is important to consider the landslide sediment contribution in watershed management. The hydrological model is an efficient way to evaluate the impacts of the climate change, land use/land cover change, and the policy of watershed management on hydrology and water quality in a watershed. Among these hydrological models, the soil and water assessment tool (SWAT) model, developed by the USDA-Agricultural Research Service in 1994, has been widely used and modified for local needs in the world. Although the SWAT model could effectively simulate the long-term watershed responses, namely discharge, sediment, nutrient, and pesticide loads under different climate or land use management scenarios, the sediment loads during extreme rainfall events are usually underestimated. In this study, we aimed to:

(1) integrate the landslide module in the SWAT model to improve the sediment simulation performance; (2) identify the characteristics of landslide-induced sediment events by calibrated landslide triggers and sediment transport parameters; (3) compare the model performance of the original SWAT model and the integrated model; (4) estimate the sediment contribution by landslide events.

The Xiuguluan River basin (XRB), located in eastern Taiwan, is selected as the study area. The XRB has an area of 1786.5 km^2 with the elevation ranging from 0 m to 3700 m. As the steepest river in Taiwan, the Xiuguluan River with the stream gradient of 1/34 result in rapid headwater erosion in the basin. Based on the landslide record during 2004-2017, the landslide areas occupy 2.1% of the XRB, bringing significant amount of sediment into the Pacific Ocean. Moreover, compared to the average annual precipitation (~ 1900 mm) in the XRB, the largest 2-day accumulated precipitation of a single event was 785 mm record in 2000 when the Xangsane typhoon occurred.

The SWAT model simulation is based on the hydrologic response units (HRUs), a unique combination of land use/land cover, soil and slop in a subbasin. The simulation results at HRU level can provide components of water balance, sediment yield, and nutrients yield. The development and examination of the landslide module integrated in the SWAT model contains two parts: identification of landslide triggers and improvement in sediment yield estimation. The landslide triggers considered in this study include: land use/land cover, daily precipitation, and soil water content. The historical landslide maps from 2004 to 2017 were used to identify and verify the classified landslide in the long-term investigated land use/land cover data. The daily precipitation data were collected from Central Weather Bureau (CWB), Taiwan. Besides observed land use/land cover and precipitation data, the simulated soil water content was obtained in the SWAT model. In order to evaluate the improvement of the integrated model, four landslide volume equations suggested by Soil and Water Conservation Handbook (Soil and Water Conservation Bureau, 2017) were examined for sediment yield estimation.

Based on the preliminary results, the SWAT model could simulate the discharge well in the XRB, but underestimated in peak flow and high sediment condition. By integrating the landslide module in the SWAT model, better performance in sediment loads was found in high sediment condition, indicating the landslide triggers could well reflect the characteristics of landslide areas and its impact on sediment loads, and the sediment yielded by landslide was successfully calculated by the landslide volume estimation equations. The next step to further improve the sediment loads at the watershed outlet is to examine different sediment transport equations in the landslide-integrated SWAT model with consideration of the change in channel morphology.

Keywords: SWAT, landslide, sediment yield modeling

TA-132L

HISTORICAL FLOOD SIMULATION AND EVALUATION THE PERFORMANCE OF GRIDDED PRECIPITATION DATASET IN PREK THNOT RIVER BASIN

Oudomsatia Huong[1], Sophal Try[2], Ty Sok[1,3,*], Sophea Rom Phy[1], Ratboren CHAN[1,3], Chantha Oeurng[1]
[1] Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia
[2] Disaster Prevention Research Institute, Kyoto University
[3] Research and Innovation Center, Institute of Technology of Cambodia, Phnom Penh, Cambodia
*Corresponding author: E-mail: sokty@itc.edu.kh

Keywords: Rainfall-runoff-inundation (RRI) model; Rainfall-runoff; Flood inundation, Gridded precipitation dataset

ABSTRACT

Introduction and Objective

Cambodia's Prek Thnot River is one of the Mekong's major tributaries, which flows across four provinces, including Kampong Speu, Takeo, Kandal, and Phnom Penh, before reaching the Tonle Bassac River. Since the basin has become increasingly vulnerable to dangers and calamities (IRD, 2018), particularly droughts and floods, the watershed is at risk of losing its ecological function. Because of the continuous deforestation and more rainfall received upstream, flooding can occur downstream at any moment. The most challenging aspect of enhanced flood risk management is reducing the consequences while retaining the benefits from the floods. However, the study of inundation modeling is still limited in river basins.

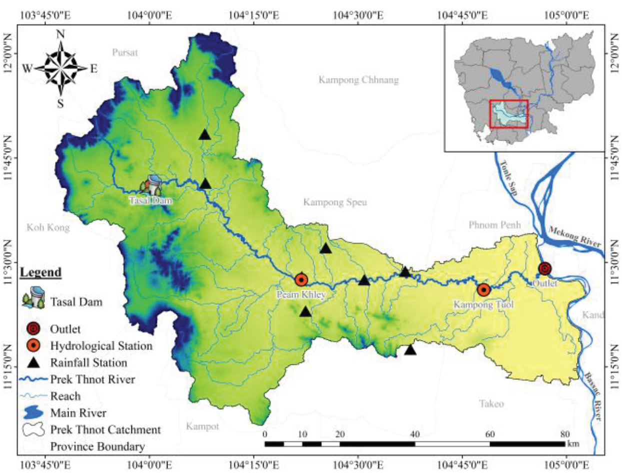


Fig. 1 Location of Prek Thnot River Basin

The purpose of this study aims to evaluate historical flood simulation and the performance of gridded precipitation datasets in the Prek Thnot River Basin.

Method

In this study, a fully distributed Rainfall-Runoff Inundation (RRI) model, developed by Sayama, Tatebe, Iwami, Tanaka, and Sciences (2015), was used to simulate historical flood hazards. The RRI model was set up using MERIT-DEM with a spatial resolution of 540 meters for river discharge and flood inundation simulations in the Prek Thnot River Basin. The study of historical flood simulation was focused mainly in 2010 from September to November. The calibration of the RRI model took place in 2010, and the validation was in 2000, 2001, and 2020. To evaluate the performance of streamflow simulation, four statistical indicators, including NSE, PBIAS, RSR, and R^2, were utilized.

Furthermore, ground rain gauge and five different gridded precipitation datasets, including APHRODITE, GPCC, PERSIANN, GSMaP, and TRMM, were used for the rainfall comparison in terms of performance for the whole Prek Thnot River Basin. Since gridded precipitation datasets came with different periods, both rain gauge data and gridded precipitation datasets were arranged for 12 years, from 2000 to 2011.

Result and Discussion

After the model verification, the simulation of 2000, 2001, 2010 and 2020 flood events resulted an overall of good performance with NSE of 0.55, 0.78, 0.64, and 0.70; PBIAS of 8.34, 1.01, -2.26, and -13.75; RSR of 0.67, 0.47, 0.60, and 0.55; and R^2 of 0.57, 0.79, 0.76, and 0.76. Moreover, the potentially flooded areas based on water depths shows in Fig. 2. The water depths could reach as high as 4 meters in 2000, 2 meters in 2001, and 3 meters in 2010 and 2020. Among the four flood events, flooded areas during 2000 were the largest, occupying more than 514.77 km^2 (9.23%). The flood events in 2010, 2001, and 2020 occupy 298.89 km^2 (5.35%) and 357.03 km^2 (6.41%), and 277.48 km^2 (4.98%), respectively. Fig. 3 shows the hydrograph and the scatter plot between APHRODITE (best-fit) dataset and the rain gauge. The figure demonstrated that the dataset and rain gauge have a strong correlation, with the coefficient of determination (R^2) of 0.6956.

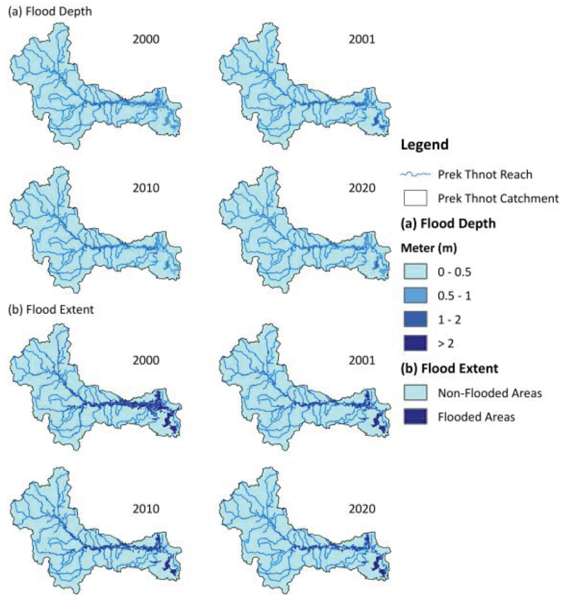


Fig. 2 Flood Depth and Flood Extent map over the Prek Thnot River Basin in 2000, 2001, 2010, and 2020

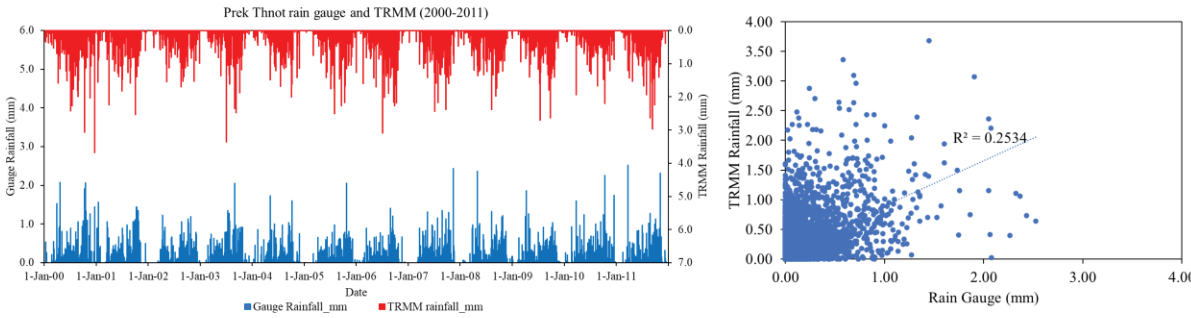


Fig. 3 Hydrograph and Scatter plot between APHRODITE dataset and rain gauge from 2000 to 2011

Conclusions

In conclusion, the results between the observed and simulated discharges based on graphical and statistical methods indicated an agreement of satisfactory in 2000, very good in 2001, and good in 2010 and 2020. The simulation also identified the flood inundation pattern, which occurred downstream of the river basin. Moreover, among the gridded precipitation datasets, APHRODITE was the best-fit dataset compared to the rain gauge.

Acknowledgement

I would like to acknowledge and thank the Cambodia Higher Education Improvement Project (Credit No. 6221-KH), for their financial support.

References

(1) IRD. (2018). *Contribution to Watershed Management Planning for Prek Thnot Watershed 2019 - 2029*. Retrieved from https://www.irdfa.org/wp-content/uploads/2019/11/Report_IWRM_Plan_Prek_Thnot_Watershed_English.pdf
(2) Sayama, T., Tatebe, Y., Iwami, Y., Tanaka, S. J. N. H., & Sciences, E. S. (2015). Hydrologic sensitivity of flood runoff and inundation: 2011 Thailand floods in the Chao Phraya River basin. *15*(7), 1617-1630.

TA-133L

Assessing Flood Risk in Prek Thnot River Basin Using AHP and GIS Analysis

Chanponleourothana Samrith[1], Ty Sok[1,2,*], Sophal Try[3], Ilan Ich[1], Ratboren Chan[1,2], Chantha Oeurng[1]
[1]Faculty of Water Resources and Hydrology, Institute of Technology of Cambodia
[2]Research and Innovation Centre, Institute of Technology of Cambodia, Phnom Penh, Cambodia
[3]Disaster Prevention Research Institute, Kyoto University, Japan
*Corresponding author: E-mail: sokty@itc.edu.kh

Keywords – Analytical Hierarchy Process, GIS, Flood hazard mapping, Prek Thnot River Basin

Introduction

Prek Thnot River is one of the larger tributaries of the Lower Mekong River in Cambodia. The majority of the Prek Thnot River Basin is located in Kampong Speu province. This area has been exposed to hazards and disasters, particularly floods (IRD, 2018), where people suffered critical damage from flash floods. The information and analysis of flash floods from reliable sources are plausible in an attempt to reduce the impact of floods (Elkhrachy, 2015). Identifying flood-prone zones is essential for mitigation and prevention measures (Radwan, Alazba, & Mossad). Consequently, flood hazard mapping provides a great deal of information for decision-makers and the community to effective implementation and preparedness.

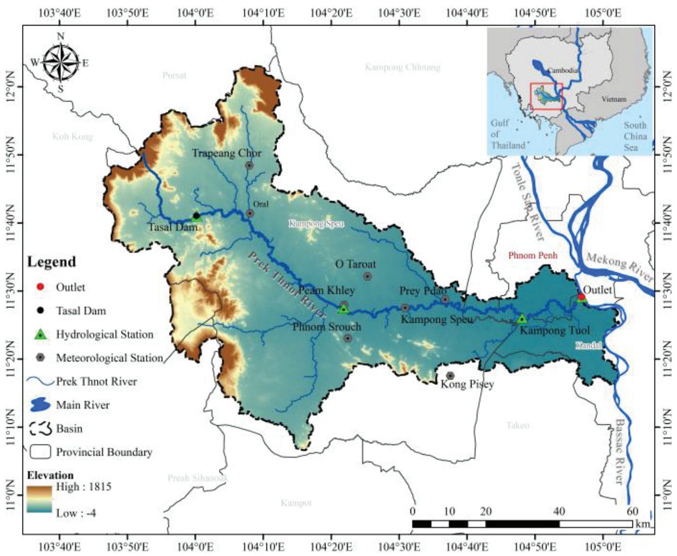


Fig 1. Prek Thnot River Basin

The study on flood hazard mapping is currently sparse in Cambodia, including the basin of the Prek Thnot River. This study aims to determine flood hazard risk levels across the Prek Thnot River Basin (Fig. 1) using coupling AHP-GIS analysis.

Method

The requirement data input in assessing flood hazard risk in Prek Thnot River Basin was rainfall, digital elevation model (DEM), soil types, and land used. The rainfall data were from the Ministry of Water Resources and Meteorology (MOWRAM). The observed data were collected from eight ground observed rainfall stations measured daily time steps for 15 years (1997-2011). The resolution of DEM was 30m × 30m obtained from ASTER-GDEM2. The soil type and land used were obtained from the Mekong River Commission (MRC) with a 250m × 250m resolution.

This study first categorized various factors associated with flood events based on literature reviews and historical records in the basin to define the flood hazard risk for an area. The selected parameters were Rainfall intensity (R), Elevation (E), Slope (Sl), Flow accumulation (F), Drainage density (DD), Distance to rivers (D), Soil types (So), and Land-use (Lu). Using the GIS technique, then, all the selected factors were developed and reclassified. Afterward, the AHP tool was utilized to weigh the parameters (Saaty, 2008). Then, Flood Hazard Index (FHI) multiplied the rated score by the priority weight from the AHP of each parameter. The composite FHI is defined as Eq. 1. However, the “Weighted Overlay” tool of GIS was applied to obtain a flood hazard map. Then, the flood risk hotspot area was classified into five levels, including “Very Low”, “Low”, “Moderate”, “High”, and “Very High”. Finally, the flood hazard map is compared with flood maps from the satellite to confirm if it is acceptable.

$$FHI = \sum_{i=1}^{n} r_i \cdot w_i \qquad \text{(Eq. 1)}$$

Where r_i: score rating of a parameter, w_i: effective weight of a parameter, n: number of parameters

Result and Discussion

The AHP method weighted eight selected parameters resulting in weights for the criteria based on pairwise comparisons (Table. 1) with a consistency ratio (CR) of 0.9%. Rainfall, elevation, and slope are the most significant parameters that dominate the flood hazard, and the remaining other parameters are also substantial with a lower priority percentage. The flood hazard map was developed utilizing the GIS technique to convert each parameter to raster grid cells and classify it into five risk levels (Fig. 2). As compared to the other satellite flood maps, it was confirmed to be acceptable. The very low, low, moderate, high, and very high hazard levels are covered 695km^2, 1079km^2, 2187km^2, 1263km^2, 311 km^2 of the total area, respectively (Table 2). The high and very high flood hazard levels are found over the downstream and area along the Prek Thnot River, which are in low elevation and gradual slope, and close to the rivers and dam; meanwhile, the other three levels are found over the Northwest, West, and the Southwest of the basin along the boundary, which are located in high elevation and steep slope, particularly mountains.

Table 1. Pairwise comparison for flood hazard and the priorities result from AHP method

Para.	R	E	Sl	DD	D	F	So	Lu
R	**1**	1	1	5	6	3	8	9
E	1	**1**	1	5	6	3	8	9
Sl	1	1	**1**	5	6	3	8	9
DD	0.20	0.20	0.20	**1**	1	0.50	2	3
D	0.17	0.17	0.17	1	**1**	0.33	2	3
F	0.33	0.33	0.33	2	3	**1**	3	4
So	0.13	0.13	0.13	0.50	0.50	0.33	**1**	1
Lu	0.11	0.11	0.11	0.33	0.33	0.25	1	**1**
AHP	**25%**	**25%**	**25%**	**5%**	**5%**	**10%**	**3%**	**2%**

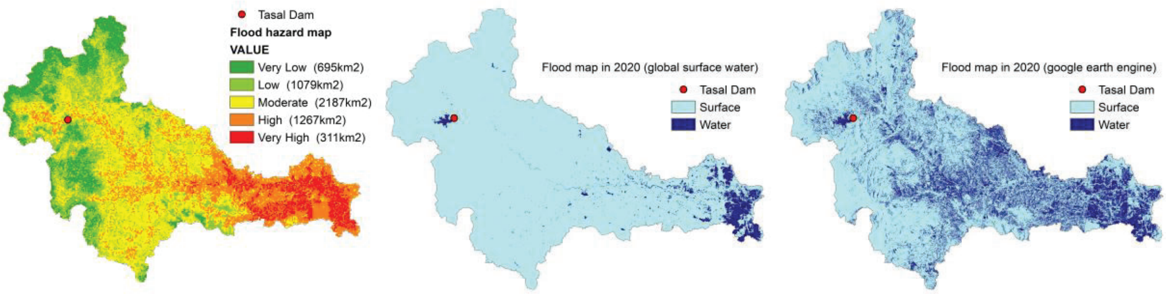


Figure 2. Flood hazard map in Prek Thnot Basin

Conclusion

The coupling AHP-GIS analysis takes the intention of assessing flood risk hazards into account. In conclusion, the results of this study indicated that flood tendency extent at the low-lying area and area near the Prek Thnot River and its reach. These areas are exposed to the risk of flooding. Twelve out of seventeen districts are at a very high risk of flooding, requiring decision-makers to establish appropriate plans for future flood occurrences.

Acknowledgement

Author would like to acknowledge financial support from Cambodia Higher Education Improvement Project (Credit No. 6221-KH).

References

(1) Elkhrachy, I. (2015). Flash flood hazard mapping using satellite images and GIS tools: a case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Science, 18*(2), 261-278.

(2) IRD. (2018). *Contribution to Watershed Management Planning for Prek Thnot Watershed 2019 - 2029*. Retrieved from Phnom Penh, Cambodia:

(3) Radwan, F., Alazba, A., & Mossad, A. (2019). Flood risk assessment and mapping using AHP in arid and semiarid regions. *Acta Geophysica, 67*(1), 215-229.

(4) Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences, 1*(1), 83-98.

TA-135L

Model of water leakage beneath reservoir and above diversion water tunnel;

Mae Prachum reservoir area, Mae Taeng, Chiang Mai Province

Noppadol Poomvises[1st], Anchalee Kongsuk[2nd], Benjamas Sawasdipong[3rd], and Tanapon Suklim[4th]
[1234]Bureau of Engineering Topographical and Geotechnical Survey
Royal Irrigation Department, Samsen rd., Bangkok, Thailand
npoomvises@gmail.com, noinarid@gmail.com, kaekai_ben@gmail.com and tanaponsuklim@gmail.com

***Keywords*—**model of water leakage, geological observation, geophysical modeling, analysis of discontinuity

ABSTRACT

Intuitively, climate change causes Mae Kuang reservoir facing a drought-water problem for decades. To address the issue, a diversion tunnel project of twenty-three kilometers in length is being built for conveying forty-seven million cubic meters of water per year from Mae Ngad to Mae Kuang reservoir. While a tunnel was being constructed beneath a small-scale reservoir, Huai Mae Prachum, the storage water level in the reservoir rapidly drew down and a large volume of water flowed into the tunnel conduit in the meantime. In order to develop a leakage model, three main methods are performed in this account, geological observation, electrical resistivity imaging (ERI), and orientation analysis of discontinuities.

According to geological observations along Huai Khun Mi, an intermittent stream located near the eastern rim of the reservoir and nearly above the tunnel route, many rock exposures show evidence of opened joint, fracture, cavity, and associated fold structure. They are interpreted as the channel that water flowing out of reservoir (Fig. 1). Result of ERI modeling (Fig. 2), covering reservoir floor, clearly reveals anomalous bodies of low resistivity, interpreted as a waterway from the reservoir above, which leaked down to the tunnel conduit below. In subsequent, combination of stereo plots of plane of bedding, joint, and fault, clearly shows the average direction of north 27 degree to west and dipping angle of 63 degree to southwest, interpreted as the opening channels that water flowing into tunnel conduit under the reservoir area.

As the results, the treatment of tunnel is preliminary conducted. After grouting intact rock around the conduit with suitable method, the problem of water inflowing is solved. To the present day, designing work has been completed and improvement of the reservoir floor will be the next step to carry out.

SUMMARY

1. Water leaks out from reservoir floor and intermittent stream, and flows down to subsurface.
2. Geophysical model reveals the waterway from reservoir above to tunnel conduit below.
3. The combination of geological observation, geophysical modeling, and orientation analysis of discontinuities, efficiently creates the model of water leakage at the Huai Mae Prachum reservoir area.

REFERENCES

(1) Royal Irrigation Department (2015), Standard of geotechnical investigation for dam and accessory, internal standard in Thai for RID practical work, 52 p.
(2) Royal Irrigation Department (2021), Report of geological and geophysical investigation, Huai Mae Prachum, Royal Initiative Project, Mae Taeng, Chiang Mai province, surveying by Bureau of Engineering Topographical and Geotechnical Survey, Internal report in Thai, Code of report GOPH. 18/2564, 87 p.

Fig. 1. Rock exposures at Huai Khun Mi, showing opened joint, fracture, and cavity (white), associated with fold structure (red) as channels that water outflowing from reservoir.

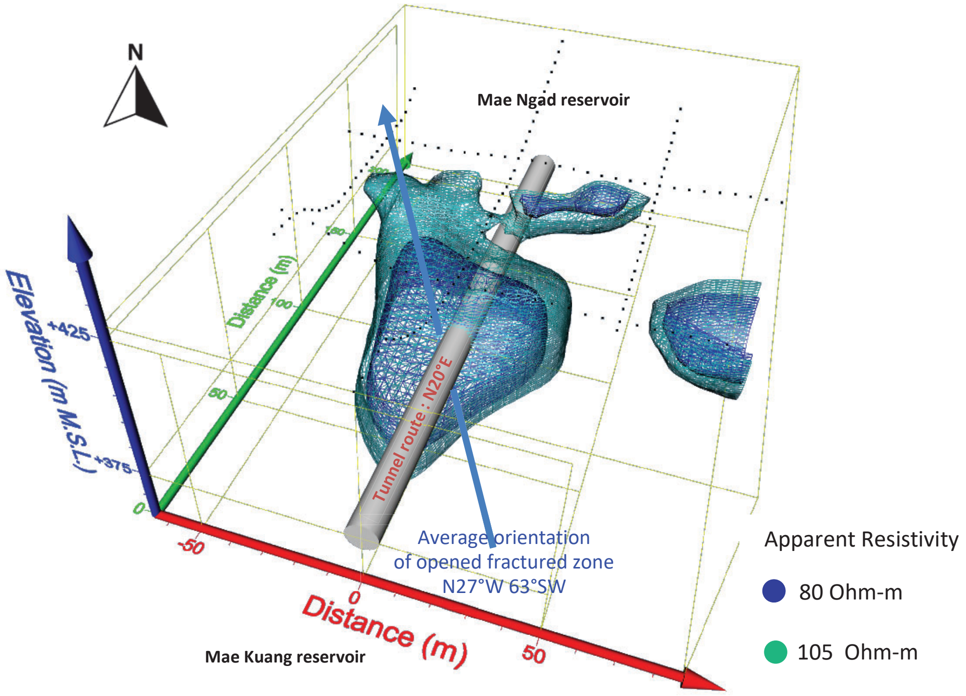


Fig. 2. Model of water leakage by using electrical resistivity imaging data.
Note : Tunnel direction = N20°E, scale X:Y:Z = 1:1:1

TA-136L

Aquatic weed removal with a rake to optimize water delivery

Jirawat Phuphanutada
Regional Irrigation Office 13
Royal Irrigation Department
Bangkok, Thailand
ji_phu@hotmail.com

Chawakorn Rewtragulpaibul and Kitsada Khunnakun
Research and Development Office
Royal Irrigation Department
Bangkok, Thailand
Yimmax3399@gmail.com
fam.kitsada@gmail.com

ABSTRACT
Aquatic weed infestations are caused by various types of weed in irrigation channels, such as floating weeds, emergent weeds and submerged weeds. Other causes of the infestations include land-use change, excessive fertilization, or even global warming. There are many ways to weed depending on suitability, such as the use of large machines, chemicals, and manpower regularly. Likewise, the Royal Irrigation Department (RID) usually eliminates weeds in irrigation channels. In 2020, the budget was allocated to weeding in irrigation channels in the amount of 141.38 million baht, equivalent to 2,749,774 tons of weeds eliminated. (RID 2020).

The objective of this research is to study, design, and develop a tool to eliminate the submerged weeds. The tool was designed by taking into account materials that are applicable, easily found, at the proper weight, convenient to move, and able to work efficiently. The tool was tested in the irrigation canal area, at the Water Transmission and Maintenance Department 3, Water Delivery and Maintenance Project, Kamphaeng Saen, Nakhon Pathom Province, Irrigation Office 13. The testing eliminated submerged weeds, such as Potamogeton nodosus Poir, Hydrilla verticillata, and Ottelia alismoides. In order to suit the width of the canal, the researchers developed a submerged weed control tool in two types: Cart rake set and Wheelbarrow rake set. The cart rake type is used at the bottom of the canal with a width size from 0.5 - 1.0 meters, while the wheelbarrow rake type is used at the bottom of the canal, with a width size from 1.0 - 2.0 meters. As a result of testing the tools in a canal with a width of 1.0 - 2.0 meters, the tools were able to weed 5.52 - 9.69 tons per day (approximately 1.1 - 1.7 kilometers canal length), using six workers and two pickup trucks. The weed rake is an innovation in weeding, in order to support the irrigation water delivery in being more efficient and effective.

Keywords— Weed Rake, Aquatic Weed, Submerge Weed, Efficiency of water management

INTRODUCTION
According to the policy of the Director-General of the Royal Irrigation Department in the removal of weeds obstructing irrigation water, the weeds in irrigation channels are obviously considered as a direct obstacle to currents, causing the speed of the current to decrease, the change in flow direction not in corresponding to the design principle, and eventually leading the current to resist the regular flow in the channels resulting in a calm look. These causes directly impact the water management by not allowing some water to be delivered to the target area and increasing the amount of wasted water. This results in an allocation of excessive water meeting the needs of the plants.

There are many suitable ways to weed, such as the regular use of large machines, chemicals and manpower. Likewise, the Royal Irrigation Department (RID) has regularly eliminated weeds in irrigation channels. There is a budget allocation to weed limitation in irrigation channels, along with the likelihood for more budget for continuously resolving weed infestation.

1. BLACKGROUND AND SINIFICANCE OF THE RESEARCH

The Water Transmission and Maintenance Department 3, Kamphaeng Saen Water Delivery and Maintenance Project, Irrigation Office 13 surveyed the canal area and found 3 types of submerged weeds; Potamogeton nodosus Poir, Hydrilla verticillata, and Ottelia alismoides, which currently present problems in delivering water. Therefore, an innovative idea was formulated to design a submerged weed removal tool (weed rake) for the project operation.

Fig. 1. Irrigation weed problems

2. OBJECTIVES

2.1 To research and develop submerged weed removal tools in irrigation canals
2.2 To innovate submerged weed removal tools including (their) usability testing
2.3 To disseminate the inventions used for the duties of the Royal Irrigation Department and other departments within the Ministry of Agriculture and Cooperatives.

3. RESEARCH METHODOLOGY

3.1 Relevant research data exploration.
3.2 Conducting a survey of the area and discovering the irrigation canals with submerged weeds ; Potamogeton nodosus Poir, Hydrilla verticillata, and Ottelia alismoides, etc., which root firmly in the ground underwater.
3.3 Innovating a submerged wood removal tool, "Weed rake", suitable for the size of the canal with a bottom width of 1.0-2.0 meters and a depth of about 1.5-2.0 meters. There is no complexity in the production of a weed rake tool; on the contrary, its materials, which are known for their low cost, compactness, lightness, portability, and simple maintenance, are generally available on the market. The weed rake tool can be illustrated in two types below.

Fig. 1. - Cart rake set. For canals with a bottom width of 0.5 to 1.0 m.

Fig. 2. Wheelbarrow rake set. For canals with a bottom width of 1.0 to 2.0 meters.

3.4 Testing the performance and efficiency of the submerged weed removal tool in the irrigation canal area at the Water Transmission and Maintenance Department 3, Kamphaeng Saen Water Delivery and Maintenance Project, Nakhon Pathom Province, Irrigation Office 13, which has the following weed removal tools:

3.4.1. Basic submerged weed removal tools; 1 set of weed rakes.

3.4.2 Two wire rope slings with two loop ends of 6 millimeters in diameter, and 25 meters in length.each, and hook kits for hauling tool carts, etc.

3.4.3 One - two small trucks or tractors for hauling weed rake tools.

3.4.4. This tool is designed to be used by four operational staff. That is, one person is in the water to support the tool, one to two people to drive and two people to scoop up weeds from the water onto the bank.

TABLE 1 FIELD TESTS

No.	Canals	Distance (kms)	Amount of weeds (tons)	Remarks
1	2R-1R-1L-5L	1.60	9.28	Laem Bua Subdistrict, Nakhon Chai Si District, Nakhon Pathom Province
2	2R-1R-1L-5L	1.00	5.63	Huai Phra Subdistrict, Don Tum District, Nakhon Pathom Province
3	2L-5L	1.50	8.45	Nong Ngu Luam Subdistrict, Mueang District, Nakhon Pathom Province
4	2R-1R-1L-5L	1.70	9.69	Huai Khwang Subdistrict, Kamphaeng Saen District, Nakhon Pathom Province
5	2L-5L	0.98	5.52	Thap Luang Subdistrict, Mueang District, Nakhon Pathom Province
6	2L-5L	1.20	7.08	Huai Duan Subdistrict, Don Tum, District, Nakhon Pathom Province
7	2R-1R-1L-5L	1.10	6.60	Huai Khwang Subdistrict, Kamphaeng Saen District, Nakhon Pathom Province
8	2L-5L	1.10	6.19	Nong Ngu Luam Subdistrict, Mueang District, Nakhon Pathom Province
9	2L-5L	0.70	4.20	Nong Ngu Luam Subdistrict, Mueang District, Nakhon Pathom Province
10	2L-5L	1.10	6.44	Nong Ngu Luam Subdistrict, Mueang District, Nakhon Pathom Province
11	2L-5L	1.30	7.93	Takong Subdistrict, Mueang District, Nakhon Pathom Province
Total		13.28	76.99	

Note: Tested in the area of the Water Transmission and Maintenance Department 3, Kamphaeng Saen Water Delivery and Maintenance Project, Nakhon Pathom Province, Irrigation Office 13

Fig. 4. Removing weeds from the water onto the bank with weed rakes.

Fig. 5. Wheelbarrow rake set.For canals with a bottom width of 1.0 to 2.0 meters.

Fig. 6. Removing weeds with weed rakes and two pickup trucks (Aerial view)

Fig. 7. Data collection of size, length and weight of weeds to calculate the density of weeds per square meter

4. DISCUSSION AND CONCLUSION

4.1 According to the 10 test results of the canal with medium to high density of Potamogeton nodosus Poir, using the weed rake tools in one day (3-7 hours) **could remove weeds of** 1.10 -1.70 kilometers, with an average of 1.21 kilometers. The weight of Potamogeton nodosus Poir was approximately 5.52 - 9.69 tons/day, averaging 7.0 tons/day or 1.0-2.33 tons/hour, at the hauling speed of 5-9 km/hour, with 6 operational workers. However, the removal distance and the amount of submerged weeds removed depend on the density of weed infestation.

4.2 **Tool Prices**

The price of tools, consisting of the rake set and wheelbarrow, is about 5,000 baht.

The price of tools, consisting of the rake set and trolley, is about 3,000 baht

*** These prices exclude other tools, such as wire rope slings and steel rakes.

Fig. 8. Before and after weeding

TABLE 2 COST COMPARISON AND THE AMOUNT OF WEED REMOVAL

Weed method	Number of operational workers	Cost/Day (Baht)	Weeding distance (km/day)	Amount of weeds (tons/day)	Amount of money per ton
Manpower	6	2,264	0.4-0.5	2.25-2.80	896
Weed rake tools and manpower	6	2,568	1.1-1.7	5.52-9.69	337
Backhoe machine	1	8,000	0.7-0.8	3.90-4.50	1,904

Note: All tests had similar weed densities. (The weed density per square meter was already surveyed.)

Table 2 illustrates the comparison between costs and the amount of weed removed as follows:

Method 1 – removing weeds with manpower

Method 2 - removing submerged weeds with weed rake and manpower.

Method 3 - using a backhoe machine

As can be seen, removing weeds with only manpower has the lowest cost per day, which is approximately 1.13 times lower than the removal method with the Weed Rake tools, and 3.53 times lower than the use of a backhoe. This indicates that using a backhoe to remove weeds per day is the costliest, while using the weed rake tools cost nearly the same as only manpower.

5. RECOMENDATION

There should be an extension of further research and experiment at the Irrigation Office 13 and irrigation canals facing similar problems for a year, for data collection and planning, as well as establishing the annual weeding period.

REFERENCE

(1) Weeds Division (2020), Research and Development Bureau, Royal Irrigation Department, controlling submerged weeds in the irrigation season with herbicides
(2) Parinya Kamonsin (2012), Submerged aquatic weeder : Saprin Weeder Research and Development Bureau, Royal Irrigation Department
(3) Urai Pengphit (2013), Potential of IAA from cattails, water hyacinths, and giant mousetraps to stimulate the root formation of some plants and the development of the Sida tomato variety, Scientific and Environmental Research and Development Division Research and Development Bureau, Royal Irrigation Department
(4) Asst. Prof. Dr. Santimaitri Konkhamdee. (2014), Summary of teachings of Subject 109, 101 Principles of Plant Production, Weed Management, academic year 2014, Khon Kaen : Field Crops Department of Plant Science and Agricultural Resources, Faculty of Agriculture Khon Kaen University.

TA-138L

PREDICTING THE RESERVOIR INFLOW OF BHUMIBOL DAM USING XGBOOST MACHINE LEARNING ALGORITHM

Pheeranat Dornpunya[1], Areeya Rittima[2*], Yutthana Phankamolsil[3], Allan Sriratana Tabucanon[4], Wudhichart Sawangphol[5], Jidapa Kraisangka[6], Yutthana Talaluxmana[7], Varawoot Vudhivanich[8], and Assada Kijpayung[9]
[1, 2*]Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Thailand
[3]Environmental Engineering and Disaster Management Program, Mahidol University, Kanchanaburi Campus, Thailand
[4]Faculty of Environment and Resource Studies, Mahidol University, Thailand
[5, 6]Faculty of Information and Communication Technology, Mahidol University, Thailand
[7]Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand
[8]Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Thailand
[9]Royal Irrigation Department, Thailand
*Corresponding author's e–mail: areeya.rit@mahidol.ac.th

Keywords— Bhumibol Dam, Extreme Gradient Boosting (XGBoost), Reservoir Inflow Prediction

ABSTRACT

XGBoost, a tree-based ensemble machine learning algorithm, was used to predict the daily and monthly reservoir inflows of Bhumibol Dam in Thailand. The prediction models were developed using the observed inflow and climate data from 2000 to 2020 as major features. The structures of prediction model were determined by defining the future reservoir inflow at the predictive lead time steps as a function of the past inflow, precipitation, and humidity at time step t, as well as average inflow at the delayed time steps. Consequently, 54 XGBoost scenarios of the daily and monthly inflow prediction models were trained and validated by altering the model parameters namely; training–testing dataset ratio, learning rates, maximum number of iterations, and early stopping rounds. The statistical performance metrics namely; RMSE, MSE, R^2, R, and NSE were employed to evaluate the model performance. It can be drawn from the validation results that the XGBoost model can deliver reliable and robust prediction outcomes. In addition, the XGBoost model is capable of predicting the complete performance of the daily reservoir inflow with higher accuracy than the monthly inflow.

INTRODUCTION

A more frequent occurrence of flood and drought in Thailand particularly in the past decade reflects the uncertainty of hydrological data due to changes in the regional climate and economic growth of the country. This has significant implications for the operational actors to revise the strategic plan based upon the data-driven decision-support tools to reduce disaster risks and losses. The accurate and reliable hydrological prediction plays vital role in the decision-making process specifically for real time operation of dam-reservoir system. Machine Learning (ML) which is the advanced area of Artificial Intelligence (AI), has been extensively used to improve predictive accuracy and understand hydrological uncertainty and provide the multiple lead times. It has proved a great success in predicting hydrological data such as rainfall, reservoir inflow, and river flow. [1]. Therefore, this study aims at evaluating the predictability of machine learning-based prediction models for reservoir inflow prediction. The extreme gradient boosting (XGBoost) algorithm with R programming language was employed to develop the daily and monthly prediction models of Bhumibol Dam where high variability of reservoir inflow has apparently found and probabilistic forecast has become increasingly important.

METHODOLOGY

Setting up the prediction model structures were performed by specifying the highly-correlated predictor variables as the model features including number of average inflow at the delayed time steps, climate data at time step t, and observed inflow data at time step t. Three datasets of training–testing ratio namely; 60:40, 70:30, and 80:20 and learning rates of 0.1, 0.01, and 0.001 were specified. Accordingly, 54 XGBoost scenarios of daily and monthly models were trained and validated to produce good predictive results. In the predictive modelling process, predictor variables were firstly imported into the prediction models. Secondly, the time series of selected variables were divided into training and testing datasets according to the designated ratio. Thirdly, development of XGBoost model was controlled by the hyperparameter setting such as number of iterations (nrounds), learning rate (Eta), and early stopping rounds parameters. Accordingly, the maximum number of iterations was 10,000. The learning rate allows model to achieve faster convergence of training dataset. So, the learning rates of 0.1, 0.01, and 0.001 were determined in this study. The early stopping rounds are generally used to stop training procedures when the loss on training dataset starts increasing. Lastly, the level of agreement between the predicted values and observed values were evaluated by the statistical methods namely; RMSE, MSE, R^2, R, and NSE.

RESULTS AND DISCUSSIONS

It is appeared that the best daily reservoir inflow prediction model can be made by specifying the reservoir inflow at lead time t+1 as a function of the observed inflow at time step t, average inflow at the delayed time steps t–1 to t–3 with learning rate of 0.1. The best input structures for monthly prediction model are the observed inflow at time step t, average inflow at the delayed time steps t–1 to t–7, precipitation and humidity at time step t with learning rate of 0.001. Moreover, splitting the training and testing datasets using 60:40 and 80:20 ratio gave the robust performance for the daily model and monthly model, respectively. The predictive performance for the daily model reached high with R^2 of 0.8854 and NSE of 0.8619 after the validation process was completely done. However, it is found that the predictive performance was lower for the monthly model with R^2 of 0.6788 and NSE of 0.6746. Fig.1 depicts the qualitative performance of the best daily and monthly prediction models for reservoir inflow of Bhumibol Dam. It was likely similar in terms of the inflow pattern between the observed and predicted inflows during 2000–2020. The average daily predicted inflow performed by the testing dataset of prediction model was really closed to the observed average values with small percentage difference of +0.27% and -2.85% for the daily and monthly predicted inflows, respectively. However, under-estimated predictive results were found for the daily and monthly prediction models when the peak inflows were considerably investigated.

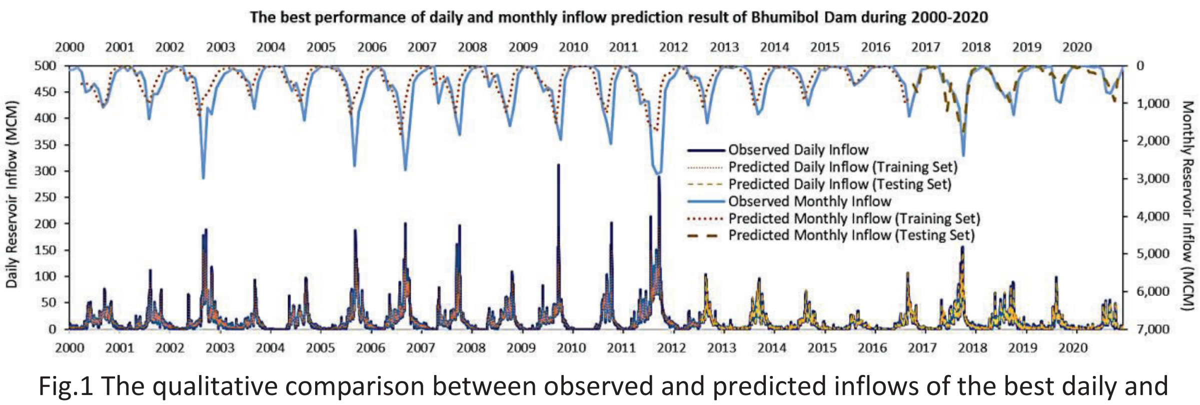


Fig.1 The qualitative comparison between observed and predicted inflows of the best daily and monthly prediction model of the Bhumibol Dam

SUMMARY AND ACKNOWLEDGMENTS

The daily and monthly reservoir inflows of the Bhumibol Dam were predicted using XGBoost algorithm. It is exhibited that the XGBoost model provided consistent and robust prediction results particularly for the daily prediction model with the greatest values of R^2, R, NSE, and the lowest values of RMSE and MSE. The XGBoost model is capable of predicting the complete performance of the daily reservoir inflow with higher accuracy than the monthly inflow.

This work was financially supported by the Agricultural Research Development Agency (Public Organization).

REFERENCES

[1] Chai, S., (2004). Artificial intelligence and social theory: a one–way street. Perspectives, 27(4):11–12.

TA-139S

TACKLING THE 2021 TROPICAL STORM DIANMU FLOOD IN THE GREATER CHAO PHRAYA RIVER BASIN, THAILAND: THE PERSPECTIVE VIEWS THROUGH CO–RUN EXERCISE UNDER THE SPEARHEAD RESEARCH PROGRAM

Areeya Rittima*
Faculty of Engineering, Mahidol University, Thailand
Phone: 66–02–889–2138 ext. 6384, Fax: 66–02–889–2138 ext. 6388 E–mail: areeya.rit@mahidol.ac.th
Yutthana Phankamolsil
Environmental Engineering and Disaster Management Program, Mahidol University, Kanchanaburi Campus, Thailand
Kanoksri Sarinnapakorn
Hydro–Informatics Institute (Public Organization), Thailand
Sucharit Koontanakulvong
Faculty of Engineering, Chulalongkorn University, Thailand
Allan Sriratana Tabucanon
Faculty of Environment and Resource Studies, Mahidol University, Thailand
Wudhichart Sawangphol and Jidapa Kraisangka
Faculty of Information and Communication Technology, Mahidol University, Thailand
Yutthana Talaluxmana
Faculty of Engineering, Kasetsart University, Thailand
Varawoot Vudhivanich
Faculty of Engineering at Kamphaengsaen, Kasetsart University, Thailand
Assada Kijpayung
Royal Irrigation Department, Thailand
Wanpen Kaewkamthong
Electricity Generating Authority of Thailand

ABSTRACT
The descriptive study on flooding triggered by the tropical storm Dianmu in late rainy season in the Greater Chao Phraya River Basin (GCPYRB) was conducted. The status of water storage of major dams; Bhumibol (BB), Sirikit (SK), Khwaenoi Bumrung Dan (KNB), Pasak Jolasid (PS) before and after Dianmu storm periods were considerably analyzed and compared. The inundated areas of flooding were also investigated and visualized to unveil the extent of flood damage in the Greater Chao Phraya Irrigation Scheme (GCPYIS) during late–September 2021. The dam and reservoir operation, water flows at key gauging stations, and discharges at Chao Phraya Diversion Dam were also explored to brighten up the operational practice of water resources in GCPYRB during the critical Dianmu flood periods. In addition, the results of co–run exercise under the Spearhead Research Program (SIP) including reservoir inflow forecast using Machine Learning (ML) technique and predetermined dam release by the Constraint Programming (CP) model were also presented. The tropical storm Dianmu in 2021 has become a lesson learned particularly for the operational actors to reconsider the water resource management plan due to the abnormality of regional climate data. Importantly, tackling the critical floods through the well–prepared plan and rapid framework for decision making based upon recent information with supportive tools can help assist flood moderation to a considerable extent.

Key words: Tropical Storm Dianmu, Greater Chao Phraya River Basin, Spearhead Research Program

1 INTRODUCTION

The influence of the tropical storm Dianmu hitting parts of Thailand during late– September 2021 caused considerable flood damages particularly in the north, northeast and central regions. The tropical storm

Dianmu brought the heavy rainfall and resulted in flash floods in the upper regions of Thailand on September 23–24. The Department of Disaster Prevention and Mitigation (PWA) has reported that thousands of household area in at least 30 provinces have been affected and some agricultural land areas specifically in the Greater Chao Phraya Irrigation Scheme have been devastated due to flooding [1]. Floodwater caused by the tropical storm Dianmu combined with the seasonal monsoon rains and concurrent storms has still persisted at the end of October and widespread on the left and right banks of the Chao Phraya River.

It was reported that the tropical storm Dianmu was originated from the South China Sea on September 21 and tracked west–northwestwards across Indochina affecting several parts of Vietnam, Lao, Cambodia, and Thailand [2]. A distinct change in rainfall amount and extreme weather was reported and monitored in various parts of the central Vietnam, southern Laos, northeastern Cambodia, and northeastern Thailand. In Vietnam, the tropical storm Dianmu made the landfall, mudslide, and flooding in the mountainous areas of the northern region. The arrival of the tropical storm Dianmu also led to flooding in some parts of southern Lao. Several low–lying areas near streams and rivers, and urbans areas with poor drainage system have been sparsely inundated over this region. In addition, fatality and injury, and property damages were also reported.

In Thailand, according to the past 7–day satellite–based flood map published by the Geo–Informatics and Space Technology Development Agency (GISTDA) of Thailand on September 30 [3], it was exhibited that the inundated areas covered 6 provinces in the north; Sukhothai, Phitsanulok, Kamphaeng Phet, Phichit, Tak, and Phetchabun, 8 provinces in the northeast; Loei, Khon Kaen, Roi Et, Kalasin, Chaiyaphum, Nakhon Ratchasima, Buriram and Surin, 7 provinces in the east; Nakhon Nayok, Prachin Buri, Sa Kaeo, Chachoengsao, Chonburi, Rayong, and Trat and 9 provinces in the upper part of central region; Nakhon Sawan, Lop Buri, Uthai Thani, Chai Nat, Saraburi, Sing Buri, Ang thong, Ayutthaya, and Suphan buri. In addition, flooding is expected to be prolonged and receded in the Pathum Thani, Nonthaburi, Bangkok and metropolitan areas in the Lower Chao Phraya River Basin.

The role of the researchers under the Spearhead Research Program, the National Research Council of Thailand (NRCT) on water resources management has been undertaken through the co–run exercise in the Greater Chao Phraya River Basin (GCPYRB) to deliver clear and straightforward information and possible guideline for dam operation. Therefore, the objective of this study aims at reporting the current situation in views of water storage status in reservoirs, the associated inundated areas, and operational practice during the 2021 Dianmu storm.

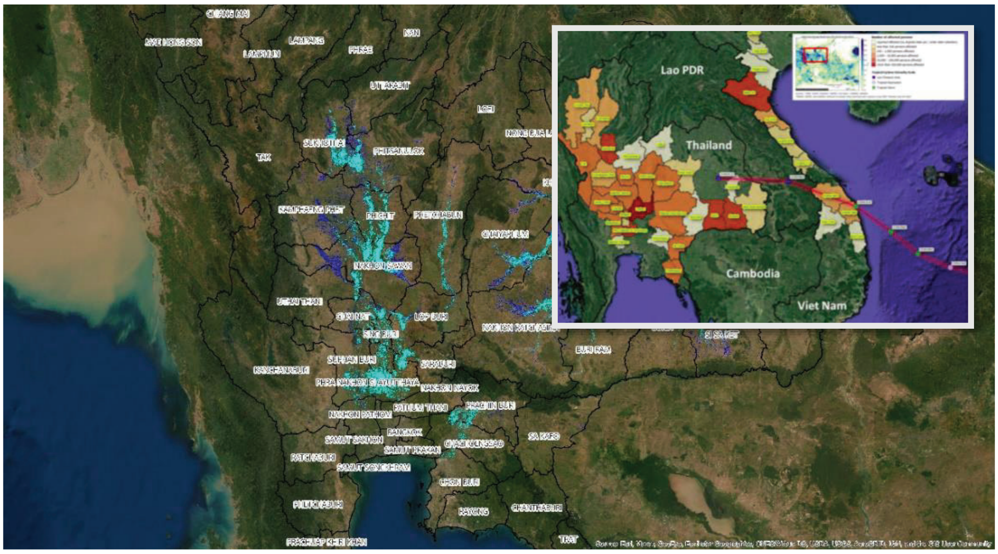


Fig. 1. The map of inundated areas in the Greater Chao Phraya River Basin due to the 2021 Dianmu flood; Dark blue–dated on Sep 30, Light blue–dated on Oct 8.

2 METHODOLOGY

The descriptive study on flooding in GCPYRB was conducted due to the occurrence of the tropical storm Dianmu in September 2021. The status of water storage of major dams; BB, SK, KNB, PS before and after Dianmu storm was considerably analyzed and compared. The inundated areas of flooding were also investigated and visualized to unveil the extent of flood damage particularly in GCPYIS during late–September 2021. The dam and reservoir operation, water flows at key gauging stations, and discharges at Chao Phraya Diversion Dam were also explored to brighten up the operational practice of water resources in GCPYRB during the critical Dianmu flood periods. In addition, the results of co–run exercise under the Spearhead Research Program including reservoir inflow forecast using machine learning technique [4] and predetermined water release by the constraint programming model [5] were also presented.

3 RESULT AND DISCUSSION

3.1 Water storage status of major dams before and after Dianmu

The current status of reservoir water storages of four storage dams; BB, SK, KNB, and PS before the Dianmu hit some areas in Thailand, were considerably investigated. It is found that the available water storage on September 5, were at 9.09%, 12.14%, 30.16% and 12.77% of active storage for BB, SK, KNB, and PS Dams, respectively signifying high holding capacity of all reservoirs to collect incoming floodwater as can be seen in Fig. 2 and Fig. 3. The cumulative observed inflows till the 5th of September 2021 were 1,249, 2,281, 555, and 201 mcm, for BB, SK, KNB, and PS Reservoirs, respectively which were relatively low by comparing with the long–term average values for all the dams. In other words, the water availability in reservoirs were likely declined due to unbalancing between inflows and outflows before the Dianmu hit. The cumulative volume of released water till the 5th of September 2021 were merely 1,703, 3,772, 634, and 612 mcm for BB, SK, KNB, and PS Dams, respectively which were determined corresponding to the target water allocation plan for dry year operation.

However, it is investigated that the influence of the tropical storm Dianmu led to the minor increase of active water storage of BB and SK Dams accounting for 29.08% and 19.77% of active storages on September 30. During the storm period, zero or minimum discharges were determined for the dam release. However, this tropical storm had significant impact on high likelihood of reservoir inflows of KNB and PS Dams particularly since September 26. It was reported that the water storage of KNB and PS Dams reached up to 90.70% and 107% of active capacity on September 30. Accordingly, the extra water were released from KNB and PS Dams creating floodwater on the downstream side of PS Dam. Trends of reservoir inflows and water released from all dams in 2021 are presented in Fig. 4. It is investigated that the ratio of average reservoir inflows to reservoir capacity of KNB and PS Dams were at 1.44 and 1.55 in 2021 after the tropical storm Dianmu as shown in Table 1. This implies the sudden changes of reservoir inflows of these two dams which were definitely critical and tough in terms of dam operation and flood prevention.

Table 1 Ratio of average reservoir inflows to reservoir capacity of major dams in GCPYRB

Avg. Reservoir Inflow: Capacity Ratio	Long–Term Data	Short–Term Data				
		Wet Year	Normal Year	Dry Year	Before Dianmu	After Dianmu
BB	0.40[1/]	0.73	0.39	0.20	0.09[4/]	0.24[5/]
SK	0.64[1/]	0.89	0.64	0.45	0.24[4/]	0.30[5/]
KNB	1.72[2/]	3.92	1.90	0.92	0.72[4/]	1.44[5/]
PS	2.83[3/]	5.33	3.02	1.09	0.26[4/]	1.52[5/]

Remark: [1/]Long–term data during 2000–2020
[2/]Long–term data during 2009–2020
[3/]Long–term data during 2003–2020
[4/]Data on September 5, 2021
[5/]Data on September 30, 2021

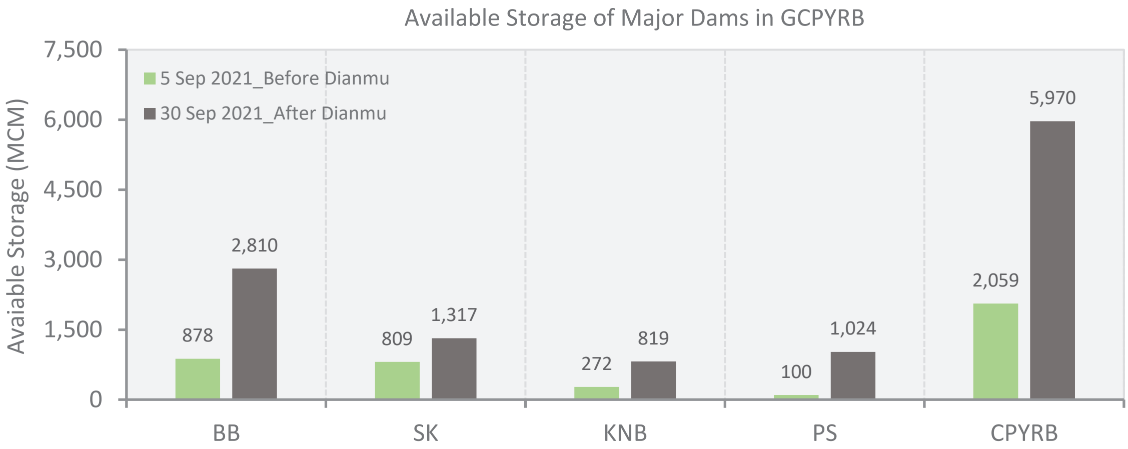


Fig. 2. Avaiable water storage of major dams in GCPYRB in September 2021

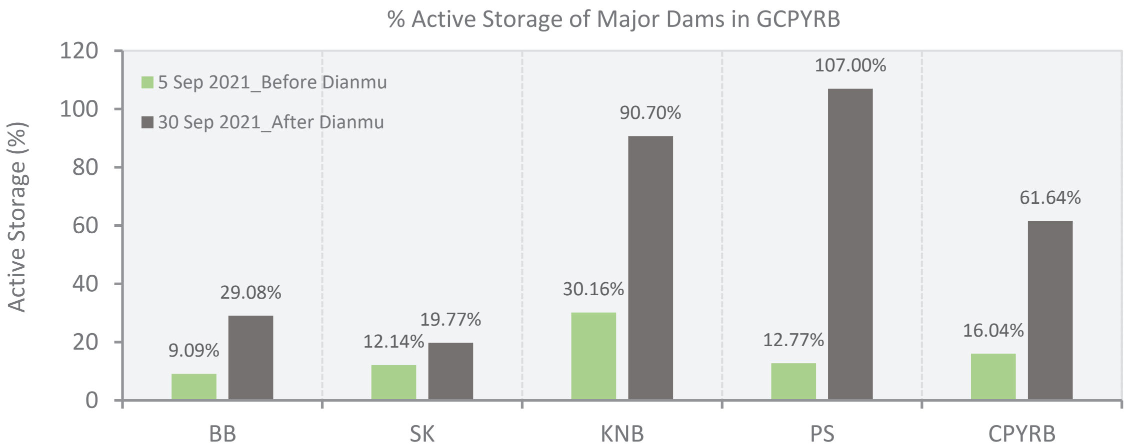


Fig. 3. Percent of active storage of major dams in GCPYRB in September 2021

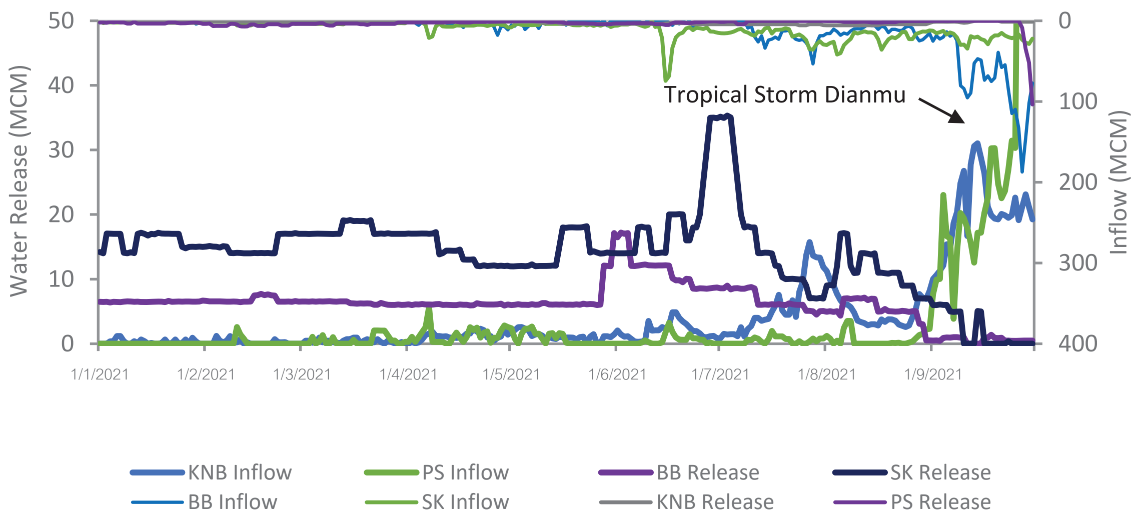


Fig. 4. Trends of reservoir inflows and water released from BB–SK–KNB–PS Dams in 2021

3.2 Evaluation of inundated areas caused by the 2021 Dianmu Flood

The undated areas caused by the 2021 Dianmu flood were evaluated using the past 7–day satellite–based flood map and compared the results in late September–early October. It is apparently found that the total inundated area in GCPYRB on September 27–October 2 was 4,168 sq.km. which was equivalent to 2,605,000 rai. Approximately 942,694 rai of the inundated areas was existed in the agricultural land areas in GCPYIS as shown in Table 2. The flood inundation in agricultural land areas on October 8 was decreased by 33.26%. Although the decline of flood inundation areas was found in the north and upper central regions on October 8, however, the water levels in the main rivers and streamflow rates were still high. Moreover, effect of flooding triggered by the tropical storm Dianmu was transported over a wide area in the lower central and eastern regions of Thailand. More than 50% of the inundated areas in GCPYRB was definitely persisted in the Yom–Nan, Chaochet Bangyeehon, Phak Hai, and Khokkathiam Irrigation Schemes as can be seen in Fig. 4.

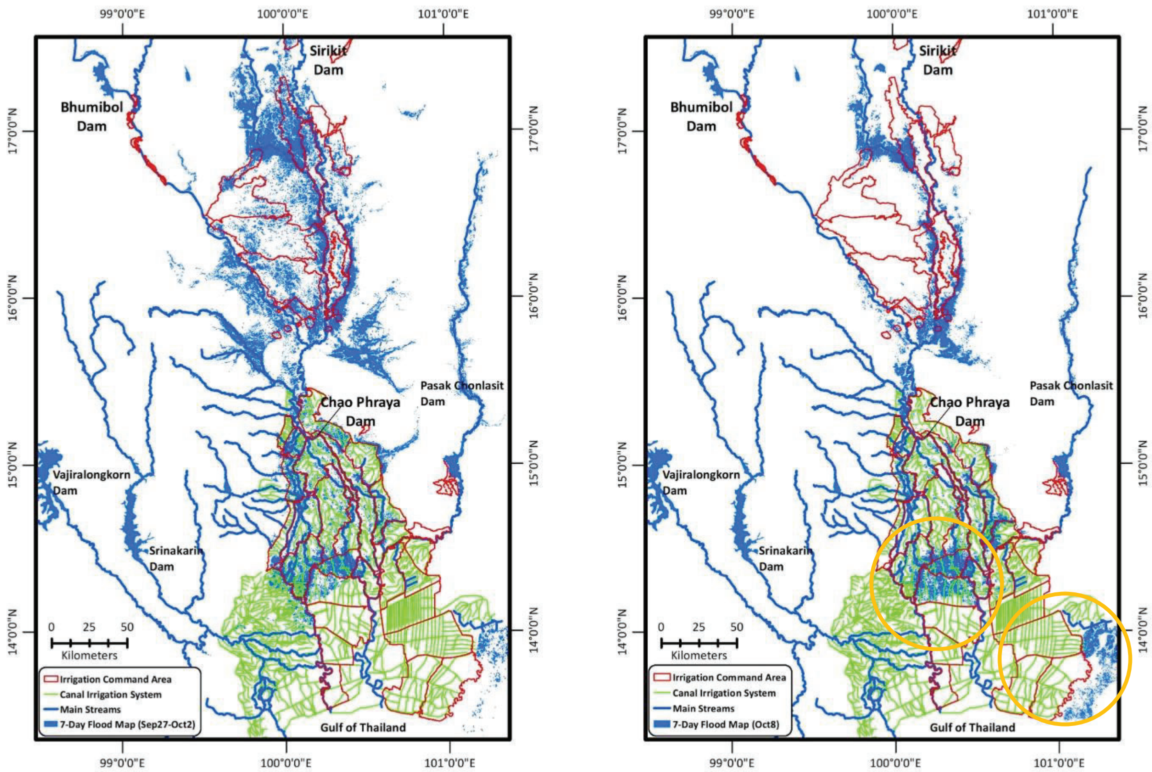


Fig. 4. Comparison of inundated areas on September 27–October 2 and October 8 due to the 2021 Dianmu flood.

Table 2 The inundated areas in the Greater Chao Phraya Irrigation Scheme

Name of Irrigation Scheme	Type of Irrigation Scheme	Cultivated Area in 2020/2021 (rai)[1/]	Inundated Area	
			(rai)	(percentage)[2/]
Lower Ping Irrigation Zone				
Tortongdang	Inundation	651,037	52,183	8.02
Wangbua	Inundation	694,566	49,322	7.10
Wangyang– Nongkwan	Inundation	439,511	72,380	16.47
Lower Nan Irrigation Zone				
Dongsetthee	Gravity	151,982	19,596	12.89
Plaichumpol	Gravity	255,377	41,325	16.18
Naresuan	Gravity	95,215	309	0.32
Thabua	Gravity	157,489	25,564	16.23

Name of Irrigation Scheme	Type of Irrigation Scheme	Cultivated Area in 2020/2021 (rai)[1/]	Inundated Area	
			(rai)	(percentage)[2/]
Yom–Nan	Inundation	368,180	131,497	35.72
Chao Phraya–Thachin Irrigation Zone				
Bang Bal	Pumping	176,627	10,100	5.72
Borommathat	Gravity	212,101	21,614	10.19
Chanasute	Gravity	307,503	39,640	12.89
Chaochet Bangyeehon	Inundation	629,072	31,948	5.08
Donjedee	Gravity	91,961	13,497	14.68
Phak Hai	Gravity	278,899	96,187	34.49
Phophraya	Gravity	537,783	71,779	13.35
Pollathep	Gravity	170,204	15,821	9.30
Samchuk	Gravity	243,499	12,658	5.20
Thabot	Gravity	114,138	31,563	27.65
Wat Sing	Pumping	6,616	–	–
Yangmanee	Gravity	142,808	18,332	12.84
Pasicharoen	Inundation	44,668	–	–
Phayabunlue	Inundation	382,642	528	0.14
Prapimon	Inundation	205,285	–	–
Chong Kae	Gravity	116,219	14,100	12.13
Khokkathiam	Gravity	208,183	16,752	8.05
Maharaj	Gravity	210,765	31,687	15.03
Manorom	Gravity	202,231	41,146	20.35
Roeng Rang	Gravity	143,533	7,386	5.15
Klong Dan	Inundation	221,970	–	–
Nakhon Luang	Gravity	94,640	–	–
Northern Rangsit	Gravity	181,898	–	–
Praong Chao Chaiya Nuchit	Inundation	495,845	–	–
Southern Pasak	Gravity	140,407	–	–
Southern Rangsit	Gravity	682,143	–	–
Additional Cultivated Area in 2020/2021				
Tak	–	19,900	–	–
Khwae Noi Bamrung Dan	–	21,469	21,745	101.29
Samut Sakhon	–	37,638	–	–
Khlong Priew–Sao Hai	–	36,250	–	–
Pasak Jolasid	–	79,234	–	–
Lop Buri	–	70,690	–	–
Chainat	–	–	3,338	–
Uttaradit	–	–	4,716	–
Total	–	9,481,953	942,694	9.94

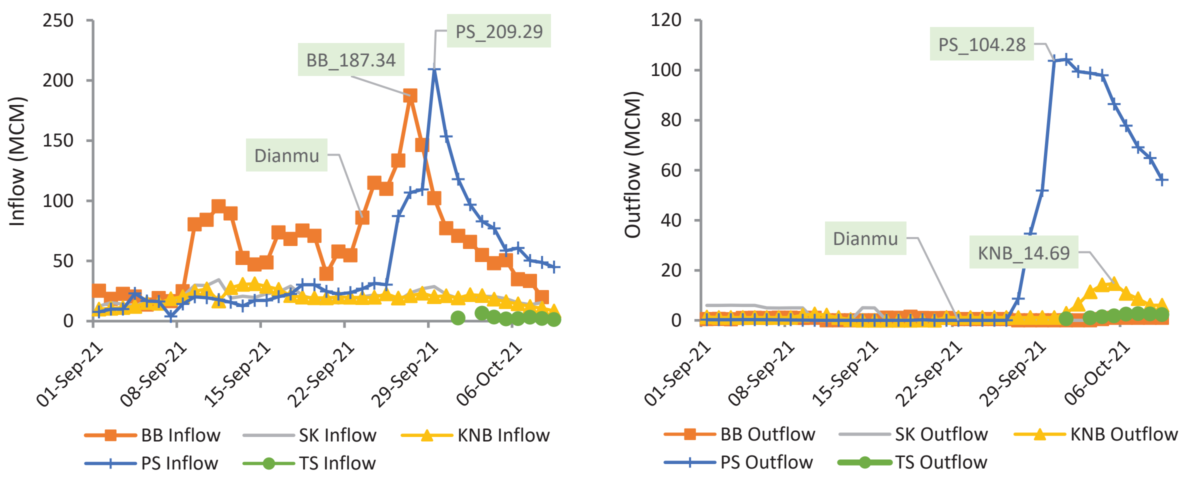
Remark: [1/] The cumulative area size cultivated from November 1, 2020 to July 12, 2021.
[2/] The percentage values were calculated as the ratio of flooded area to cultivated area in 2020/2021.

3.3 Evaluation of reservoir operational data triggered by the tropical storm Dianmu

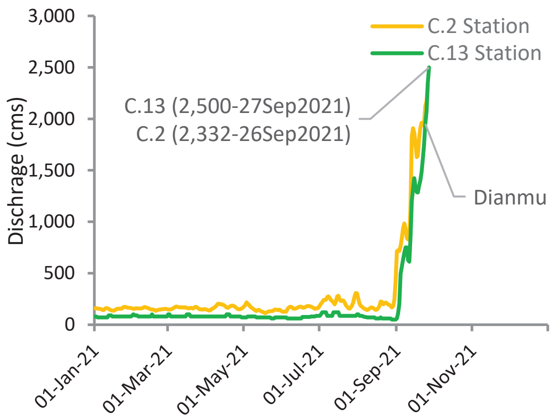
The tropical storm Dianmu and seasonal monsoon rains producing substantial amounts of rainwater in the northern and central Thailand significantly led to the increase of the reservoir inflows of all major dams in GCPYRB in late September. It is investigated that the reservoir inflows of BB and PS were considerably increased during the storm periods. The reservoir inflows reached up to 187.34 MCM per day for BB Dam and 209.29 MCM per day for PS Dam as explicitly shown in Fig. 5(a). However, after September 30, the tendency of observed inflows of all major dams were likely decreased which was associated with those predicted results of reservoir inflow performed by using machine learning technique and 2–week rainfall forecast by using WRF–ROMS (CFSV2) model in the upstream areas of these four major dams.

It is found that releasing water from all major dams in early October 2021 were kept as zero or minimum requirement to reduce flood damage downstream except PS Dam. The surplus water was released from PS Dam to increase holding capacity of reservoir and dam safety. It is reported that the reservoir outflow of PS Dam climbed up to 104.28 MCM per day on October 1 when it reached full capacity as shown in Fig. 5(b). This led to widespread flooding on the Lower Eastern Chao Phraya Irrigation Scheme which is located downstream of PS Dam. In addition, it caused rapid change of increased water level in the Pasak River downstream of Rama 6 Dam which flows eastward into the Chao Phraya River. Since October 1, the amount of water release from PS Dam tended to be continuously decreased corresponding to the decline of reservoir inflow.

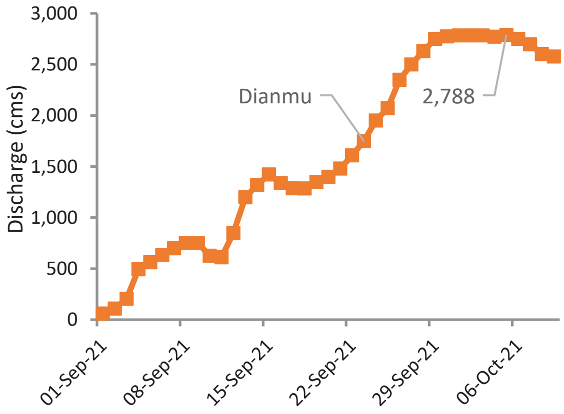
The floodwater travelled from the upper north in the Ping, Wang, Yom, and Nan River Basins combined with the seasonal monsoon rainfall downstream led to the rising water levels in the Chao Phraya River inevitably. Therefore, the operational practice during the critical flood periods was undertaken by cutting off the peak flows in the Chao Phraya River into the canal irrigation system on the left and right banks of the Chao Phraya River and the potential flood retention areas. It is observable that the river discharge at C.2 gauged station monitored at Nakhon Sawan Province started increasing at the beginning of September before the occurrence of the Dianmu storm and ascending to the peak flow of more than 2,500 cms during late September. The decision to increase the discharge rates at Chao Phraya Dam (C.13 gauged station) to accommodate the huge flow and transported floodwater in the main river was implemented by the Royal Irrigation Department (RID) of Thailand as can be seen in Fig. 5(c). Consequently, flood warning for the results of the increased discharge rates through the Chao Phraya Dam were made especially in the low lying areas and communities along the river banks with poor flood levee structures in Chainat, Sing Buri, Ang Thong, and Ayutthaya. It would be seen in Fig. 5(d) that the increasing discharge rates at Chao Phraya Dam was allowed since the beginning of September and it reached the highest peak in late September–early October. In recent days (October 23), it was reported that flood situation in the CPYRB has progressively improved. The discharge rates passing through the Chao Phraya Dam downstream was reduced by fluctuating around 2,000 cms at the end of October. In addition, the official authorities said that flood situation in GCPYRB is expected to return to normal by the end of November [7].



(a) Reservoir inflow (b) Reservoir outflow



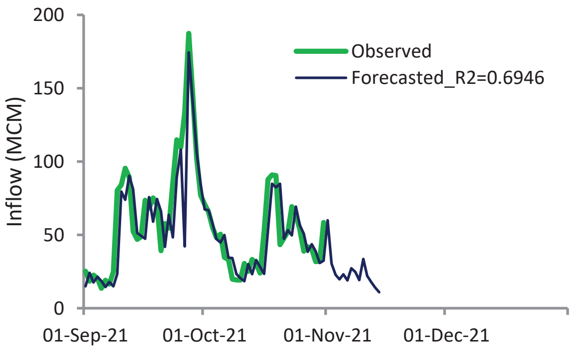
(c) Discharge at key runoff stations



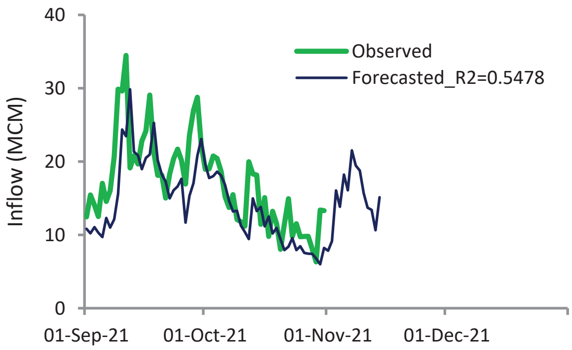
(d) Discharge at CPY Dam

Fig. 5. Reservoir operational data before and after Dianmu

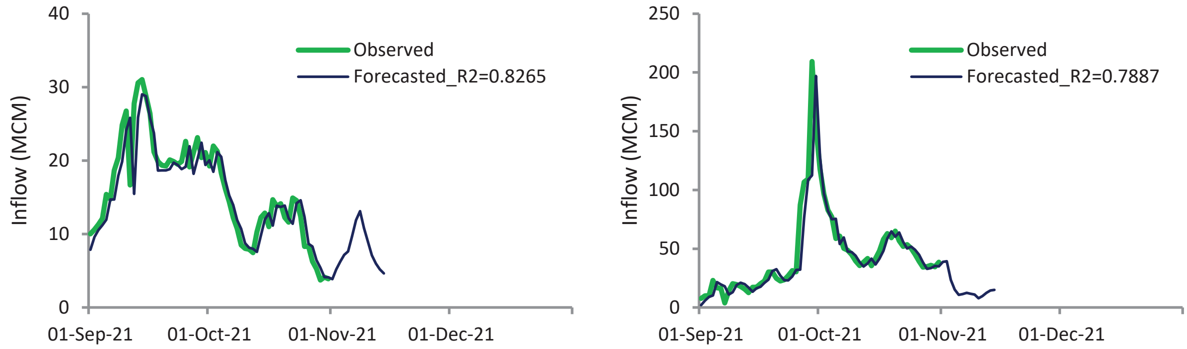
The results of modelling works through the co–run exercise were presented for real time multi–reservoir operation in GCPYRB during the storm periods. The machine learning which is branch of artificial intelligence, has been widely applied in the field of water resources engineering with the great success for hydrological predictions [6]. Therefore, machine learning with Long Short–Term Memory (LSTM) algorithm was used to develop the daily reservoir inflow prediction models of BB, SK, KNB and PS Dams. Multi–objective optimization by constraint programming model was applied by aiming to minimize the water deficit and spilled water as well as to reduce the excessive water in GCPYRB. The CP model with yearly and seasonal constraints were developed based upon the dam–reservoir system and physical conditions in GCPYRB. In addition, the observed sideflow data and the predicted outputs of reservoir inflow were also used to identify the constraints of multi–objective optimization model to predetermine the amount of water release of four major dams. The results of reservoir inflow forecast by machine learning technique and predetermined water release by the constraint programming model during September 1–Noveber 11 were presented in Fig. 6 and Fig. 7.



(a) BB Dam

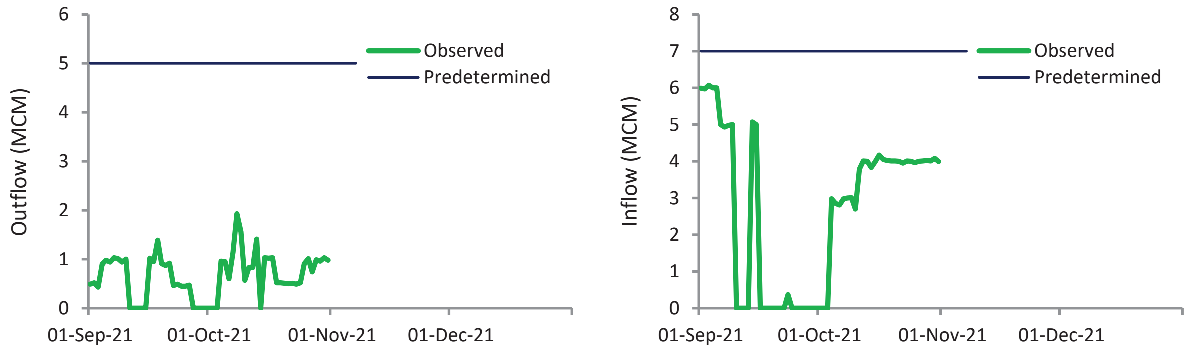


(b) SK Dam

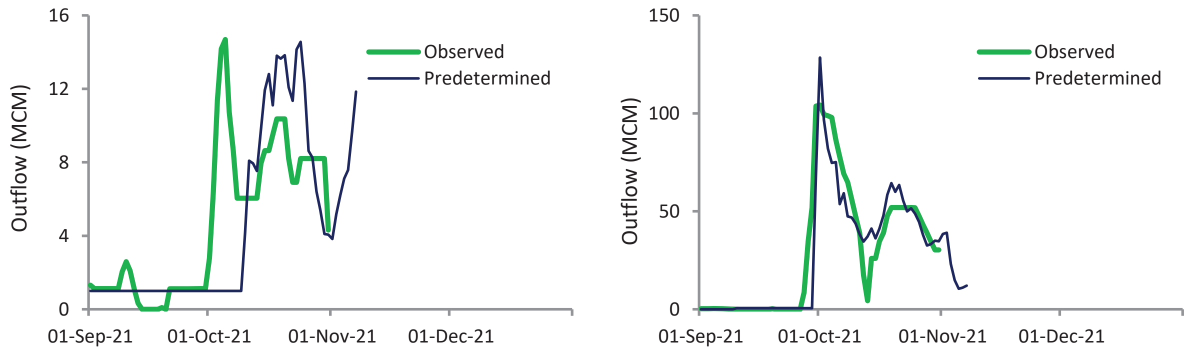


(c) KNB Dam (d) PS Dam

Fig. 6. The predicted reservoir inflows of major dams in GCPYRB during the Dianmu storm period.



(a) BB Dam (b) SK Dam



(c) KNB Dam (d) PS Dam

Fig. 7. The predetermined water release of major dams in GCPYRB during the Dianmu storm period.

It is found that the one–step ahead daily inflow prediction with 14–day lead time could provide good predictive results of R^2 of 0.6946, 0.5478, 0.8265, and 0.7887 for BB, SK, KNB, and PS Reservoirs during September 1–November 11. The best structure of predictive model developed requires the past and current reservoir inflows as major inputs to capture and forecast the future trends and predicted values of reservoir inflows. The rising trends of predicted inflows were found for these four reservoirs from late–September to the first week of October. However, it tended to be decreased in the second week of October which was relative to the behaviors of observed inflows. The predicted reservoir inflows with 14–day lead time were then used as inputs to predetermine the released water by constraint programming model. Releasing water from BB and SK reservoirs with minimum water requirement was accordingly recommended by the CP model for the next 14 days in November. However, it recommended to increase the amount of released water from KNB and PS reservoirs since September 26 due to the rapid increase of the reservoir inflows.

Even the flooding situation caused by the tropical storm Dianmu in GCPYRB is expected to recede in November 2021 [7]. However, flooding continues to affect some areas in the Western Chao Phraya Irrigation Scheme along the Thachin River and low–lying areas near the stream channels in GCPYRB. The massive amounts of water transporting from the north to the Lower Chao Phraya River Basin have still overwhelmed the small to medium size reservoirs to reach full capacity such as Krasiew, Thap Salao, and Pasak Jolasid Dams inevitably at the end of October. Moreover, the intense rainfall is still forecasted in some regions. Therefore, keeping close attention to current situation of water and the new developing storms is important to reduce impact of flood events in this region.

4 CONCLUSION

Flooding triggered by the tropical storm Dianmu in late rainy season in Thailand has become a lesson learned particularly for the operational actors to reconsider the water resource management plan due to the abnormality of regional climate data. Coping with rapid change of water availability and compound flood from the concurrent storms in a short period of time is not a simple task. However, tackling the critical floods through the well–prepared plan and rapid framework for decision making based upon recent information with supportive tools can help assist flood moderation to a considerable extent. Importantly, weighting the operational strategy applicable for GCPYRB by storing floodwater in the potential flood retention areas for later use in the system or by directing surplus water to the sea immediately to reduce impact of flood inundation, plays significant role in the prospective views of sustainable development of water resources and risk–based management.

5 ACKNOWLEDGEMENT

Authors would like to acknowledge the Thailand Science Research and Innovation (TSRI) for providing financial support. We are cordially thankful to the Royal Irrigation Department (RID), Electricity Generating Authority of Thailand (EGAT), and Thai Meteorological Department (TMD) for providing research data.

REFERENCES

[1] United Nations Office for the Coordination of Humanitarian Affairs (OCHA). (2021, October 31). Thailand–Floods. Retrieved from https://reliefweb.int/report/thailand/thailand–floods–pwa–tmd–floodlist–media–echo–daily–flash–28–september–2021.

[2] Wikipedia. (2021, October 31). Tropical Storm Dianmu (2021). Retrieved from https://en.wikipedia.org/wiki/Tropical_Storm_Dianmu_(2021).

[3] Geo–Informatics and Space Technology Development Agency (GISTDA). (2021, September 30). Flood map. Retrieved from https://flood.gistda.or.th/.

[4] Cerqueira, V., Torgo L., Soares, C. (2019). Machine learning vs statistical methods for time series forecasting: size matters. arXiv:1909.13316.

[5] Rossi, F., Van Beek, P., Walsh, T. (2006). Handbook of constraint programming. New York: Elsevier Science.

[6] Dornpunya, P., Rittima, A., Phankamolsil, Y., Tabucanon, A.S., Sawangphol, W., Kraisangka, J., Yutthana Talaluxmana, Y., Vudhivanich, V. (2021). The predictability of reservoir inflow prediction model for Sirikit Dam using Xgboost machine learning algorithm. Proc. Of the 5th International Conference on Water Resources Engineering, 25–26 November 2021.

[7] The Nation Thailand. (2021, November, 2). Flooding eases in 17 of 33 provinces hit by Dianmu tropical storm. Retrieved from https://www.nationthailand.com/in–focus/40007347.

SESSION B:
NEW TECHNOLOGY IN WATER AND IRRIGATION MANAGEMENT

TB-201S

SINTEX-F seasonal prediction system and its application A brief review of my recent activities

Takeshi Doi Application Laboratory JAMSTEC
Yokohama, Japan. takeshi.doi@jamstec.go.jp

ABSTRACT

Skillful seasonal climate prediction is crucial to sustainable well-being of humankind. Successful seasonal prediction, together with an early warning system using the product, could be useful to all stakeholders involved in management of water resources. Identifying potential sources of predictability for seasonal climate is a key not only for climate research, but also for benefit to society.

The SINTEX-F climate model was developed within the EU-Japan collaborative framework to study global climate variations and predictions by use of the supercomputer “Earth Simulator” at JAMSTEC. We have been conducting seasonal predictions every month using the system and providing a real-time outlook of seasonal to interannual climate prediction on our website. It has demonstrated its outstanding performance of predicting El Niño/Southern Oscillation and the Indian Ocean Dipole. For recent example, the system successfully predicted a positive super Indian Ocean Dipole event in 2019 and the following warm winter in East Asia.

In addition, as application studies of the seasonal climate prediction, we have developed a Malaria prediction system in South Africa and a worldwide crop predication system based on SINTEX-F seasonal prediction system.

Keywords—Sesonal prediction, Indian Ocean Dipole, Malaria Prediction, Crop Prediction

1. INTRODUCTION

Almost 15 years ago, we have developed the SINTEX-F1 ocean-atmosphere coupled general circulation model under the EU-Japan research collaboration. Based on this seasonal prediction system ("F1", Luo et al. 2005). We have performed climate predictions 2 year ahead and distributed the Prediction information on JAMSTEC website since 2005 (http://www.jamstec.go.jp/aplinfo/sintexf/e/seasonal/outlook.html). As predictability is the ultimate test of scientific theory, routinely using these quasi-real time climate-forecast informed frameworks can also improve understanding of climate dynamics (e.g. Tommasi et al. 2017). Actually, the JAMSTEC/APL have achieved great successes in these years and the SINTEX-F1 has become one of the leading models of the world for predicting the tropical climate variations in particular the Indian Ocean Dipole, the El Niño/Southern Oscillation (ENSO) and the ENSO Modoki. Since a 2 year-lead time retrospective forecast is beyond most of current operational capabilities, a skill assessment of the model results could be conducted as a first attempt for some studies. For example, Doi et al. (2020a) found a new skillful prediction region of sea level anomaly in the North Pacific about 2 years lead.

To improve prediction of extratropical climate, an upgraded CGCM called SINTEX-F2 has been developed; the new system is a high-resolution version of the previous model added with a dynamical sea-ice model ("F2", Doi et al. 2016). For the tropical climate variations in the Pacific and the Indian Ocean, the SINTEX-F2 preserves the high-prediction skill, and sometimes even shows higher skill especially for strong events, as compared to the SINTEX-F1. In addition, it has turned out that the new system is more skillful in predicting the subtropics, particularly, the Indian Ocean Subtropical Dipole and the Ningaloo Niño.

The SINTEX-F1/F2 seasonal prediction systems adopt a relatively simple initialization scheme based on nudging only the sea surface temperature (SST). However, it is to be expected that the system is not sufficient to capture in detail the subsurface oceanic preconditions. Therefore, we have introduced a new three-dimensional variational ocean data assimilation (3DVAR) method that takes three-dimensional observed ocean temperature and salinity into account. This system ("F2-3DVAR", Doi et al. 2017) has successfully improved seasonal predictions in the tropical Indian and Atlantic Oceans. We have started to provide a real time seasonal prediction based on those three systems "SINTEX-F Family" (Doi et al. 2020b). The 12-member system of "F2-3DVAR" has recently been upgraded to a bigger ensemble system of 108 members using the Lagged Average Forecasting (LAF) method (Doi et al., 2019a). Observing System Experiments (OSEs); a certain observation-type is withheld from, or added to, the regularly assimilated data to evaluate existing ocean observations for seasonal prediction, are also possible at the "F2-3DVAR" system (Doi et al. 2019b).

Here, I present a brief review of my recent works with the SINTEX-F systems.

2. Methodology

We have conducted the reforecasting experiments with a 12-month lead-time with the "SINTEX-F Family", starting from the first day of each month from January 1983 to the present. The prediction anomalies were determined by removing the model mean climatology a posteriori at each lead-time using the reforecast outputs over the period 1983-2015. The outputs were used for Section 3.1. In addition, we conducted the prediction runs with a four-month lead-time from the nine initialized dates (1st–9th) in Octobers of 1983–2019 based on the 108-members prediction system. The outputs were used for Section 3.2. We note that the large ensemble may capture seasonal predictable signals, particularly in the mid-latitudes where the signal-to-noise ratio is relatively low.

In Section 3.1 and 3.2, we used analysis of inter-member co-variability. Anomalies among the ensemble members (defined as deviations from the ensemble mean) may provide useful insights into possible precursors and teleconnection patterns related to a climate event. We calculated the inter-ensemble correlation: correlation coefficient in the ensemble space between a target index and a horizontal map of a variable for each grid point among the individual members of ensemble prediction in a particular month. In this analysis, the conventional time dimension was replaced by the ensemble dimension. For the present purpose, the ensemble prediction system with 108-member has an advantage in finding possible teleconnection patterns influencing the mid-latitude climate with the large stochastic internal variability.

3. RESULTS

3.1 El Niño Modoki in the tropical Pacific Ocean was key to successfully predicting the 2019 Super Indian Ocean Dipole phenomenon

We showed that the El Niño Modoki phenomenon in the tropical Pacific Ocean played a critical role in successfully predicting the extremely strong positive Indian Ocean Dipole (IOD) that occurred in 2019.

IOD is a climate variation phenomenon that is observed in the tropical Indian Ocean once every several years from summer to autumn. This phenomenon has both positive and negative phases. When a positive Indian Ocean Dipole occurs, sea surface temperatures become cooler than in an average year on the southeastern side of the tropical Indian Ocean and warmer than in an average year on the western side. These variations in ocean temperatures cause vigorous convection that usually occurs in the eastern Indian Ocean to move westward; east Africa receives more rain, while Indonesia receives less. These variations also tend to result in less rain and higher temperatures in Japan. Conversely, when a negative Indian Ocean Dipole occurs, sea surface temperatures are warmer than in an average year in the southeastern tropical Indian Ocean and colder than in an average year in the west, causing convection in the eastern Indian Ocean to be more intense than usual, and more rain falls in Indonesia and Australia, and there is generally more rain and temperatures are lower in Japan. For these reasons, accurately predicting the occurrence of such phenomena is important not only from a scientific perspective, but from a socioeconomic one as well. However, it is extremely difficult to predict IOD phenomena, which occur from the summer to autumn, from as early as the previous autumn and across the winter season.

We distributed monthly quasi-real-time IOD prediction data up to 12 months in advance, based on the numerical prediction system "SINTEX-F", which uses the "Earth Simulator" supercomputer (URL: http://www.jamstec.go.jp/aplinfo/sintexf/e/seasonal/outlook.html). While the current predictive accuracy of simulations conducted from the previous autumn remain low, the 2019 prediction of the strong IOD was accurate (Figure 1). Upon further investigation, it was found that the occurrence of the El Niño Modoki phenomenon in the tropical Pacific Ocean was a key factor that controlled the accuracy in this prediction. The results of this study are expected to advance our understanding of the mutual relationships between the IOD and El Niño Modoki phenomena, as well as the development of agricultural and infectious disease research based on related predictive data.

This study was published as Doi et al (2020b).

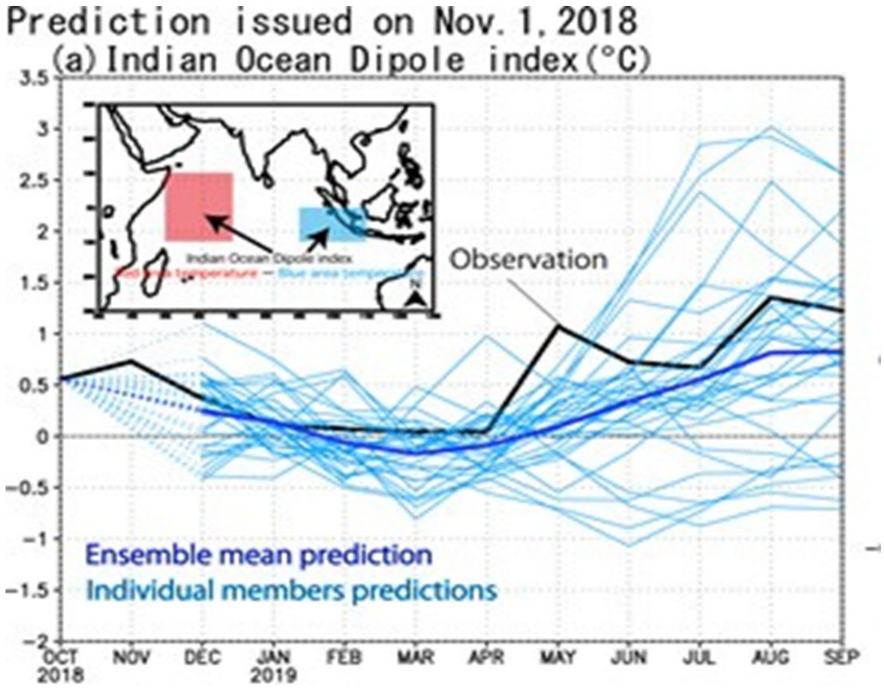


Figure 1: Indian Ocean Dipole index. The black line is the observed value and colored lines are the predictions made on November 1, 2018 (light blue lines: predicted values of each ensemble member; dark blue lines: averaged value of the ensemble members). The trajectories of the dark blue line and the black line are very similar, and the prediction is thought to have been broadly successful. From the light blue lines, it can be seen that there is variation between the ensemble members, with some overestimating and others underestimating the occurrence of a dipole event.

3.2 Wintertime impacts of the 2019 super IOD on East Asia

Many parts of East Asia, including Japan, experienced extremely warm conditions during the 2019–2020 winter. Warm SST anomalies associated with the super Indian Ocean Dipole in 2019 persisted even through the winter. Prolonged active convection over the western pole of the Indian Ocean Dipole may explain the unusual winter.

Doi et al. (2020c) showed that the 2019–2020 East Asian warm winter was successfully predicted in October of 2019 by the 108-member ensemble seasonal prediction system based on the SINTEX-F climate model (Figure 2). By analyzing co-variability of inter-member anomalies defined as deviations from the ensemble mean, we have found that the active convection over the western pole of the Indian Ocean Dipole caused these unusual conditions over East Asia by generating the meander of the subtropical jet. The ensemble prediction system with 108-member may have an advantage in finding such kind of the teleconnection influencing the mid-latitude climate with the large stochastic internal variability. Successful prediction of the teleconnection of such a super event may contribute to reducing the risks of socio-economic losses under suitable measures for adaptation and mitigation.

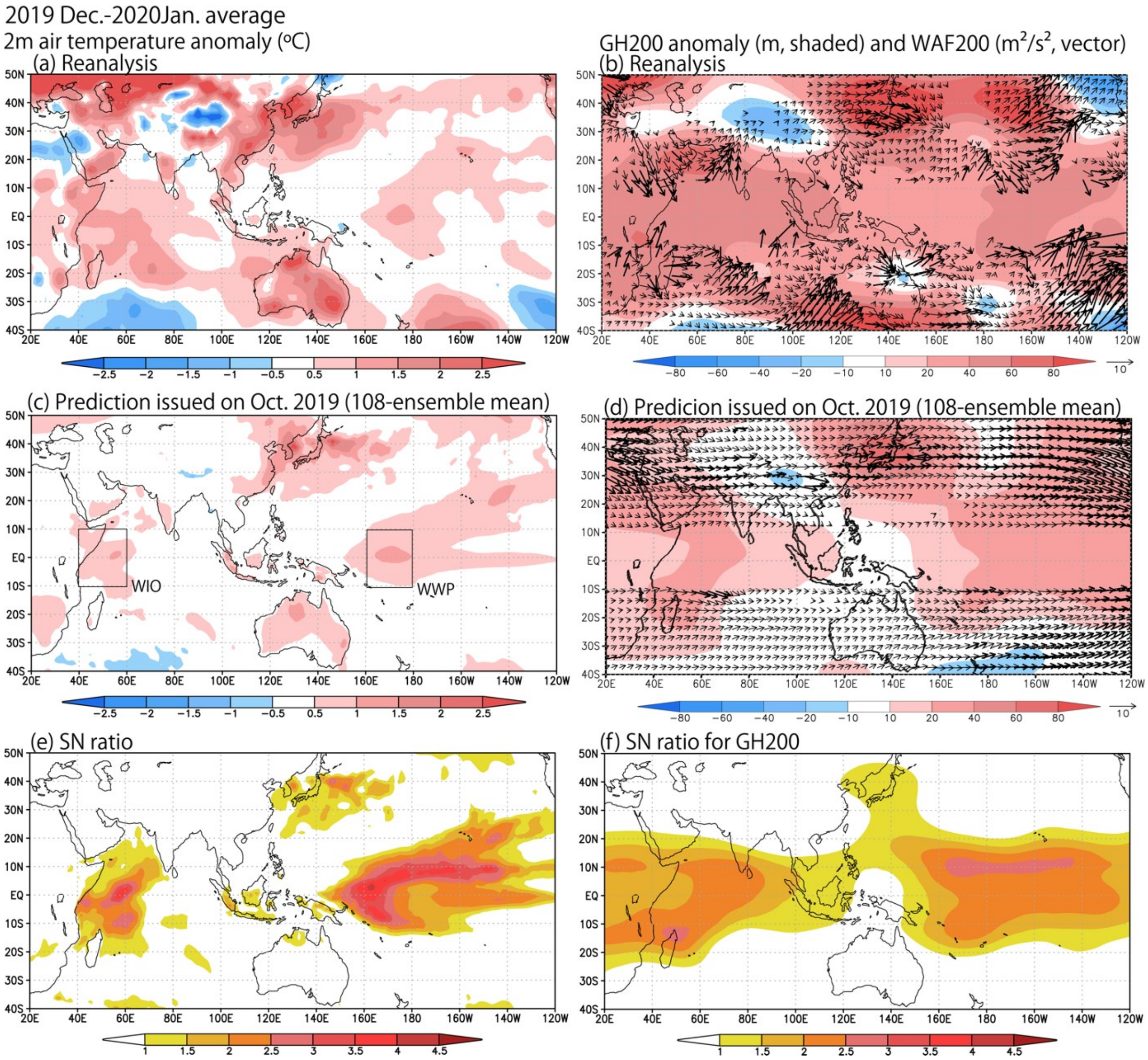


Figure 2. (a) 2m air temperature anomaly (ºC) from the NCEP/NCAR reanalysis data averaged in December 2019–January 2020. (b) Same as (a), but for the geopotential height anomaly (m; shaded) and the wave activity flux (m2s-2; vector) at 200hPa. For the wave activity flux, values above 5.0 (1.0) m2s-2 are shown by thick (thin) arrows, except for the tropics (10ºS-10ºN). (c) Same as (a), but for the prediction issued on early October 2019 (108-ensemble mean). Two regions are shown by boxes (WIO: 40ºE-60ºE, 10ºS-10ºN; WWP: 160ºE-180ºE, 10ºS-10ºN). (d) Same as (b), but for the prediction issued on early October 2019 (108-ensemble mean). (e) Signal-to-noise (SN) ratio for prediction of 2m air temperature anomaly in December 2019–January 2020 issued on early October: the ensemble mean values divided by the ensemble spread. (d) Same as (c), but for geopotential height at 200hPa.

3.3 Malaria predictions in South Africa based on our seasonal climate forecasts: A time series distributed lag nonlinear model

We developed a malaria prediction model taking into account nonlinear and delayed complexities of the malaria–climate dynamics (Kim et al. 2019). The prediction model showed good performance at the short-term lead time, and the prediction accuracy decreased as the lead time increased but retained fairly good performance. We also demonstrated the weekly-updated malaria prediction process based on seasonal climate forecasts and found that the malaria predictions for short-term lead time coincided closely with the observed malaria cases (Figure 3). The malaria prediction model we developed is promising because it is feasibly applicable in practice together with the skillful seasonal climate forecasts and existing malaria surveillance system in South Africa. Establishing an automated operating system based on real-time data inputs could potentially be beneficial for the malaria early warning system in Limpopo, South Africa, and can be an instructive example for other malaria-endemic areas.

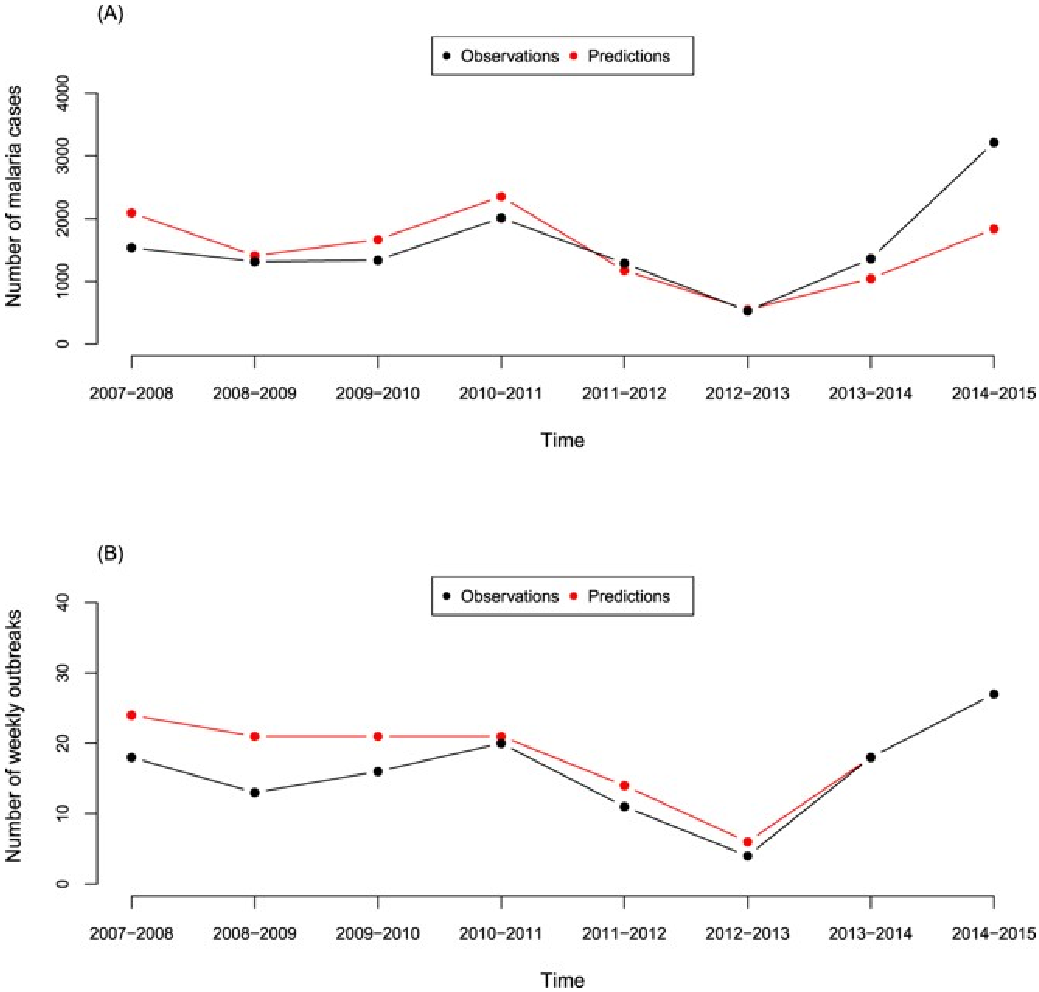


Figure 3: Cumulative annual number of malaria incidence and malaria outbreaks, defined by the 40th percentile of the past moving 5-years malaria cases during the endemic season (September–May), for the 2-weeks-ahead lead time (red, predictions; black, observations) in the demonstration of the weekly-updated malaria prediction process based on SINTEX-F seasonal climate forecasts.

3.4 Seasonal predictability of four major crop yields worldwide by a hybrid system of dynamical climate prediction and eco-physiological crop-growth simulation

Doi et al. (2020d) evaluated the prediction accuracy of a newly developed crop yield prediction system, composed of SINTEX-F2 and an eco-physiological process-based crop growth model (PRYSBI2). We explored the 3-month lead prediction accuracy of year-to-year variations in yield of four major crops (maize, rice, wheat, and soybean) in global regions and evaluated for which crops and in which areas the system performs well. The results indicated the system is more accurate for wheat relative to the other crops (Figure 4). Also, we found that different strategies would be useful in improving the system, depending on the crop. For winter wheat and rice, we need to improve the temperature predictions, particularly over the mid-latitudes, whereas improving rainfall predictions was more important for maize. For spring wheat and soybeans, the crop growth simulation itself should be improved. Although this study is only a first step, we believe that additional efforts to improve the system by understanding and incorporating processes of climate and crop growth will potentially provide useful prediction information to big stakeholders like global agribusiness companies and countries for improving food security in regions where crop yield is vulnerable to extreme climate shocks and where food markets are isolated from international trade.

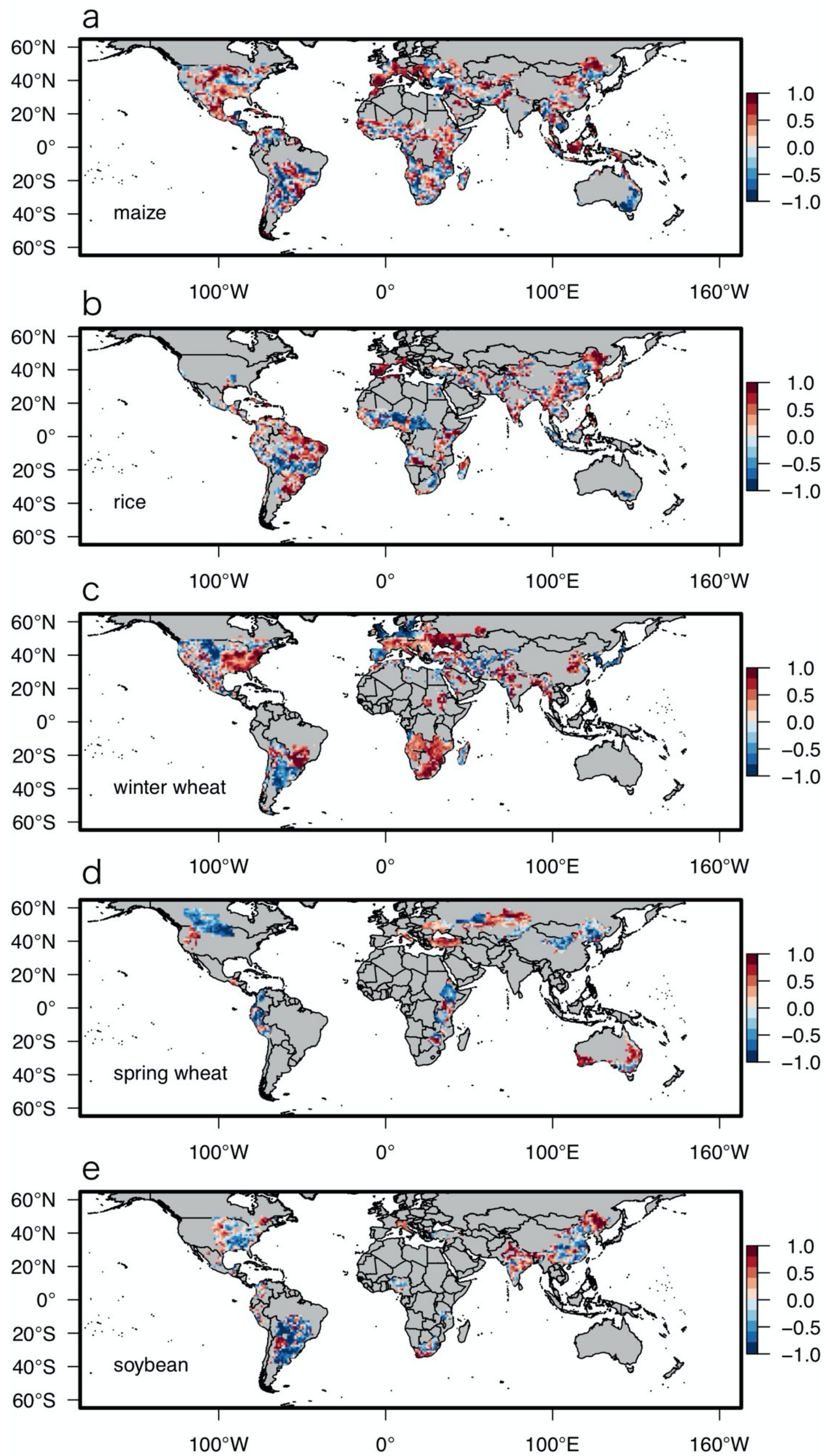


Figure 4. Horizontal distributions of ACC accuracy scores for a three-month lead prediction of year-to-year variations in yields of (a) maize, (b) rice, (c) winter wheat, (d) spring wheat, and (e) soybean. Gray indicates non-growing areas for the respective crops.

4. Conclusions

The SINTEX-F climate model was developed within the EU-Japan collaborative framework to study global climate variations and predictions. It has demonstrated its outstanding performance of predicting El Niño/Southern Oscillation and the Indian Ocean Dipole, which can work as main potential sources of seasonal climate predictability of precipitation as well as temperature over many parts of the tropical and subtropical regions. Recently, the system successfully predicted co-occurrence of a positive Indian Ocean Dipole event and an El Niño-Modoki event in 2019 and the following warm winter in East Asia. The successes are partly due to the large ensemble members with the SINTEX-F system. In addition, we have started application studies of the seasonal climate prediction, for example, a Malaria prediction system in South Africa and a worldwide crop predication system based on SINTEX- F seasonal prediction system. I hope that those studies will help stakeholders interpret limits as well as potential of seasonal climate predictions for possible societal applications.

REFERENCES

1) Luo, J.–J., Masson S., Behera S., Shingu, S. and Yamagata T. (2009), Seasonal climate predictability in a coupled OAGCM using a different approach for ensemble forecasts, Journal of Climate, Vol. 18. 4474-4494.
2) Tommasi, D., Stock C., Hobday A., Methot R., Kaplan I., et al.. (2017), Managing living marine resources in a dynamic environment: The role of seasonal to decadal climate forecasts. Progress in Oceanography, 152, 15-49.
3) Doi, T., Nonaka T. and Behera S. (2020a), Skill Assessment of Seasonal-to-Interannual Prediction of Sea Level Anomaly in the North Pacific Based on the SINTEX-F Climate Model, Frontiers in Marine Science, Vol. 7. Doi:10.3389/fmars.2020.546587
4) Doi, T., Behera S. and Yamagata T. (2016), Improved seasonal prediction using the SINTEX-F2 coupled model, Journal of Advances in Modeling Earth Systems, Vol. 8. 1847-1867.
5) Doi, T., Storto A., Behera S., A. Navarra and Yamagata T. (2017), Improved prediction of the Indian Ocean Dipole Mode by use of subsurface ocean observations, Journal of Climate, Vol. 30. 7953-7970.
6) Doi, T., Behera S. and Yamagata T. (2020b), Predictability of the super IOD event in 2019 and its link with El Nin Modoki, Geophysical Research Letters, Vol. 47. e2019GL086713.
7) Doi, T., Behera S. and Yamagata T. (2019a), Merits of a 108-member ensemble system in ENSO and IOD predictions, Journal of Climate, Vol. 32. 957-972.
8) Doi, T., Storto A., Fukuoka T., Suganuma H. and Sato K. (2019b), Impacts of temperature measurements from sea turtles on seasonal prediction around the Arafura Sea, Frontiers in Marine Science, Vol. 6. Doi:10.3389/fmars.2019.00719
9) Doi, T., Behera S. and Yamagata T. (2020c), Wintertime Impacts of the 2019 Super IOD on East Asia, Geophysical Research Letters, Vol. 47. e2020GL089456.
10) Kim, Y., and Coauthors (2019), Malaria predictions based on seasonal climate forecasts in South Africa: A time series distributed lag nonlinear model, Scientific Reports, Article No. 17882
11) Doi, T., Sakurai G., and Iizumi T. (2020d), Seasonal predictability of four major crop yields worldwide by a hybrid system of dynamical climate prediction and eco-physiological crop-growth simulation, Frontiers in Sustainable Food Systems, Vol. 4. Doi:10.3389/fsufs.2020.000

TB-203S

Reducing Irrigation water requirements of the Chao Chet - Bang Yihon Operation and Maintenance Project by Defining New Cropping Calendar based on Time Series NDVI.

Manatchanok Pannak
Department of Irrigation Engineering, Kasetsart University, Nakhon Pathom, 73140, Thailand.
Bureau of Project Management, Royal Irrigation Department, Bangkok 10300, Thailand
manatchanok.p@ku.th

Thundorn Okwala
Department of Irrigation Engineering, Kasetsart University, Nakhon Pathom, 73140, Thailand.
fengtdo@ku.ac.th

Chuphan Chompuchan
Department of Irrigation Engineering, Kasetsart University, Nakhon Pathom, 73140, Thailand.
fengcpcc@ku.ac.th

ABSTRACT

The Chao Chet - Bang Yihon operation and maintenance project (CCBY) is low-laying and frequently flooded. During the flood season of 2017-2018, the CCBY project area was planned to be used as flood detention to mitigate the violence of floods in the lower Chao Phraya basin. Therefore, the cropping calendar was required to shift the in-season rice cultivation ahead of schedule in May and complete harvesting before mid-September. Paddy fields in the CCBY project were reserved as flood detention areas from mid-September to mid-December. After the flood had been drained, the off-season rice could be cultivated.

This study proposed the new cropping calendar based on the historical rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite. The Reservoir Operation Study (ROS) is a water requirement calculation developed under Royal Irrigation Department (RID) guidelines. The new cropping calendar was applied to ROS to calculate the water requirement. In addition, land preparation water for the off-season rice cultivation had been excluded by assuming that the farmers could take advantage of the remaining floodwater.

The new cropping calendar illustrates that the in-season and off-season rice cultivation should be started in mid-April and mid-December, respectively. The total irrigation water requirements could be saved about 185.05 MCM (11.01%) and 117.98 MCM (8.54%) in 2017 and 2018. This study will benefit the RID for water delivery planning in lowland areas.

Keywords: Low-laying area, NDVI, Water requirement, Cropping calendar

---

1.Introduction

Due to the unprecedented flood catastrophe in 2011, Thailand is considered vulnerable to future climate change impacts over the next 30 years, which urgently require countermeasure plans for flood prevention, flood mitigation, and flood adaptation (1). There are several flood adaptation strategies for farmers to change their cultivation practices, such as changing cropping calendars, changing crop varieties, and changes in the area for cultivation (2). Shifting the planting date could be a low-cost adaptation strategy that is likely more effective for large-scale implementation in a changing climate (3)(4).

Generally, Royal Irrigation Department (RID) has an irrigation water allocation plan of in-season cultivation according to the cropping calendar in May – October. However, Chao Chet - Bang Yihon operation and maintenance project (CCBY), mostly lowland paddy fields, was limited to cultivation due to repeated flooding during September – November. Under the traditional RID's cropping calendar, paddy fields are particularly vulnerable to flooding in the pre-harvest in-season rice cultivation. In 2017-2018, RID announced the flood prevention and mitigation strategy plan by applying the low-laying areas over the Lower Part of the Chao Phraya River Basin as flood detention areas. Therefore, farmers were suggested to bring forward the in-season rice cultivation and complete the harvest before mid-Sep. Moreover, farmers can take advantage of the remaining floodwater for land preparation for off-season rice cultivation.

Regarding cropping calendar adjustment, the land preparation and sowing date change are the most important since all the remaining agricultural activities depend on it (5). Also, the shift of the cropping calendar certainly affects irrigation water requirements calculation. This study aimed to compare water demand in the CCBY using the traditional RID's cropping calendar and the actual rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite. The results of this study could be used as an alternative water allocation planning to cope with flood risk.

2. Material and methods

2.1 Study Areas

Chao Chet - Bang Yihon operation and maintenance project locates between the west bank area of the Chao Phraya River and the east bank area of Tha Chin River (Fig. 1.). The CCBY project is controlled by Regional Irrigation Office 11 (RIO.11). The total irrigated area of the CCBY project is 65,000 ha, 80% of the area (approximately 56,000 ha) is rice paddy fields. The main type of rice is photo-insensitive, medium tillering varieties. In a normal year, RIO.11 has established an irrigation water allocation plan from 1st May to 30th October for the wet season and from 1st November to 30th April for the dry season.

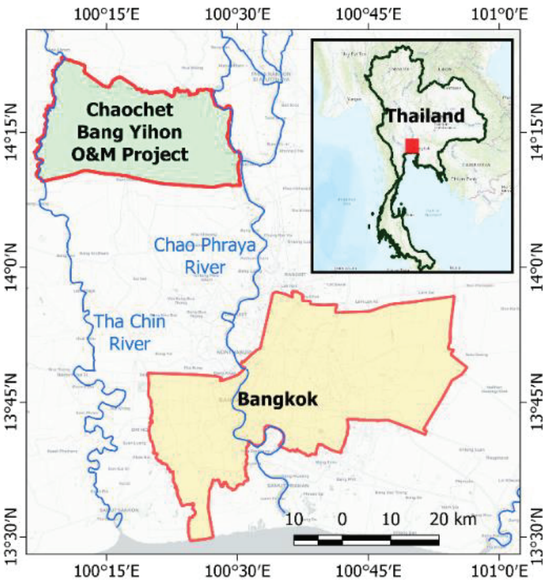


Fig. 1. Location map of the study area.

The CCBY is a low-laying and regularly reserved as a flood detention area to prevent urban flooding downstream of the Chao Phraya River. Flood volumes are recurrently stored from mid-September to mid-December. In 2017-2018, the Ministry of Agriculture and Cooperatives (MOAC) announced a policy to setting flood detention areas in the Lower Chao Phraya Basin, and commandment integrated various government agencies to support farmers. RIO.11 is necessary to reschedule the water allocation plan to ensure enough irrigation water for farmlands during the shifted cropping calendar. The 2017-18 cropping calendar was assigned wet season from 1st May to 15th September and dry season from 15th December to 30th April. During the flood detention period (15th September to 15th December), most of the paddy fields in the CCBY were inundated and could not cultivate, as shown in Fig. 2. Flood detention areas could be utilized as temporary aquaculture. The Number of fish supported by the Department of Fisheries was released in flood detention areas to maintain the farmer's income.

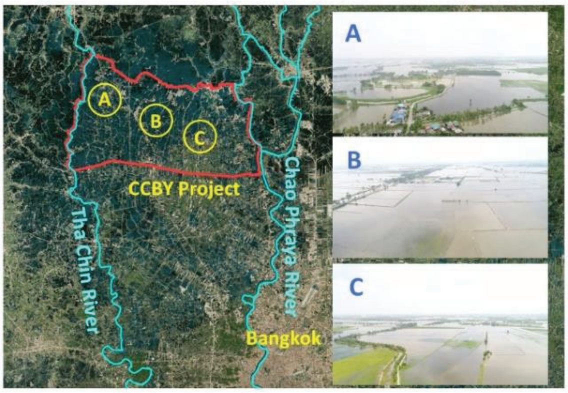


Fig. 2. Flooding on 8th October 2017.
(A) Bang Pla Ma District, Suphan Buri Province
(B) Bang Sai District, Ayutthaya Province
(C) Sena District, Ayutthaya Province

2.2 Methods

The flowchart of this study has shown in Fig. 3. Reservoir Operation Study (ROS) calculation sheet was used to determine the irrigation water requirements of the CCBY project on 2017-18. Two cropping calendars were compared, i.e., the traditional cropping calendar assigned from RIO.11 and the actual cropping calendar retrieved from historical time series NDVI from Terra/MODIS satellite data.

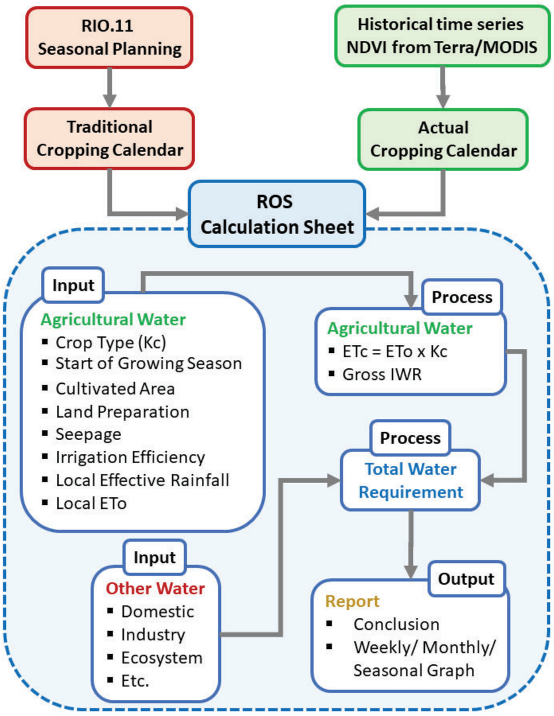


Fig. 3. Flowchart of the study.

2.2.1 Time series NDVI data

Terra/MODIS 8-day composite products (MOD09Q1) at 500m resolution were downloaded from United States Geological Survey (USGS) Earth Explorer (URL http://earthexplorer.usgs.gov/). Each scene, Band 1 (red band, 620-670 nm) and band 2 (near-infrared band, 841-876 nm), were selected to calculate Normalized Difference Vegetation Index (NDVI), which is defined as follow:

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}}} \quad (1)$$

Where ρ_{RED} and ρ_{NIR} are the surface reflectance of visible red (RED) and near-infrared (NIR) bands, respectively, the range of NDVI values is between -1 to 1. In general, high values of NDVI (0.6 - 0.8) indicate a dense green vegetation canopy. Low values of NDVI (near zero) characterize bare area or urban area, whereas negative values of NDVI mainly correspond to water and cloud.

2.2.2 Reservoir Operation Study (ROS)

Reservoir Operation Study (ROS) is a Microsoft Excel sheet to calculate irrigation water requirements (6). RID developed this program for water allocation planning of the irrigation schemes. The main processes of the ROS irrigation water requirements calculation are as follow.

1) Select the provincial area of the irrigation scheme to set reference crop evapotranspiration (ET_o) and effective rainfall (R_e).
2) Select crop type to set crop coefficient (K_c).
3) Input cropping pattern, cultivated area, water depth of land preparation and seepage, irrigation efficiency
4) Input the volume of water for other activities, including domestic consumption, industry, and ecosystem conservation.

The actual cropping calendar obtained from the time series NDVI was used to determine the cropping pattern as a substitute for RIO.11's cropping pattern. In 2017 and 2018, in-season rice areas were expected to be 56,000 ha and 53,216 ha, whereas off-season rice areas were expected to be 53,083 ha and 39,859 ha. An irrigation efficiency of 45% was used. Land preparation and seepage of 240 mm week^{-1} and 7 mm week^{-1} were assigned. The gross irrigation water requirements (W_g) (equation 2-4) could be estimated (7).

$$W_g = \frac{W_n}{E_i} \quad (2)$$

$$W_n = ET_c - R_e \quad (3)$$

$$ET_c = K_c \times ET_o \quad (4)$$

Where W_n is the net water application, E_i is the irrigation efficiency that considers the water lost during the diversion from the canal to the field, ET_c is the crop evapotranspiration (mm day^{-1}) which depends on the growing stage of the crop and is used to quantify crop water requirement, R_e is the effective rainfall (mm day^{-1}), K_c is the crop coefficient representing important parameters for irrigation scheduling and water allocation, and ET_o is the reference evapotranspiration (mm day^{-1}).

In this study, ET_o was calculated using the Penman-Monteith method. K_c values were obtained from RID's crop coefficient database. Effective rainfall was calculated using the weighted rainfall method from RID, as shown in Table 1.

TABLE 1 Effective rainfall for rice (RID method)

Rainfall (mm.)	Effective Rainfall (mm.)
0-10	0
11-100	Rainfall x 0.80
101-200	Rainfall x 0.70
201-250	Rainfall x 0.60
251-300	Rainfall x 0.55
301-up	Rainfall x 0.50

3.Results and discussion

Fig.4. shows the average NDVI obtained from Terra/MODIS satellite during 2012 -2019. The graph reveals that the in-season rice cultivation starts on April – September and the off-season rice cultivation starts on December – April. The flood detention period always occurs from September – December. The maps in Fig.5. show the changes in the distribution of NDVI during the dry season of 2016-2017. According to a study by Huang et al. (2012), NDVI of 0.15 is a threshold value between vegetation and water surface area (8). Therefore, an NDVI value of less than 0.15 is defined as the water surface area. The NDVI map on 1st November and 11th December 2016 shows that some parts of the CCBY still was inundated. After that, on 17th January and 18th February 2017, the rice fields in the CCBY were cultivated. However, NDVI maps exposed that rice is not planted simultaneously. NDVI values on the eastern area were higher than that of the western area, which could be interpreted as the flooding on the eastern area could be drained before the western area.

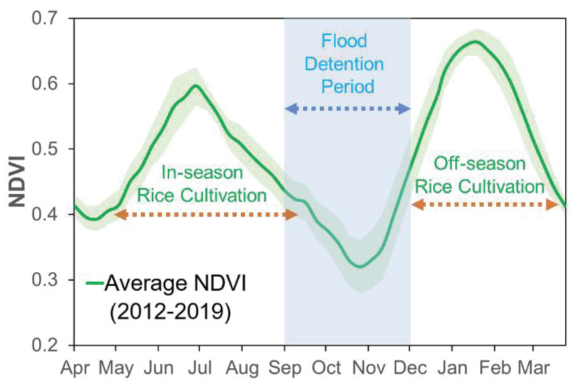


Fig.4. Average NDVI obtained from Terra/MODIS satellite during 2012-1019.

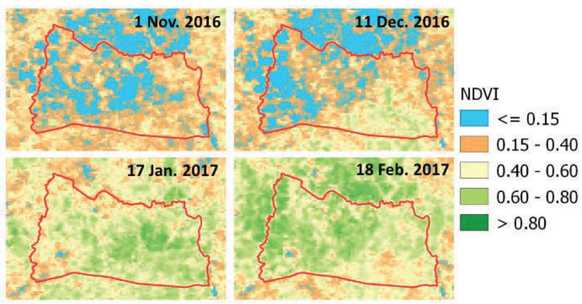


Fig. 5. NDVI maps of the CCBY during the dry season of 2016/17.

Fig. 6. shows the comparison of irrigation water requirements (IWR) for rice cultivation. The IWR based on the traditional cropping calendar of RIO.11 was shown in the red dash line, whereas IWR based on historical NDVI was shown in the green line. During the flood detention period, both methods have not estimated IWR. The graph illustrated that the flood detention period of NDVI retrieving is more extended than that of RIO.11 planning. In addition, the off-season rice cultivation of the NDVI method has been shortened than that of the RIO.11 method. The RIO.11 method planned the start of the in-season rice cultivation on 9-15 May, whereas the historical NDVI detected the start of the in-season rice cultivation on 4-10 April. It could be explained that the farmers in the CCBY have been adapting to avoid flood damage by shifting their cropping calendar for several years. Therefore, the policy of shifting the cropping calendar in 2017-18 is not well-matched with an identical pattern according to the historical NDVI.

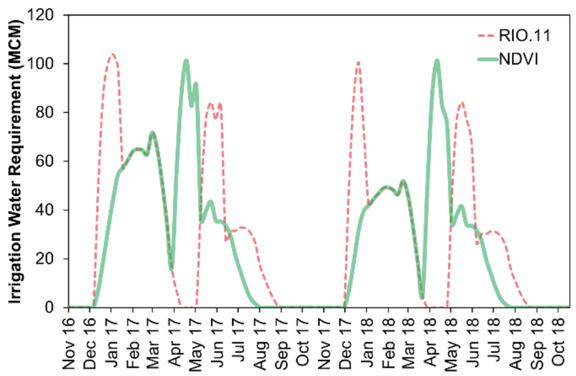


Fig. 6. Weekly irrigation water requirements of the CCBY during 2017- 2018.

Furthermore, RIO.11 method still required the water for land preparation for both seasons. Farmers can use the inundation water as land preparation water for off-season rice cultivation. Thus, for the NDVI method, land preparation water had been excluded by assuming that the farmers could take advantage of the remaining floodwater. As a result, the IWR of the NDVI method was less than that of the RIO.11 method at the beginning of the growing season in December (Fig. 6.). According to the gross IWR calculation in 2017 and 2018 (Table 2), the results from ROS have shown that the gross IWR for off-season rice cultivation decreased from 1,060.56 MCM to 777.45 MCM in 2017 and decreased from 792.50 MCM to 579.92 MCM in 2018. On the other hand, the gross IWR for in-season rice cultivation of the NDVI method was higher than the RIO.11 method because of early start cultivation in April. In general, the rainy season in central Thailand starts around mid-May. Therefore, starting rice cultivation in April may require more irrigation water due to less effective rainfall.

TABLE 2 Gross irrigation water requirements of the CCBY

Year	**Season**	**Gross IWR (MCM)**	
		RIO.11	**NDVI**
2017	Off-season rice	1,060.56	777.45
	In-season rice	619.18	717.19
	Total	1,679.69	1,494.64
	Difference	**185.05 (11.01%)**	
2018	Off-season rice	792.50	579.92
	In-season rice	589.66	684.26
	Total	1,382.16	1,264.18
	Difference	**117.98 (8.54%)**	

Since the physical characteristics of the CCBY are lowland and frequent flooding, flood mitigation and adaptation practices were necessary. There are various flood adaption methods for agricultural farmland in the flooded area, including engineering and non-engineering options. The most widely adopted adaptation practices include altering the timing of planting or adjustment in the cropping calendar to avoid flood season (10-11). The shifted rice cropping pattern derived from the time series NDVI indicated that farmers had an autonomous adaptation to flooding before the Ministry of Agriculture and Cooperative policy was promulgated. To enhance resilience to flooding, the shifted rice cropping calendar for the wet year should be modified according to the results of this study. In addition, floodwater during the benefit period is valuable for preparing the land to cultivate rice (12). Thus, land preparation water should not be taken into account in the gross IWR calculation after the flood detention period.

The study results could be used as an alternative water allocation planning to cope with flood risk. However, changing the cropping calendar is suggested to photo-insensitive rice varieties only due to the constant crop duration and not affecting irrigation water requirements. Also, RID should further consider saving off-season land preparation water for flood detention areas and ensuring sufficient irrigation water for the subsequent in-season cultivation.

4.Conclusion

This study proposed a new crop calendar based on the historical rice cropping pattern derived from the time series NDVI of the Terra/MODIS satellite during 2017 -2018 to calculate irrigation water requirements in the Chao Chet - Bang Yihon Operation and Maintenance Project using Reservoir Operation Study (ROS). The results revealed that the appropriate starting date of growing rice in the wet and dry season should be 4-10 April and 13-19 December, respectively. Due to the long flood period, irrigation water requirements in the dry season could be reduced because farmers can take advantage of the remaining floodwater for land preparation of the off-season rice cultivation. According to the results, it was found that irrigation water could be saved about 185.05 MCM (11.01%) and 117.98 MCM (8.54%) in 2017 and 2018.

5. Acknowledgment

This paper was supported by grant from the Faculty of Engineering at Kamphaeng Saen, Kasetsart University (Kamphaeng Saen Campus) and Agricultural Research Development Agency (Public Organization), Thailand. The authors would also like to express their gratitude to RIO.11 and USGS Earth Explorer for their kind support and providing of data input for analysis in this study.

REFERENCES

(1) Apipattanavis, S., Ketpratoom, S., and Kladkempetch, P. (2018), Water Management in Thailand, Irrigation and Drainage, Vol. 67, No.1, pp. 113-117.
(2) Shrestha, R.P., Raut, N., Swe, L.M.M. and Tieng, T. (2018), Climate Change Adaptation Strategies in Agriculture: Cases from Southeast Asia, Sustainable Agriculture Research, Vol. 7, No.3, pp.39-51.
(3) Farooq, N. and Gheewala, S. (2020), Assessing the Impact of Climate Change on Sugarcane and Adaptation Actions in Pakistan, Acta Geophysica, Vol. 68, pp.1489-1503.
(4) Acharjeea, T.K., van Halsemab, G., Ludwiga, F., Hellegersb, P. and Supit, I. (2019), Shifting Planting Date of Boro Rice as a Climate Change Adaptation Strategy to Reduce Water Use, Agricultural Systems, Vol. 168, pp. 131-143.
(5) Yegbemey, R.N., Kabir, H., Awoye, O.H.R., Yabi, J.A. and Paraïso, A.A. (2014), Managing the Agricultural Calendar as Coping Mechanism to Climate Variability: A Case Study of Maize Farming in Northern Benin, West Africa. Climate Risk Management, Vol. 3, pp.13–23.
(6) Royal Irrigation Department (2011), Work Manual: Allocate Water using Reservoir Operation Study, Royal Irrigation Department, Bangkok.
(7) Royal Irrigation Department (2011), Work Manual: Calculate Effective Rainfall, Royal Irrigation Department, Bangkok.

(8) Huang, S., Li, J., and Xu, M. (2012), Water Surface Variations Monitoring and Food Hazard Analysis in Dongting Lake Area using Long-term Terra/MODIS Data Time Series. Natural Hazards, Vol. 62, No.1, pp. 93-100.
(9) Zhang, Y., Wang, Y., and Niu, H. (2019), Effects of Temperature, Precipitation and Carbon Dioxide Concentrations on the Requirements for Crop Irrigation Water in China under Future Climate Scenarios, Science of the Total Environment, Vol. 656, pp.373-387.
(10) Tambo, J. (2016), Adaptation and Resilience to Climate Change and Variability in North-east Ghana, International Journal of Disaster Risk Reduction, Vol.67, pp.85-94.
(11) Li, H., Hsiao, Y., Chang, C., Chen, Y., and Lin, L. (2021), Agriculture Adaptation Options for Flood Impacts under Climate Change – A Simulation Analysis in the Dajia River Basin, Sustainability, Vol.13, No.13, pp. 7311.
(12) Hassan, S. (2019), Impacts of Flooding on the Rice Production of Bangladesh. Master Thesis, Colorado State University.

TB-205L

WEEKLY GROUNDWATER PUMPAGE ESTIMATION IN UPPER CENTRAL PLAIN THAILAND VIA ARTIFICIAL NEURAL TECHNIQUE

Tran Thanh Long[1,2*], Chokchai Suthidhummajita[3] and Sucharit Koontanakulvong[3]

Abstract. Under the water stress in the recent dry years, the farmers in the Upper Central Plain Basin of Thailand have adapted conjunctive water use to meet high demand from rice cultivation. Conjunctive water management is an optimal tool of groundwater pumping guideline under reservoir water release conditions for sustainable development. However, weekly conjunctive water management operation remains difficult due to the difficulties on estimations of groundwater pumpage and reservoir water storage due to the complex modeling techniques, consuming time, and survey data.
Therefore, this study aims to apply an artificial neural network to improve the estimation of weekly groundwater availability under extreme climate scenarios. First, the weekly pumping pattern was calculated via monthly artificial neural networks through groundwater level, reservoir storage, and rainfall. Second, the weekly groundwater pumping of the Younger Terrace Aquifer was validated through groundwater modeling, obtaining the region's piezometric head. The validation shows good performance when the R^2 is over 0.7 and the RMSE is lower than 1m. Second, the potential groundwater was estimated based on three scenarios under sustainable drawdown criteria: wet year, drought year, and normal year scenarios. Finally, the rainfall, groundwater level, and dam storage data from three climate scenarios were re-trained into the artificial neural network for the weekly available groundwater pumping. As a result, the ANN tool could guide properly the region's available groundwater by utilizing the relatively surface water data, less laborious, and cost-effective.

Keywords: Groundwater pumping estimation, ANN, groundwater yields

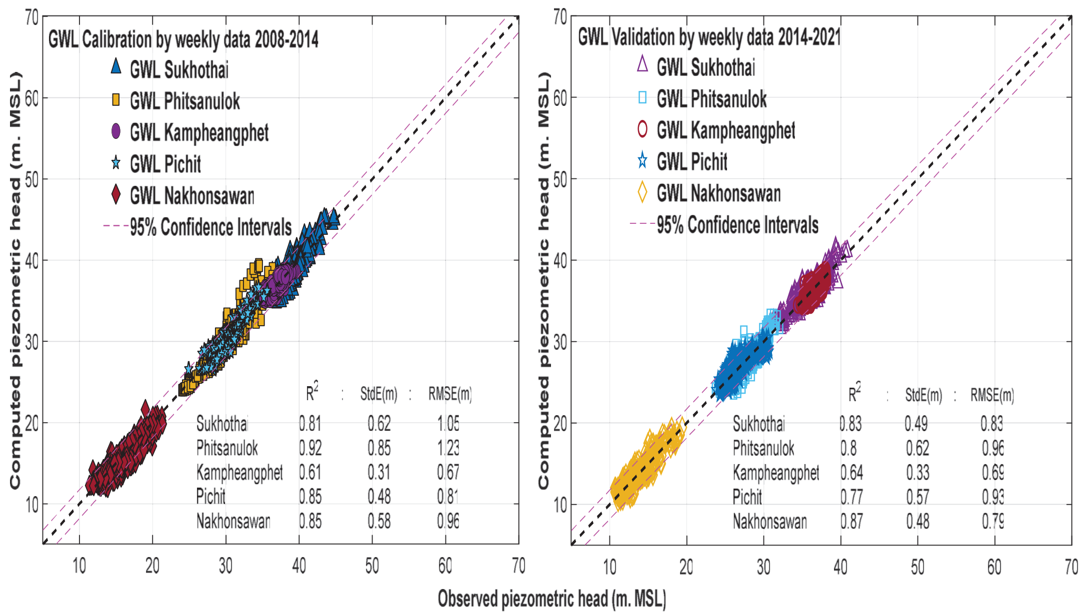


Figure 1. Evalution weekly piezometric head in regional after estiamted weeky groundawter pumping via ANN

[1]Faculty of Civil Engineering, Hochiminh City University of Technology, 268 Ly Thuong Kiet Street, District 10, Ho Chi Minh City, Vietnam
[2]Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam

[2]Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

*E-mail: ttlong@hcmut.edu.vn (Corresponding author)

TB-206L

AN EXTENDED-RANGE WEATHER FORCAST OVER TWO WEEKS USING A COUPLED WRF-ROMS MODEL: A CASE STUDY OF CHAO PHRAYA (CPY) RIVER BASIN

Kritanai Torsri*, Rati Sawangwattanaphaibun, Kanoksri Sarinnapakorn, Surajate Boonya-aroonnet

Hydro-Informatics Innovation Division, Hydro-Informatics Institute (HII),
Ministry of Higher Education, Science, Research and Innovation (MHESI), Bangkok, Thailand

Corresponding E-mail: kritanai@hii.or.th

Abstract- This study is focusing on validating 2-week heavy rainfall events in 2011 to see how well the model can estimate rainfall in the next two weeks over the CPY river basin.

Keywords: 2-week rainfall forecast, Coupled WRF-ROMS, Rainfall prediction, Thailand

1. Introduction

It is acknowledged that, nowadays, short- term weather forecasts (3-7 days in advance) are becoming even more accurate and showing significant skill, but not too perfect. However, looking beyond the first seven days of model prediction, speaking of 14 days or 2 weeks is far more challenging and would yield better benefits for weather forecast and water resources management in Thailand.

2. Methodology

This study is focusing on validating how well a dynamical modeling system can reproduce extreme rainfall over two weeks. In this case, a modeling system called Coupled- Ocean-Atmosphere-Wave-Sediment Transport (COAWST) that was originally developed by the U.S. Geological Survey (USGS) was used [1]. It represents a complex interaction between several components of the Earth System (e.g., atmosphere, ocean, wave, sediment transport, and sea-ice). The prediction skill of the couple modeling system was showed to be reliable over Thailand and, then has been officially operating for 3-7-days weather forecasting at the HII since 2016 [2]. Here, we focus on synoptic to meso-scale weather phenomena, specifically heavy rainfall events with extending period for a 2-week prediction. An atmospheric model (WRF) and a regional oceanic model (ROMS) embedded in the COAWST system were activated for this study by which the models were concurrently coupled for exchanging momentum and heat fluxes.

In 2011, Thailand suffered from severe flooding, mainly due to moisture surplus transported from the Indian Ocean into the region by the southwest monsoon causing above-average rainfall in March and April. Heavy rains continued throughout the summer together with overland flow crossing over the north of the Chao Phraya River basin (CPY) during the rainy season (July to September) due to several tropical storms. The study, therefore, selected two heavy rainfall events that occurred over the CPY during 20-30 June 2011 (EXP-01) and 28 July to 4 Aug 2011 (EXP-02) which were associated with the tropical storms Haima and Nockten, respectively.

For model configurations, two experiments were designed by following the selected heavy rainfall events. Each experiment was setup for a 15-day simulation (one day for model spin- up) with two different lead times (i.e., initialized at 1-week and 2-week before an event occurred) to investigate whether the model can see the upcoming heavy rainfall events in the first and second weeks. To obtain a high spatial resolution of rainfall, double-nested domains were employed for WRF with a horizontal resolution of 25 km and 5 km with 38 vertical levels. To include the impact of SST from Indian Ocean and Pacific Ocean into the model integration, a single domain of ROMS was setup with a horizontal resolution of 25 km and with 16 layers for vertical depths (Figure 1).

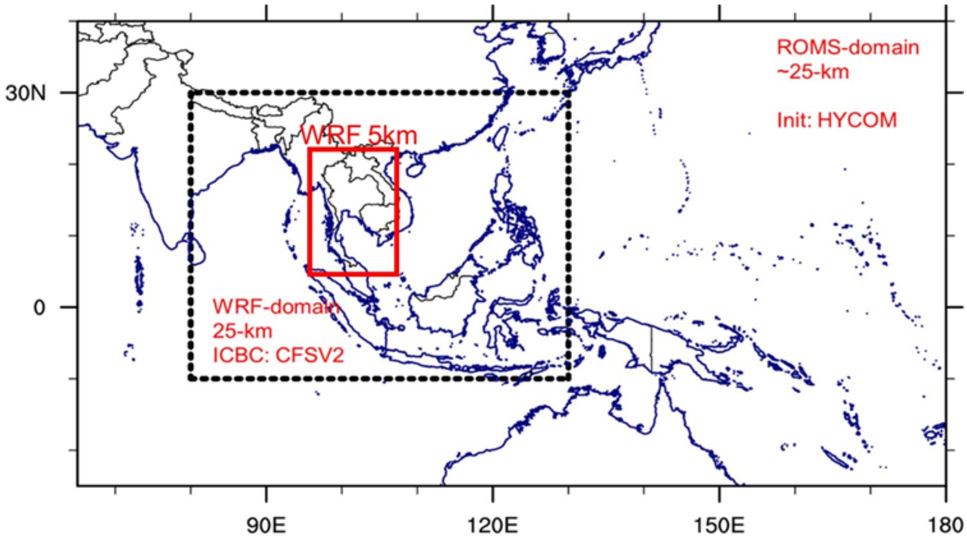


Figure 1 Modeling domains with a 2-nested WRF and a single ROMS domain

For the initial and boundary conditions of WRF, 6-hr NCEP Climate Forecast System (CFS) Reanalysis data was used to update meteorological fields. The simulated net surface heat and momentum fluxes were then transferred to the ROMS model, which in turn, feeds sea surface temperature (SST) information back to WRF model by which the exchanging interval between two models is hourly. In this case, states of the ocean (i.e., SST, salinity, and ocean currents) were initiated by using near-real-time global ocean hindcast (analysis) data provided by the Hybrid Coordinate Ocean Model (HYCOM) and the Navy Coupled Ocean Data Assimilation (NCODA). For statistical analysis, weekly simulated rainfall over the CPY during the selected events were compared with observation considering mean bias (MB) and root mean square error (RMSE).

3. Results and discussion

As a result, the model generally shows reasonable agreement with observation for both week-1 and week-2 in both cases (Figure 2).

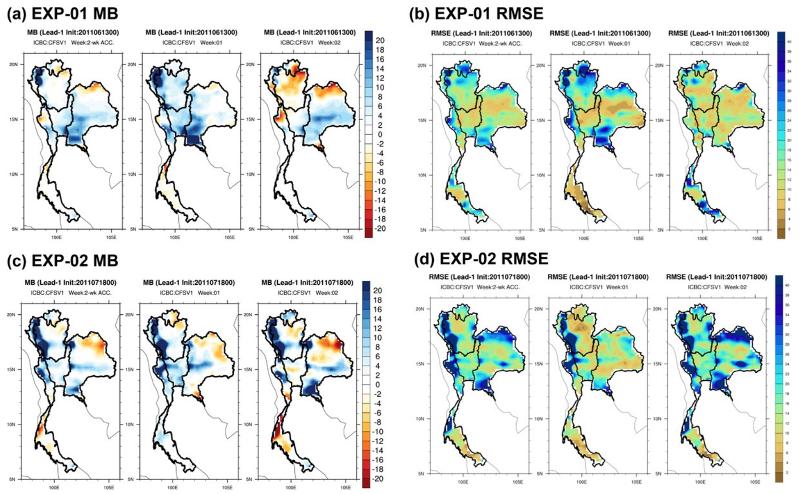


Figure 2 Statistical comparison between observation and prediction (i.e., MB and RMSE) with two different lead-times (week-1 and week-2).

Overall, the simulated rainfall is spatially and temporally varying also depending on case by case. For the EXP-01, at lead-1, two- week simulations yield better results compared to weekly predictions with absolute MB ≤ 6 mm/day and RMSE ≤ 20 mm/day. However, in this case, the model tends to overestimate and underestimate rainfall over the CPY region in week-1 and week-2, respectively. For the EXP-02, lead-1, the model is generally comparable to the observation, but an overestimation of rainfall can also be seen in both weeks with MB up to 20 mm/day and RMSE up to 40 mm/day in the western part of the upper CPY.

4. Conclusions

This study shows an effort in developing a modeling system weather prediction over two weeks, still, there are gaps opened for future research and more challenge for further model development. Currently, the modeling system has also been routinely operating at the HII for 2-week weather forecasting over the CPY basin and available online at https://live1.hii.or.th/product/latest/forecast/rainfall/cpy/wrfroms_cfsv2_cpy.html.

5. Acknowledgement

This work was financially supported by the Thailand Science Research and Innovation (TSRI) (SIP6230012), the National Research Council of Thailand (NRCT), NRCT-TSRI Spearhead Research Program on Water (464042-ODU014).

6. References

[1] Warner, J.C., Armstrong, B., He, R., and Zambon, J.B., 2010, Development of a Coupled Ocean-Atmosphere- Wave-Sediment Transport (COAWST) modeling system: Ocean Modeling, v. 35, no. 3, p. 230-244.

[2] Torsri, K., Wannawong, W., Sarinnapakorn K., Boonya-Aroonnet, S., Chitradon, R., 2014, An Application of Air-Sea Model Components in the Coupled Ocean- Atmosphere-Wave-Sediment Transport (COAWAST) Modeling System Over an Indochina Peninsular Sub- region: Impact of high spatiotemporal SST on WRF model in precipitation prediction, Poster presented at the 11th AOGS, 2014, Sapporo, Japan.

TB-207L

A DEVELOPMENT OF SOIL MOISTURE MONITORING SYSTEM FOR INCREASING IRRIGATION SUPPLY EFFICIENCY APPLIED IN THORTHONGDAENG OPERATION AND MAINTANANCE PROJECT, KAMPHANGPHET, THAILAND.

Panuwat Pinthong*, Supitcha Thaikheaw and Krotsuwan Phosuwan
Center for Water Engineering and Infrastructures Research (CWEIR),
King Mongkut's University of Technology North Bangkok

Keywords: Soil moisture monitoring; Crop water requirement; Irrigation efficiency

Thorthongdaeng Operation and Maintenance Project (TTD) is an irrigation project under Royal irrigation Department (RID) initiated for allocating irrigation water to agriculture land coverage area around 550,000 rai which is the largest area of irrigation project in Thailand. TTD project delivers water supply to each water user group of agricultural area through main canals and sub-main canals by gate controlling. The quantity of water allocation according to weekly crop survey is distributed to each group of water user built on subdistrict area. During Thailand drought crisis, TTD project recently faced with confliction between operators and farmers who always asking for additional irrigation supply for their crops. It consequently causes the difficult in preserving water distribution plan due to inadequate of water supply.

This paper presents system for soil moisture monitoring linked to crop water requirement considering soil moisture capacity at real-time situation. The moisture content monitoring system and model development is used to simulate for determining crop water requirement corresponding to water content status and supply availability. Crops water demand can be calculated using traditionally reference potential evapotranspiration (ETo) factor that gives result in moderate correctness and suitable for conventional purposes. While FAO method which considers soil moisture content in various root zones and in different crop types gives crop demand estimation in more exactness on water need for planting. Thus, this research develops soil moisture monitoring system by applying sensor instrument using Time-domain reflectometry (TDR) method. The Advantage of TDR method is precisely in measuring and commonly used for quantifying soil content in both of laboratory and agricultural land. TDR principle works by transmitting and reflecting signals into the soil to analyze dielectric constant and permittivity as a water content by wave propagation. Developed soil moisture monitoring system utilizes TDR sensor together with microcontroller unit (MCU) to read output as percentage of soil content. The solar energy is connected to battery as power source to receive data from MCU and sent out to cloud server through internet 3G/4G sim card in every 3 hours. It consumes less power and beneficially can remain active status in recording data to server without sunlight continuously up to 3 days.

This study also presents a concept of rearranged irrigated area from subdistrict sectors into water user zone. Water user zone is reorganized depending on farmer’s group who use same irrigation canal in crop cultivation. The position of water content sensor instrument installation is considered as four points in each water user zone to be representative station for observing soil moisture status in areas of upstream, downstream, lowland, and highland. Cropping period is also divided into four groups of all water user zone based on farmer’s cropping behavior comprising of starting period on first of April, first of May, on May 4th and on May 7th. The duration of receiving irrigation water in each group is of 3 to 9 days and rotates to other groups since beginning to the cropping season end.

There are 120 water content sensor stations installed coverage all 20 water user zones. All input parameters in FAO method such as soil type, field capacity and bulk density are investigated in laboratory by collecting soil sample in each sensor station. It is found that mostly TTD’s irrigated area is clay soil and field capacity is between 16.4% to 48.5% by volume consistency with bulk density that is 1.0 to 1.67 g/cm^3.

Crop water requirement is modeled in various root zones depth and crop types by considering soil characteristics from laboratory test and moisture content data obtained from sensor monitoring. Effective rainfall is also taken as primary supply to simulate supplementary irrigation water need in cropping. Rice cultivation area is obtained from weekly surveying in record. Four cases of supply scenario during rainy season are applied in simulation period such as dry year in 2015, normal year in 2016, wet year in 2017, and present year in 2019. Crop demand is derived by FAO method and water allocation is planned afterwards to evaluate irrigation supply efficiency in using soil moisture monitoring system comparison with existing operation.

It is revealed that by using FAO method along with data from soil moisture monitoring system, the irrigation water supply for all crop types of whole TTD irrigation area is between 168.06 to 524.50 million cubic meters (MCM) that can conserve water supply up to 52.81% compared to routine operation. In the meanwhile, total demand estimation from ETo method is much more water requirement that is about 356.14 to 622.26 MCM for a season.

The recommendation of irrigation supply in relating with crop water demand is verified during dry season 2017 and 2018. The performance of water supply use for crop cultivation is assessed and compared to existing operation. In dry season 2017, observation data of rice cultivation area is around 344,948 rai and in that season TTD project has supplied water through irrigation system totally 93.62 MCM. Using the developed system, it is required only 78.20 MCM. The saving water irrigation supply is about 16.47% of the total. Additionally, data recorded of water supply in 2018, TTD project irrigated water 270.50 MCM to entirely 373,799 rai of rice cultivate area, the model suggested to supply the irrigation water of 202.33 MCM, which is about 25.20 percent of water supply saving.

The application of soil moisture monitoring system integrated with crop demand modeling using FAO method can be achieved for increasing efficiency of irrigation supply over 15%. It can be concluded that this study is matching all water demand and water irrigation supply all the time. Using soil content in root zone, amount of water irrigated can be determined to each zone area accurately with crop water need in terms of time and quantity constraint. Moreover, as a results of soil moisture sensor status can signify crop cultivation stage in relating to soil content that can use for reporting real situation in overall. This developed modeling system can be further applied into rainfed area for enhanced water use efficiency under the crisis of water supply changed circumstance that become more severity nowadays.

Panuwat Pinthong
Center for Water Engineering and Infrastructures Research
King Mongkut's University of Technology North Bangkok
Panuwat.pinthong@gmail.com

TB-208L

Discussion on the Suitability of SWAT Model Applied to Hydrological Simulation of Paddy Field in Taiwan

Jyun-Yi Huang[1] and Li-Chi Chiang[1]*

[1]National Taiwan University, Department of Bioenvironmental Systems Engineering No.1, Sec.4, Roosevelt Rd., Taipei 10617, Taiwan
*Corresponding author: lchiang@ntu.edu.tw

In Taiwan, rice is highly demanded as an important role in agriculture. Thus, irrigation water consumption of paddy fields accounts for the majority of agricultural water usage. With the increasingly extreme drought and flood events in recent years, the unstable supply of irrigation water in the rice-growing period shows that the distribution and utilization of irrigation water are very critical. Taoyuan City is the second largest rice production area in North Taiwan, among which the Nankan River Basin is one of the important rice irrigation areas with dense irrigation channel networks for providing stable water sources in this area. Since the establishment of Irrigation Agency of the Council of Agriculture, Executive Yuan, the Taoyuan Management Office and Shihmen Management Office have implemented planned irrigation and water supply for the irrigation areas in Taoyuan. Each workstation of the management offices is in charge of collecting basic statistical information of paddy fields for each irrigation group, from which annual irrigation plan will be drawn to calculate the quantity of water for irrigation and supply. After years of implementation, the results showed that the systematic irrigation water and supply strategy can satisfy the demand of water requirement of different rice crops during each growth stages, achieving the best outcome of agricultural operation for paddy fields. Many domestic studies in Taiwan have used the data on the quantity of irrigation water provided by the management offices to evaluate the benefits of the established management measures for irrigation/drainage of agricultural operation in paddy fields of Nankang River basin. The management offices could then use these study results as reference to continuously improve the management strategy in practice. Although the research on evaluations of agricultural management of paddy field in Taiwan has been significantly advanced, there are only few studies on the suitability of hydrological model simulation for paddy fields. In this study, the Soil and Water Assessment Tool (SWAT) model, a hydrological model, was used to assess the mechanism of paddy simulation and the water balance of paddy fields in the Nankan River Basin, and further examine the feasibility and effectiveness of agricultural management practices and evaluate the suitability of the model when applied to two stages of hydrological stimulation of paddy fields in Taiwan.

The Nankan River Basin includes the main stream of the Nankan River and the upstream basins of the Jiadong and Dakwai River, and the paddy fields planted with two-period rice cultivation from 2009 to 2013 were simulated in this study. The SWAT 2012 model used in this study simulates paddy fields as potholes. In order to match the actual irrigated paddy field area, we set up a designed classification system to reclassify the 2nd land surveying data and used the degree of coverage as the basis for evaluating the effectiveness of land use integration. We collected the statistics provided by the Taoyuan and Shihmen Management Offices to establish the irrigation water quantity during different farming periods of each group as the planned irrigation water depth. Moreover, multiple irrigation and drainage scenarios with different pothole situations were included in the simulations. The hydrological algorithm of SWAT model was primarily the water yield of pothole in terms of water balance point, as the theoretical water yield of pothole could be calculated from the theoretical hydrological formula of the model, and the simulation results of the model were compared to determine if the water balance was reached. Then, the accuracy of the model reflecting the trend of hydrological change in paddy fields could be examined.

The results showed that the area of paddy fields simulated by the model could cover approximately 70% of the actual irrigated area through the land use classification and integration, with good correlation (R^2 = 0.82). In terms of statistical error, it showed that the root mean square error (RMSE) of paddy field area after classification and integration was 25.46 ha, which was significantly lower than before (44.91 ha). By comparing the model simulations with and without pothole setting, the statistics values of NSE, PBIAS and R^2 of the streamflow simulation (without potholes) were -0.02, 50.8%, and 0.80, respectively, while the NSE, PBIAS and R2 with potholes were -0.31 ~ -0.14, 64% ~ 67%, and 0.31 ~ 0.59, respectively. By storage/drainage, the model could simulate the change of water quantity in potholes and streams, and also display the actual irrigation and drainage scenarios in the paddy fields of the study area. However, these results obviously overestimated the peak value on drainage day. It is suggested that the model should be improved in the future. When analyzing the simulation of pothole's water balance, the results of comparing theoretical water yield with the simulated water yield via the model were consistent with the non-pothole circumstance, which confirmed that the water balance theory was valid. However, in the pothole scenario, it was observed that the simulation results of the pothole model did not completely capture the data of water quantity generated by the surface runoff in the pothole for replenishing the river, which led to an underestimation of the theoretical calculation of water yield. In this study, we found that the difference between the analysis results had a similar trend with the amount of rainfall, indicating a necessity to modify the relationship between rainfall and runoff in the pothole model. The results of simulating paddy fields with pothole in the SWAT model showed that the model could clearly illustrate the unique hydrological features of paddy fields, despite the lack of accurate parameter settings and detailed hydrological algorithm for paddy fields. Therefore, when using the SWAT model for paddy irrigation simulation, we should refer to the irrigation and drainage strategy of the actual irrigated area, optimize the parameters of agricultural operations, and plan the input period of paddy fields in terms of agricultural management, as a more reasonable simulation of the hydrology of paddy fields in study. In addition, it is suggested to include data on rainfall, establish the relationship of rainfall and runoff, and examine the correlation between water yield and river discharge, so as to improve the suitability of the model of hydrological simulation of paddy field.

Keywords: SWAT model; Nankan river basin; Paddy field; irrigation

TB-209L

REAL-TIME RESERVOIR OPTIMIZATION FOR LONG-TERM OPERATION CONSIDERING SEASONAL ENSEMBLE PRECIPITATION FORECASTS: A CASE STUDY OF THE SIRIKIT DAM IN 2019

Thatkiat Meema[1,2]* Supattana Wichakul[1] and Yasuto Tachikawa[2]

[1]TEAM Consulting Engineering and Management Public Company Limited, Bangkok, Thailand
[2]Department of Civil and Earth Resources Engineering, Kyoto University, Kyoto, Japan
E-mail: thatkiat.meema@gmail.com

Introduction

The Sirikit reservoir—one of the two large reservoirs in the Chao Phraya River Basin (CPRB)—has a primary role in effectively managing the water resources of the basin. However, the reservoir is located in a tropical climate with significant seasonal differences and uncertainty regarding the basin's hydrological condition. These conditions cause both floods and droughts which proved to be very challenging for reservoir operation. Furthermore, the Sirikit dam has frequently faced drought conditions since 2011 massive flooding occurred in the basin which the mean annual inflow of the reservoir from 2012 to 2021 is lower than the historical 30-year average. Regarding the downstream water requirement, this resulted in a low storage volume of the reservoirs as a result of the imbalance between inflows and outflows. The events resulted in difficulties in water management for the coming years as a result of insufficient reservoir water storage. In addition, climate change complicates future water resource management in CPRB because of increasing extreme weather fluctuations (Wichakul *et al*., 2015).
Recently, Meema *et al*. (2021) indicated potential advantages of considering medium-range ensemble precipitation forecasts (EPF) for real-time reservoir operation using dynamic programming (DP). However, the study presented significant differences in reservoir operation results driven by future long-term inflow assumptions (for determining storage penalty in DP). For more robust decision-making during real-time reservoir operation, this study aims to introduce the seasonal forecast information for long-term reservoir operation to improve the real-time optimization scheme for mitigating drought conditions. Thus, the main objective is to utilize the seasonal river flow prediction for real-time reservoir optimization using DP for a case study of the drought event in 2019.

Methodology

Fig. 1 illustrated the real-time reservoir optimization scheme for 1-week in advance release strategy. The 2-week inflow forecast (Q_t and Q_{t+1}) obtained from the hydrological model (simulated with 2-week advanced medium-range EPF) was input into the DP to optimize the 1-week advanced release strategy (R_t) at any storage level. To optimize the release strategy using the DP algorithm, the potential future droughts damage at the end of the target period (F_{t+2}) is required to associate the penalties to the lower storage levels of the reservoir to avoid the reservoir drawdown to low storage levels by releasing excess water to generate quantified benefits during the optimization period. For this purpose, the seasonal ensemble precipitation forecast conducted by the European Centre for Medium-Range Weather Forecasts (ECMWF) was employed with the improved 1K-DHM (Meema and Tachikawa, 2020) for seasonal ensemble inflow predictions of the reservoir. To determine the initial conditions of the model, a cost-effective approach—empirical data assimilation (Collischonn *et al*., 2005)—was applied. The seasonal ensemble inflow predictions extended seven months in the future were performed once a month regarding the updated ECMWF seasonal forecast.

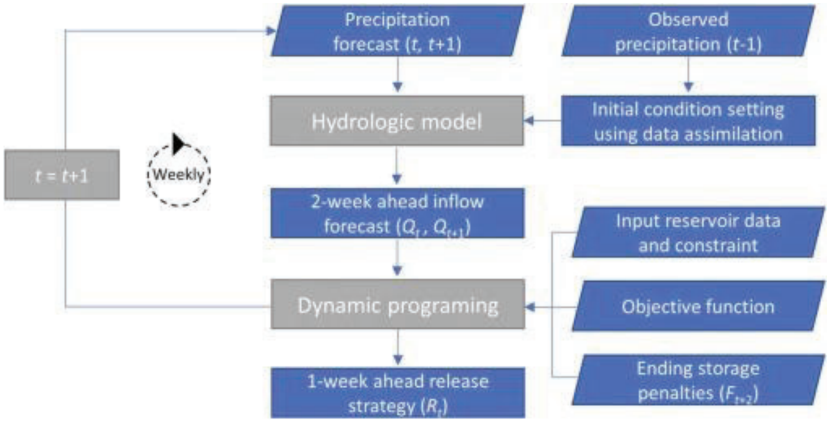


Fig. 1 Real-time reservoir optimization scheme for 1-week in advance dam release strategy for long-term reservoir operation considering medium-range and seasonal EPF.

Result and discussions

Regarding the previous study, there are advantages when associating forecast information with real-time optimization for decision-making in reservoir operation and providing more efficient operating decisions than employing historical data. However, the future long-term inflow assumption (for ending storage penalty determination) has a significant effect on the results of the reservoir operation. To improve optimization process efficiency, utilizing seasonal reservoir inflow forecasts may improve the real-time optimization scheme for the long-term reservoir operation by minimizing the future drought damage and increasing the potential of hydropower generation. The results of this study may be useful for long-term reservoir operation. This achievement would be practical and provide benefits to society in terms of water resources management.

References

Collischonn, W., Haas, R., Andreolli, I., Tucci, C.E.M., 2005. Forecasting River Uruguay flow using rainfall forecasts from a regional weather-prediction model. J. Hydrol. 305, 87–98. 10.1016/j.jhydrol.2004.08.028.

Meema, T., Tachikawa, Y., 2020. Structural improvement of a kinematic wave-based distributed hydrologic model to estimate long-term river discharge in a tropical climate basin. Hydrol. Res. Lett. 14, 104–110. 10.3178/hrl.14.104.

Meema, T., Tachikawa, Y., Ichikawa, Y., Yorozu, K., 2021. Real-time optimization of a large-scale reservoir operation in Thailand using adaptive inflow prediction with medium-range ensemble precipitation forecasts. J. Hydrol. Reg. Stud. 38, 100939. 10.1016/j.ejrh.2021.100939.

Wichakul, S., Tachikawa, Y., Shiiba, M., Yorozu, K., 2015. River discharge assessment under a changing climate in the Chao Phraya River Thailand by using MRIAGCM3.2S. Hydrol. Res. Lett. 9, 84–89. 10.3178/hrl.9.84.

Keywords: real-time optimization, ensemble inflow forecasts, seasonal forecast, dynamic programming

TB-211L

MULTI-OBJECTIVE MONITORING FOR THE QUALITY IMPROVEMENT OF NETTED MELON (*CUCUMIS MELO* L. VAR. *RETICULATUS*) THROUGH PRECISE NITROGEN AND POTASSIUM MANAGEMENT IN A HYDROPONIC SYSTEM

Rita S.W. YAM[1]*, Jing-Tian LIN[2], Chihhao FAN[1], Hsiao-Feng LO[2]
[1]Dept. Bioenvironmental Systems Engineering, National Taiwan University, Taiwan
[2]Dept. Horticulture and Landscape Architecture, National Taiwan University, Taiwan

Subtropical Taiwan has long been impacted by agricultural losses due to pest invasion, and various natural disasters such as typhoons, heavy precipitation and seasonal drought. The advancement of protective cultivation technology and precision agriculture helps to reduce these hazards and enhance crop yield. Precision agriculture relies on accurate knowledge of crop growth response to various environmental factors. In recent decades, the quality-oriented fruit production in well-controlled enclosed hydroponic systems has been greatly enhanced by the technology of precision agriculture. Over-fertilisation has been commonly applied to the traditional hydroponic culture of fruit crops, without considering different nutrient demands during development. Adjusting the nutrient formulations depending on crop developmental stages could enable efficient fertilisation to increase yield quality.

In this study, we investigated the production of low-Potassium content netted melon (*Cucumis melo* L. var. *reticulatus*) through hydroponic nutrient management in soilless culture in the controlled greenhouse environment. We established wireless environmental sensing and monitoring network for collecting accurate data of growth, yield and fruit quality of netted melon crop in response to the irrigation water quality, environmental conditions, and pesticide application. Based on continuous real-time environmental data collection during crop growth, the conditions of crop growth can be precisely obtained and combined with various physiological responses of crop to establish the relationship between each other via logistic analyses. Moreover, N-reduced and K-modified nutrient solutions were applied for a two-step nutrient manipulation experiment, to improve the fruit quality (Experiment I) and optimise the fertilisation schemes (Experiment II) of hydroponic netted melon (*Cucumis melo* L. var. *reticulatus*). The N-reduced and K-modified treatments, before fruiting stage in Experiment I, obtained higher fruit quality with increased fruit weight, dry matter ratio, flesh thickness, and total soluble solids. In Experiment II, fruits cultured under treatment II-3 (applied with 100-75-100% N and 100-125-75% K during VG-PYF-FEM) had the highest overall preferences, with 'rich' aroma, 'dense' texture, and 'perfect' sweetness, compared to all other experimental treatments. Our study successfully improved the fertilisation schemes for a hydroponic netted melon with precise N- and K-nutrient formulations specific to different developmental stages.

We successfully established the wireless environmental sensing and monitoring network for collecting accurate data of growth, yield and fruit quality of netted melon crop in response to the irrigation water quality in the well-controlled greenhouse environment. This will help to provide the upstream information of scientific data of smart agricultural system and integrate systematic analysis, judgments, and predictions between environmental factors and crop growth efficiency and quality. Our findings on the fertilisation schemes for a hydroponic netted melon promotes the future advancement of precise fertilisation to improve fruit quality and reduce environmental pollution from farming activities.

Keywords: precise fertilization, muskmelon, soilless cultivation, nitrogen and potassium, manipulation, nutrition, real-time monitoring, irrigation water quality

TB-213L

THE OPTIMAL IRRIGATION SCHEDULING FOR SMART FARM VIA REAL-TIME SENSOR

Sak Sakulthai[1]*, Trần Thành Long[2,3], Sanphet Chunithipaisan[4]

[1]Water Resource System Research Unit, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

[2]Faculty of Civil Engineering, Hochiminh City University of Technology, 268 Ly Thuong Kiet Street, District 10, Ho Chi Minh City, Vietnam

[3]Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam

[4]Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

*E-mail: day.dreammer@gmail.com

Abstract. Although Thailand is one of the prominent exporters of agricultural production, Thailand faces many challenges in many apsects such as declining average farm size, labor shortage in the sector, and water shortage under recent drought years. Since the farmers are used to traditional farming based on the experience without considering plants and soil status, the watering somehow was operated overrated and wasted labor and water resources. The project study aims to develop smart IoT irrigation scheduling via the real-time sensor data of the green park area's soil moisture, water storage, and irrigating patterns. The soil moisture was monitored and analyzed to understand the actual water demand of plants. Then, IoT machine learning was applied to train the proper irrigation scheduling, which guides the farmers to utilize water more efficiently. The results show that the innovative irrigation system saves water for the planting 20% to 30% from the traditional irrigation schedule without any adverse impact to plants.

Keywords: sensor, Information system, communication

1) Introduction

Thailand is the world's largest exporter of tapioca products, rubber, frozen shrimp, canned tuna, and canned pineapple. However, Thailand has faced high agricultural production costs due to the inappropriate knowledge and technology applied to the "Agricultural system" in recent years. Such as, the society began to enter "Aging society," leading to "Labor shortages" and "working wages," resulting in high labor costs (Kwanmuang, Pongputhinan et al. 2020). Besides, under a critical drought climate in recent years, the water stress has raised pressure on water management authorities. Hence, "Sustainable irrigation management" is essential for farmers to ensure food security in Thailand and the region. Therefore, the Agricultural irrigation system is required to improve the efficiency of the production process, especially the lack of water sources during the drought. Therefore, adopting modern technologies were expected to promote production processes and reduce water and labor in the agriculture sector.

2) Objectives and approach

The project study aims to develop an innovative irrigation system via the real-time sensor data of the green park area's soil moisture, water storage, and watering patterns. The modified water irrigation pattern is expected to reduce the water and labor in irrigation activities.

3) Methods used

First, the study monitored the changed soil moisture, volume water use, climate data at the green park (Al Nahian, Biswas et al. 2021). The data was collected and sent to the server through IoT technology via the 3G mobile network. The IoT system was assisted in avoiding missing data under unstable signals. Second, the study team estimated the allowable water in soil via Hydrus 1D to avoild water deficit for plants. Third, the data were used to create a general curve that reveals the optimum moisture content for plant growth in each soil type (Simunek, Van Genuchten et al. 2005). Final, the optimal water irrigation was determined to maintain soil moisture retention range for the plant as a whole.

4) Results

According to the soil moisture, the soil status was divided into four levels, namely 1) saturated soil, 2) wet soil, 3) dry soil, and 4) very dry soil. Under current evapotranspiration, the soil will change the drier soil status after five days without water. Hence the team has developed a smart irrigation scheduling notification system through the Line system based on the monitored soil moisture, climate. The notification will send the guideline to the responsible person every day at 8:00 am for the decision-maker to adjust the water supply to meet the soil moisture conditions. As a result, the optimal irrigation scheduling by IoT system was saved 20%-30% compared with the traditional irrigation plan.

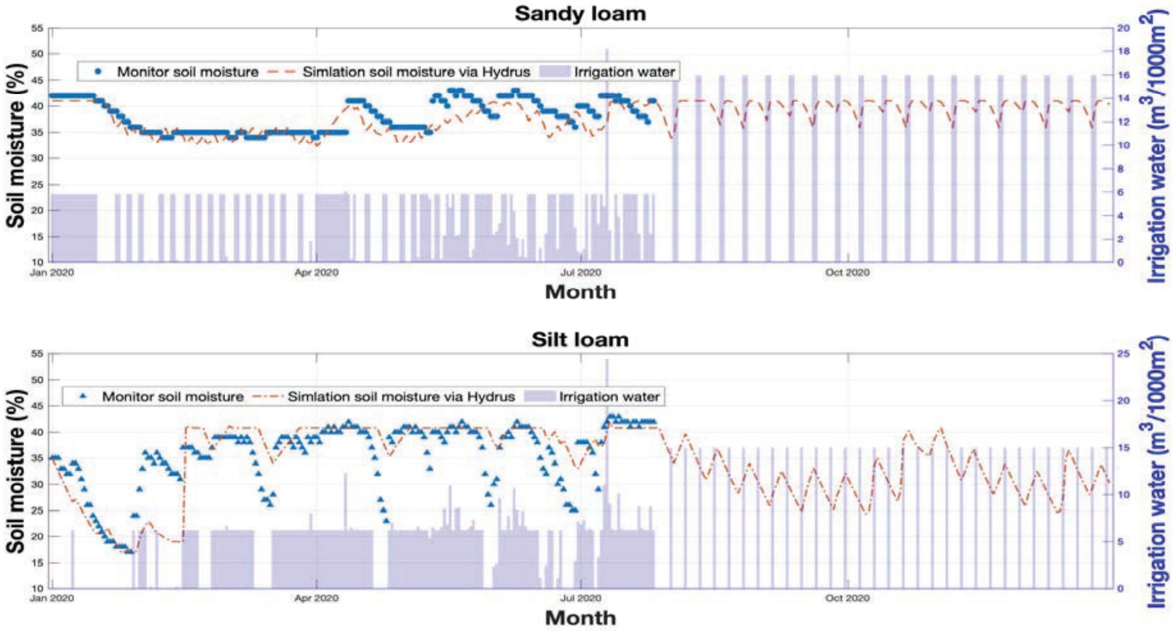


Figure 1. Comparison of soil moisture from past irrigation with an alternative irrigation model.

5) Discussion

The IoT system assists the farmer in adapting the proper watering patterns for plants and reducing water loss from traditional farming. Ready to inform the time and amount of water needed in various soil conditions. Using such tools in conjunction with soil moisture indicators and climate detectors at the plots will help control water allocation for agriculture through the Internet. An IoT server can provide a valuable guideline to support decision-making to improve the water allocation to suit the plant's needs in terms of quantity and time efficiency. The study successfully developed an intelligent irrigation management system from soil moisture sensors and weather-connected wireless networks. The study provides adequate management tools for water irrigation in the field at the plant farm level at a reasonable price, efficient and valuable. The device can be adapted to optimize the water resources for the agriculture sector in developing countries. This tool ingress minimizes the burden of agricultural water, which is the cost of the country.

6) References

Al Nahian, M. S. R., A. P. Biswas, J. Tsou and M. H. Rahman (2021). "IoT Based Soil Monitoring and Automatic Irrigation System."

Kwanmuang, K., T. Pongputhinan, A. Jabri and P. J. F.-A. Chitchumnung (2020). "Small-scale farmers under Thailand's smart farming system." 2647.

Simunek, J., M. T. Van Genuchten and M. Sejna (2005). "The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media." University of California-Riverside Research Reports **3**: 1-240.

TB-214L

Visualization of the Dynamic of Soil Moisture in Terraced Paddy Fields by Using Geoelectric Resistivity Tomography

Hsu, Shao-Yiu; Huang, Qun-Zhan; Tsai, Yi -Zhih Authors' affiliations
Department of Bioenvironmental Systems Engineering, National Taiwan University

Terraced paddy field constructed by modifying the slope into several flat steps is an important paddy rice cultivation system and, also, an important characteristic landscape in regions where lack the area of plains. An irrigation plan of the terraced paddy field requires an understand of the changes of the soil moisture, overland flow, as well as the subsurface return flow as shown in Figure 1. Unlike the plain fields, the terraced fields involve rapid terrain change. Each step of the field distributes at different elevations and connects to upper and lower steps with constructed slopes. The surface overland flow and the subsurface flow are controlled by the terrain morphology and the subsurface soil and geohydrological conditions.

Due to the complicated water flow system and very limited rice, studies on the irrigation and the hydrologic system in the terraced paddy field are rare (Deb et al., 2006). Only a few studies tried to investigate the subsurface flow under the field to show the effect of the subsurface return flow on the irrigation saving (Onishi et al.,2003). However, some studies show that irrigation water contributes to the next step through the subsurface flow, but some argue that the amount of the subsurface return flow is very little (Liu et al., 2004).

In order to observe the soil moisture changes during irrigation and rainfall and clarify the subsurface flow in terraced paddy fields, we applied the geoelectric resistivity survey on a terraced paddy field located in northern Taiwan from March to July 2021. The inversion two- dimensional electrical resistivity tomography (ERT) can picture the change of electrical resistivity of the soil. Since the change of the soil moisture is strongly linked to the soil water content, the increase of the electrical resistivity implies the decrease of the soil moisture. Also, the fertilizer dissolved in the soil water can decrease the electrical resistivity as well. Therefore, the change of the electrical resistivity below the surface represents the dynamic of the soil moisture and the potential flow path during irrigation or rainfall.

From the measured ERT images of the paddy field, we found that the rainfall and irrigation indeed changed the soil water content. The map also shows an unexpected water flow pathway under slopes. The newly discovered subsurface flow path along the slope should provide an important to the field practices and irrigation management. The resistivity change after fertilizing (in mid-April) illustrates the flow path, in which the pond water infiltrated vertically into the deep soil layer as shown in Figure 2. The result of ERT shows that the infiltration of the ponded water contributed very little to the next step under initial unsaturated conditions. After a long period of irrigation, the change of the electrical resistivity was also found in the deeper subsurface area, but a clear subsurface return flow path connecting different steps of the paddy field was not found. Based on our field, the subsurface return flow might not be considered a significant returned water resource in this study area. Nevertheless, the effect of groundwater table level, surface ponding height, and soil saturation should also be measured to better understand the hydrologic cycle in the terraced paddy field.

Keywords: Subsurface return flow, irrigation, rice field, ERT

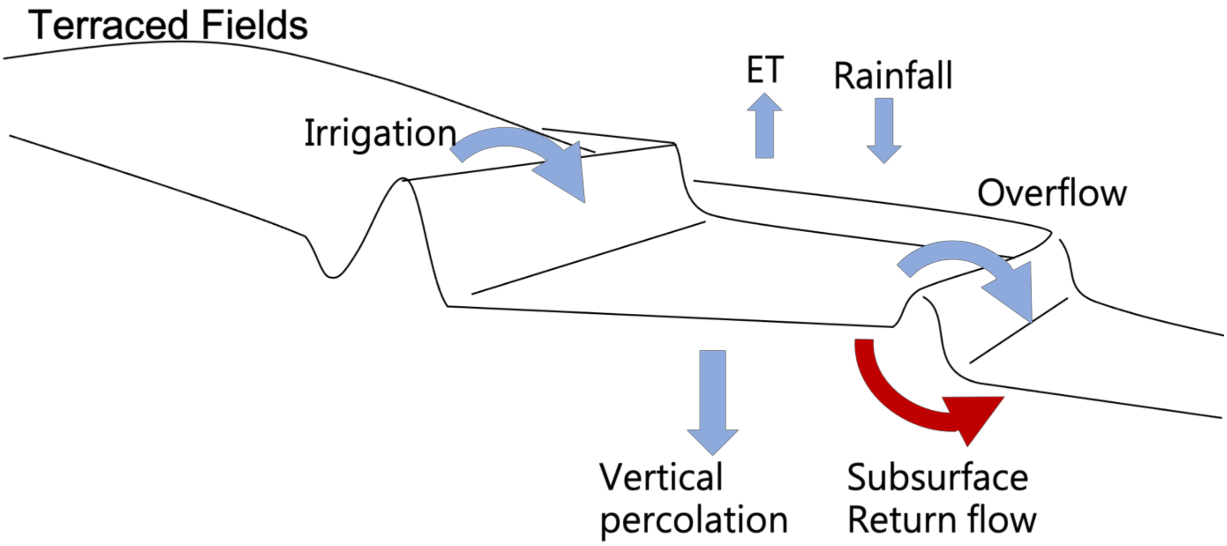


Figure 1. the conceptual model of the hydrologic processes in a terraced paddy field.

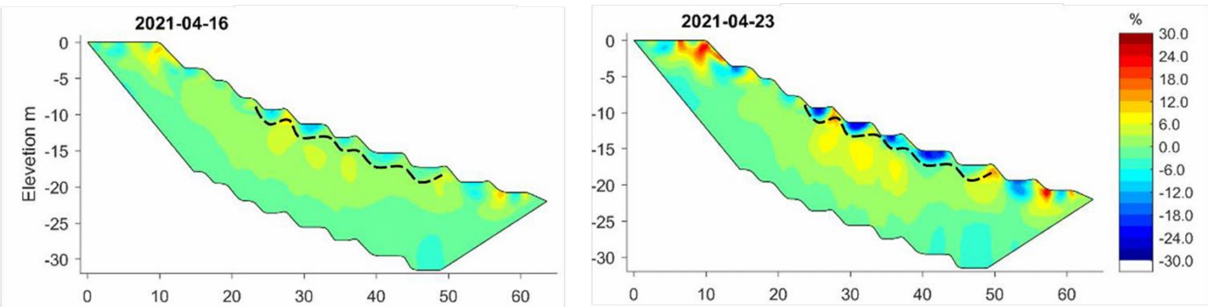


Figure 2. the changes of the electrical resistivity in the terraced paddy field (left) before fertilization (right) after fertilization.

Reference

1) DEB, S. K., MIYAZAKI, T., MIZOGUCHI, M. & SEKI, K. 2006. Return flow generating point on a hillslope layered with traffic pan. *Transactions of the Japanese Society of Irrigation, Drainage and Reclamation Engineering (Japan)*.
2) LIU, C.-W., HUANG, H.-C., CHEN, S.-K. & KUO, Y.-M. 2004. SUBSURFACE RETURN FLOW AND GROUND WATER RECHARGE OF TERRACE FIELDS IN NORTHERN TAIWAN1. JAWRA Journal of the American Water Resources Association, 40, 603-614.
3) ONISHI, T., HORINO, H., NAKAMURA, K. & MITSUNO, T. 2003. Evaluation of groundwater properties in terraced paddy fields using transient unsaturated-saturated water flow analysis. Transactions of the Japanese Society of Irrigation, Drainage and Reclamation Engineering (Japan).

TB-215L

Improving flood management through future reservoir development and operation in the Tonle Sap largest tributary

Davin Tes[1], Ty Sok[1,2,*], Ilan Ich[1], Layheang Song[1,2], Ratboren Chan[1,2], Chantha Oeurng[1] [1]Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia [2]Research and Innovation Center, Institute of Technology of Cambodia, Phnom Penh, Cambodia

[*]Corresponding author: sokty@itc.edu.kh

Keywords: SWAT, HEC-ResSim, Dam operations, Flow change, Tonle Sap tributary

Introduction

Sen River Basin, which is the largest subbasin of Tonle Sap Lake Basin, has a large potential for dam development. Assessment of dam development and operation is quite profitable to the society, economy, and livelihood in the study area due to the rise of irrigation areas and reducing flood and drought impacts. Particularly, the proposed and ongoing dams along Sen River, which are medium-scale dams, are expected to reduce peak flow during the rainy season and increase discharge flows in the dry season.

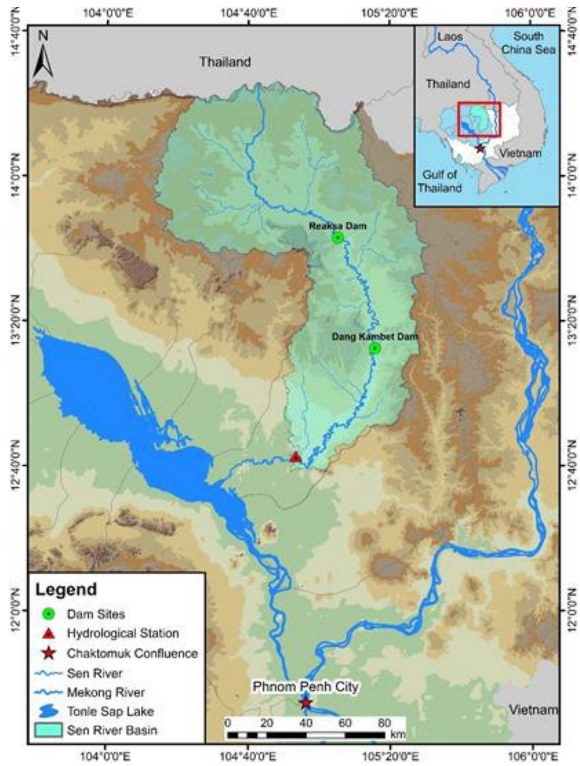


Fig. 1 Sen River Basin, tributary of Tonle Sap Lake

This study aims to assess the variation of peak flow at the downstream of the basin due to ongoing and future dam development and operation in Sen River.

Method

The impacts of dam development and operation on flow regimes was simulated using a semi-distributed and semi-physically based model, SWAT (Winchell et al., 2007) integrating with the HEC-ResSim model (Klipsch and Hurst, 2013). The simulation was based on the daily rainfall data from 1996 to 2019 throughout the basin from Tropical Rainfall Measuring Mission which were bias-corrected using linear scaling along with 3 stations of observed rainfall from 2011 to 2019. These data sets were input into the SWAT model for simulating daily flows at various locations within the basin.

Simulated flow from SWAT model were then used as inputs to the HEC-ResSim model to simulate regulated flows. A baseline scenario (BL), definite future scenario (DF) and indefinite future scenario (IF) were simulated to access the degree of changes inflows and to elucidate discussion on environmental, social, and economic effects. The target water level for multipurpose was defined by seasonal variation operation rule. These scenarios and operation aim to illustrate the possible range of the variation of flow patterns.

Table 1. Physical characteristics of Reaksa and Dang Kambet dams

Parameters	Reaksa	Dang Kambet
Easting	509593 m	528501 m
Northing	1516593 m	1460293 m
Catchment area	7,838 km^2	10,770 km^2
Dam crest length	7,900 m	3,564 m
Dam height	14 m	17.5 m
Full reservoir level	54 m	36 m
Reservoir area	110 km2	262 km2
Gross storage	453 mcm	1,109 mcm
Dead storage	47 mcm	59 mcm
Live storage	406 mcm	1,049 mcm

Results and Discussions

Simulation flows for each scenario (BL, DF, and IF) were computed using seasonal operation rule. Results showing the seven-day mean annual low and high flows are presented in Table *2*. The results demonstrate that the dam development will significantly decrease the seven-day mean annual high flow. Obviously, the high flows at both dam sites decreases approximately 300 m^3/s. Conversely, the seven-day mean annual low flow does not yield significant changes in all observed locations.

The reduction in peak flow and percentage for the years of extreme flood events was summarized in Table 3. The monthly regulated flows for each year are projected to be deceased in the rainy season and increased in the dry season. Particularly, the flow regimes reduce significantly in the late rainy season especially during the 2011 flood event which decreases at least 30%. Similarly, the 2019 flood event reveals a notable reduction in peak flow in August and September. However, for the 2017 flood event, the flows are largely to be declined during the mid-rainy season. Alternatively, in the early-dry season, the flow alteration is likely to be increased, while the late dry season does not yield significant changes for each year of extreme flood events.

Table 2. Seven-day mean annual low and high flows for development scenarios

Location	Flow	7-day mean annual (m^3/s)		
		BL	DF	IF
Reaksa	Low	8	10	10
	High	547	200	200
Dang Kambet	Low	14	18	18
	High	728	451	390
Stung Sen Town	Low	24	29	28
	High	838	633	610

Table 3. Reduction in peak flow and percentage for the years of extreme flood events

Month	2011 m^3/s (%)	2017 m^3/s (%)	2019 m^3/s (%)
May	-2 (-4)	-8 (-9)	-2 (-4)
Jun	-2 (-2)	-2 (-1)	-1 (-1)
Jul	-3 (-1)	-183 (-39)	-8 (-7)
Aug	-58 (-15)	- 134 (-19)	-85 (-23)
Sep	-502 (-48)	-42 (-8)	-399 (-41)
Oct	-324 (-33)	-95 (-18)	35 (7)
Nov	32 (6)	67 (20)	90 (35)
Dec	85 (30)	119 (62)	137 (95)
Jan	1 (1)	34 (25)	74 (82)
Feb	1 (2)	1 (1)	1 (1)
Mar	0 (0)	0 (0)	0.3 (1)
Apr	-1 (-4)	0 (0)	0.3 (-1)

Conclusion

The development of dams in the mainstream will significantly alter the flow regimes at the downstream region. The wet season flows are expected to be decreased, whereas the dry season flows will be increased.

In August, the water in dams is kept at 40% (5.5m and 6.5m of maximum 14m and 17m for Reaksa and Dang Kambet dams, respectively) of the full water level before receiving heavy rainfall in September. With this operation, the 7-day mean annual high flow reduces around 25%, about 200 m^3/s, at the downstream area compared to baseline. The reduction in peak flow has significantly reduced the flood in the downstream.

Acknowledgements: The study was supported and funded by SUMERNET 4 All Joint Action Project for strengthening flood risk management caused by climate change in Stung Sen River Basin, Cambodia (FloodCam).

References

1) Klipsch, J., Hurst, M., 2013. HEC-ResSim Reservoir System Simulation User's Manual Version 3.1. May, 556.
2) Winchell, M., Srinivasan, R., Di Luzio, M., Arnold, J.J.U.s., Blackland Research Center, Texas Agricultural Experiment Station, Temple, 2007.

TB-216L

HYBRID NEURO FUZZY-BASED RESERVOIR RE-OPERATION MODEL: CASE STUDY OF BHUMIBOL DAM IN THAILAND

Khin Muyar Kyaw[1], Areeya Rittima[2*], Yutthana Phankamolsil[3], Allan Sriratana Tabucanon[4], Wudhichart Sawangphol[5], Jidapa Kraisangka[6], Yutthana Talaluxmana[7], Varawoot Vudhivanich[8], and Assada Kijpayung[9]
[1, 2*]Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Thailand
[3]Environmental Engineering and Disaster Management Program, Mahidol University, Kanchanaburi Campus, Thailand
[4]Faculty of Environment and Resource Studies, Mahidol University, Thailand
[5, 6]Faculty of Information and Communication Technology, Mahidol University, Thailand
[7]Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand
[8]Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Thailand
[9]Royal Irrigation Department, Thailand
*Corresponding author's e–mail: areeya.rit@mahidol.ac.th

Keywords— ANFIS, Reservoir reoperation model, Reservoir performance index, Water balance model

INTRODUCTION

Dam and reservoir systems have long been introduced to support the water resources planning and management through a variety of the single and multi-purpose water resources development projects. Because of the high variability of temporal and spatial climate data creating impacts on dam and reservoir's function, escalation of reservoir operating policy and adaptation measures have been highly recommended. The reservoir re-operation is considered as one of the best ways to achieve the water resource management activities particularly in views of the water allocation sustainability and the natural disaster risk management. Accordingly, this study aims to investigate the adaptation strategy through re-operating the reservoir using artificial intelligence tool. The hybrid neuro fuzzy-based reservoir re-operation model was proposed by aiming to increase long-term reservoir water storage of Bhumibol Dam (BB) located in the Ping River Basin, Thailand. To accomplish this research goals, the reservoir re-operation model was developed by applying Adaptive Neuro Fuzzy Inference System (ANFIS) in MATLAB. ANFIS is a novel hybrid approach of artificial neural network (ANN) and fuzzy logic system (FLS), which was developed based on Takagi–Sugeno fuzzy inference system. It is revealed that ANFIS model can help ensure more efficient operation of reservoir system than the classical model based on rule curve if the informative data was sufficiently provided [1]. ANFIS can generate a set of fuzzy IF–THEN rules with appropriate membership functions by identifying the input and output training dataset through a hybrid learning rule which combines the back-propagation gradient descent and a least squares method [1].

METHODOLOGY

The daily long-term reservoir data and hydrological data from 2000 to 2020 were used to develop the hybrid neuro fuzzy-based reservoir re-operation model of BB Dam. The seasonal water allocation plan in the Greater Chao Phraya Irrigation Scheme established by the Royal Irrigation Department (RID) and Electricity Generating Authority of Thailand (EGAT) was used to determine the daily target water demand of BB Dam. To develop ANFIS model, three main variables namely, initial water storage, reservoir inflow, and target water demand were determined as inputs and the current dam release was specified as output. The 80% of dataset was used for model training to generate the rule base relationship between the input and output variables and 20% of dataset was used for model testing to verify the model performance. The optimal reservoir release rules of BB Dam were then obtained from ANFIS model. The statistical performance metrics namely, Root Mean Square Error (RMSE) and R-squared (R^2) were evaluated to assess the ANFIS-based reservoir re-operation performances for both training and testing datasets. The ANFIS rule-based model were then applied in the water balance-based reservoir operation model developed by MATLAB Simulink Toolbox to re-operate the long-term reservoir operation of BB dam. In addition, the maximum and minimum water releases constrained by the dam and reservoir systems in the Lower Ping River Basin were also assigned in the model. The last step was to evaluate the reservoir reliability performed by the ANFIS-based reservoir operation rules and compared the result with the current operation.

RESULTS AND DISCUSSIONS

The ANFIS-based reservoir operation rules were derived after the number of training epochs of 1,000 was reached and zero error tolerance was set in the model. The results show that the RMSE and R^2 between current release and simulated release accomplished by ANFIS are 6.52 and 0.70, respectively for the training dataset and 5.43 and 0.57, respectively for the testing dataset. When the water balance-based reservoir re-operation model was established and the ANFIS operation rules was embedded in the model, the long-term simulation run of BB Dam from 2000-2020 was accordingly conducted. The comparison of daily reservoir releases between current operation and simulated release by ANFIS-based reservoir operation rules is shown in Fig. 1. In addition, the reservoir re-operation performances quantified as the potential in increasing reservoir water storage during 2000-2020 and reservoir reliability are evaluated in Table 1. It can be evidently seen that ANFIS operation rule-based reservoir re-operation model can increase the reservoir storage throughout the year which is approximately 0.82% higher than current operation. The percent increase in reservoir water storage performed by ANFIS rule-based model is 0.45% in dry season (DS) and 1.26% in wet season (WS) which are higher than current operation. Moreover, the reliability index climbs up to 77% when ANFIS rule-based model was adopted which is much higher than those obtained from the current operation.

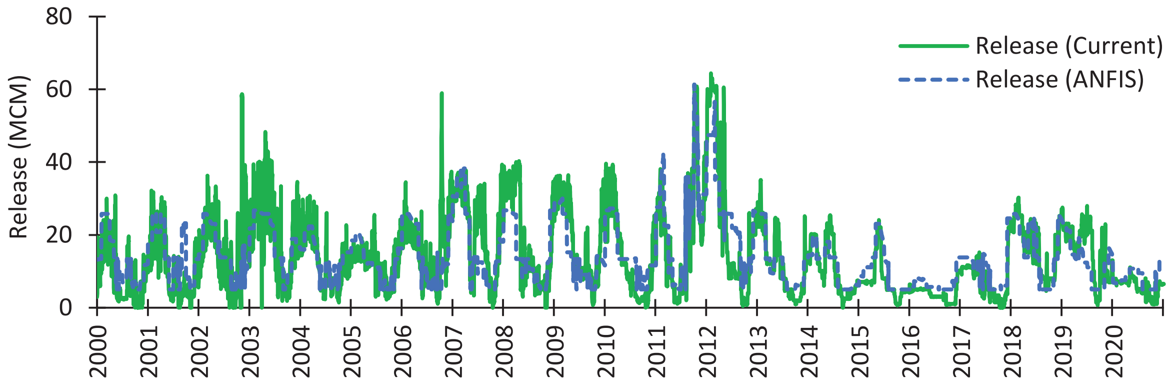


Fig. 1. Comparison of daily reservoir release simulated by ANFIS-based reservoir operation rules and current operation of BB Dam

Table 1. Average seasonal and yearly reservoir storages re-operated with ANFIS-based reservoir operation rules during 2000-2020 and reservoir reliability

Reservoir Operation	**Reservoir Storage (MCM)**			**Reliability Index (%)**
	DS	**WS**	**Yearly**	
Current operation	8,353	7,073	7,713	52
Re-operating with ANFIS rule	8,390	7,162	7,776	77
Δ% Increase	+0.45	+1.26	+0.82	+25

CONCLUSION

Hybrid neuro fuzzy-based reservoir re-operation model is a state-of-the-art technology and self-learning approach between the input and output linguistic variables that resembles the current operation in controlling complex reservoir operating systems. Research findings revealed that it can be effectively implemented in increasing reservoir storage and achieving better reservoir performance compared to the current operation.

REFERENCES

[1] Erol Keskin, M., Taylan, D., and Özlem, T., (2010). Adaptive neural-based fuzzy inference system (ANFIS) approach for modelling hydrological time series. Hydrological Sciences Journal, 51:4, 588-598.

TB-217L

Telemetry System for Irrigation

Somyot Kaewmora[1st], Thisana Sereekhodchahiran[2nd],Narongsak Sopawararat[3rd], Nipon Yupa[4th], Porntipa Pinthong[5th] and Chettana Chaiyasit[6th]

[1234]Ground Survey Division, [5]Geo Informatic Technology Division and [6]Boundary Survey and Cadastral Survey Co-ordination Division
Bureau of Engineering Topographical and Geotechnical Survey
Royal Irrigation Department (RID)
Bangkok, Thailand
somyot500@gmail.com[1st], thisana8@gmail.com[2nd], narongsak1405@gmail.com[3rd], niponyupa@gmail.com[4th,], porntipapinthong@gmail.com[5th],chatetana@gmail.com[6th]

Keywords—Telemetry, Engineering survey, GNSS- RTK, NB-IoT communication

ABSTRACT

The Royal Irrigation Department (RID.) is a government organization under the Ministry of Agriculture and Co-operatives of Thailand. RID is responsible for providing water resources for retaining, controlling, transferring, releasing, or sharing of those water resources for the usages in agriculture, energy, public utilization and industrial. The responsibility also includes reduction of the suffering from flood and drought. Water resources under the responsibility of RID comprise of 25 large size reservoirs, 412 medium size reservoirs, and many of small size reservoirs in Thailand.

The Bureau of Engineering Topographical and Geotechnical Survey is responsible for surveying the area and capacity data of these reservoirs. Due to that there are many reservoirs, the various innovative concepts of technological application were initiated in order to improve to the engineering survey for water management and irrigation operation. Therefore, the innovative Telemetry system was established for RID with the general objective reducing costs and increasing productivity of the surveying instruments. In order to achieve these objectives, the specific objectives are following;

1) To reduce cost of the equipment purchasing.
2) To reduce cost of the construction building.
3) To simplify installation and maintenance.
4) To reduce cost of the network communication and increase data transmission frequency.
5) To provide people accessing the information conveniently.

The innovative Telemetry system for Irrigation including with five features as follow;

firstly, the Real-Time Kinematic, Global Navigation Satellite System (GNSS-RTK) technique was applied to measure the water surface elevation, which does not required submersion under water as the traditional bubble gauge.

Secondly, there was no need to build a large building for traditional telemetry instruments. Due to low power consumption devices, a solar energy can be used which also enable the installation in the remote area where it's far from the conventional electricity supply.

Thirdly, this innovative Telemetry system was built on a small size of Buoy station which is not much maintenance and prevents any damage of equipment caused by water submersion.

Fourthly, the NB-IoT/LoRaWan Gateway communication protocol was used instead of the traditional 2G/3G communication protocol. Therefore, the cost associated with data transfer is reduced significantly.

Lastly, the web application and mobile application were built for displaying the real-time data and updating relevant information that can be quickly used for operating and managing the irrigated water.

As a result, the compositions of the innovative Telemetry system for Irrigation are shown in the Fig.1 which consists of the Buoy station with Solar panel, GNSS-RTK, Data network NB-IoT/LoRaWan Gateway, Database system and Web/Mobile application. The Telemetry system for Irrigation can provide a real-time data such as water surface elevation, water volume at storage level, water surface area, rainfall, temperature and humidity. All data can be accessed by real-time on mobile devices via mobile application and web application; http://rid-iot.serveftp.net:8080/index.html. They

can display data in a numerical and map. Moreover, they can display data in graphs and tables format also.

This innovative Telemetry system for Irrigation has been set up 82 Sets in many dams and reservoirs under the RID's responsibility in 2021. The example is shown in Fig.2, Installed the Telemetry System for Irrigation at Huai-Sai Khamin Reservoir, Sakon-Nakhon province, Northeastern region of Thailand.

Fig.1 The compositions of the Telemetry System for Irrigation

Fig.2 Installed the Telemetry System for Irrigation at Huai Sai Khamin Reservoir, Sakon Nakhon province, Thailand.

TB-218L

The Calibration Curve for Irrigation Reservoirs by Survey Tool Innovation

Somyot Kaewmora[1st], Thisana Sereekhodchahiran[2nd],Narongsak Sopawararat[3rd], Nipon Yupa[4th], and Porntipa Pinthong[5th]

[1234]Ground Survey Division and [5]GeoInformatic Technology Division
Bureau of Engineering topographical and Geotechnical Survey
Royal Irrigation Department (RID)
Bangkok, Thailand
somyot500@gmail.com, thisana8@gmail.com, narongsak1405@gmail.com, niponyupa@gmail.com
porntipapinthong@gmail.com

Keywords—Topographical data, Area-Capacity curve, RTK-GNSS, Echo-sounder, UAV, DEM, Orthophoto

ABSTRACT

The Royal Irrigation Department (RID) is mainly responsible for seeking the water resources and increasing the irrigation area according to their potential and natural balance, including managing and operating irrigation water efficiency to water use objectives. Currently, there are a lot of dams and reservoirs in responsibility of RID. Several of them have been used for very long time, as a result, the sediment deposition in the reservoirs. Consequently, water level and storage capacity have changed. The correlation between these factors and the typical operation rule curves is completely incoherent. According to the traditional surveying in the past, it was obsolete. The topographical information using to perform the area-capacity curves is not enough details. This can cause discrepancies in the typical rule curve data significantly. In order to address this issue, the Bureau of Engineering topographical and Geotechnical Survey's team initiated an idea to calibrate the area-capacity curve by surveying tools Innovation. The conception of this proposed innovation is both traditional and new surveying methods have been used and integrated together in order to acquire the absolute accuracy of surveying information for calibrating the area-capacity curves of the irrigation reservoirs or dams. Ground survey, underwater survey, and aerial survey have been taken into this mission. These are two general objective of this proposed innovation, 1) to improve the accuracy of area-capacity curve which can be used for operating and managing water in the reservoirs or dams efficiently. And 2) to apply the result of engineering surveying information for increasing a storage capacity of the irrigation reservoirs or dams.

The various surveying methods and tools have been integrated to calibrate the area-capacity curve for operating and managing irrigation reservoirs, as showing in Fig.1. So that the real-time kinematic global navigation satellite system (RTK GNSS) technique and the traditional surveying instruments such as Total Station and Digital Level were used to retrieve a positioning both vertical and horizontal position. Referencing to the ground surveying instruments' accuracy, RTK-GNSS receivers offer centimeter-level accuracy by the vertical accuracy is +/- 10 mm. +0.8 ppm. and horizontal accuracy is +/- 5 mm.+ 0.5 ppm. (Referencing from Topcon Positioning Systems, Inc.). A sonar echo-sounder was used to measure the water depth and combining with RTK-GNSS. Hence, the vertical positioning data could be retrieved by Echo Sounder and horizontal positioning data could be obtained by RTK-GNSS. Typically, the positioning accuracy from Echo Sounder is an absolute accuracy around 1-3 cm up to the depth of water. The unmanned aerial vehicles (UAVs) with RTK GNSS on board was used to acquire the aerial photographs and a group of point clouds which is used to perform a 3D elevation data. After that all data from those surveying methods were analyzed and performed a digital elevation model (DEM) covering over the project area and were created the contour line with a contour interval of 1 centimeter. Then, the area-capacity curve was calculated and performed accurately in centimeter-level accuracy. Finally, the report including surveying information were handed in to the responsible organization and the results of the calibration curve can be taken into account for reservoir dredging in order to increase the storage capacity in accordance with the amount of inflow.

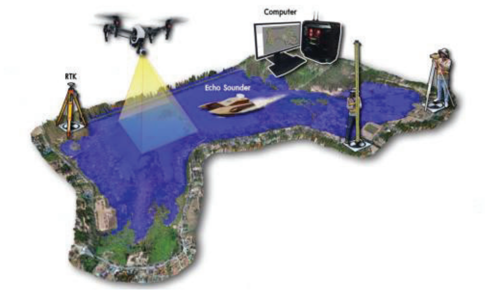
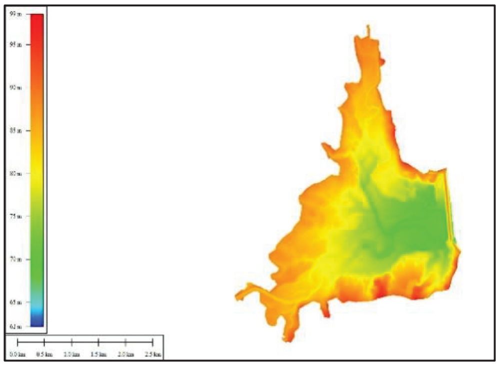


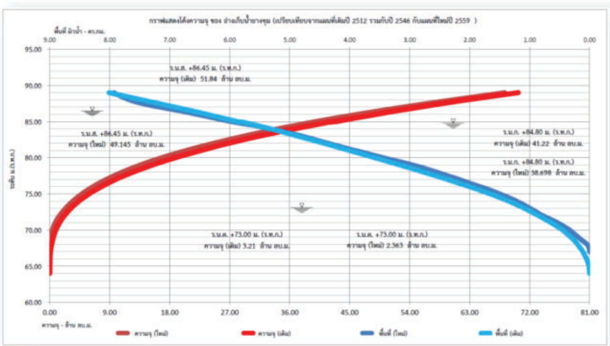
Fig.1 surveying tools or methods integration for calibrating area-capacity curve

To sum up, this calibration curve by surveying integration has been utilized for many areas of RID, for instance, in case of Yang Chum Reservoir in Prachuap Khiri Khan Province where needs to increase the storages for more efficient reservoir operation was selected. The example of products and final results of the calibration curve are shown in Fig.2. The Orthophoto products and DEM were obtained finally (Fig 2.1 and 2.2 respectively). DEM which has the positioning accuracy in centimeter-level can produce contour line with interval of 1 centimeter, besides, the Orthophoto product with pixel size of 5-15 centimeters can produced the orthophoto Map on Scale 1:2,000 1:1,000 and 1:500 up to the flying height. As the area-capacity curves comparison (Fig 2.3), the typical curves were performed by using data from a Topographic Map on scale 1:10,000 and the contour line with interval of 10 centimeters was interpolated. In contrast, the calibration curves were perform by using Topographical data from the surveying tools innovation and a contour line with interval of 1 centimeters could be obtained. This mean that the calibration curves are significantly different from the typical curves. Therefore, it is obviously that the calibration curve from the surveying tools innovation is highly accurate. This information should be recommended to the responsible organizations, it can be useful for planning and operating the storage capacity or for the further works such as a reservoir dredging work and the adjustment of operation rule curve.

(2.1) Orthophoto products



(2.2) DEM data



	Retention Water Level (m. msl.)	Water Capacity (mcm.)	Water Surface Area (km^2)
Before Calibration	+84.80	41.2200	5.7250
After Calibration	+84.80	38.6981	5.8440
Differential	-	-2.5219	0.119
% of Differential	-	-6.12%	2.08%

(2.3) Curves comparison between typical curves and calibration curves
Fig.2 Products and results of the calibration curve for Yang Chum Reservoir, Prachuap Khiri Khan Province, Thailand.

TB-219L

An Implementation of Automatic Flap Gate Weir Type III-A & III-B as Structural Irrigation Water Management Best Practice

Chaiya phoungphotisop
Director of Irrigation Development Institute (IDI)
RID Pak Kret, THAILAND
ph.chaiya44@gmail.com

Praponth Kaurpan
Advisory Engineer,
Irrigation Development Institute (IDI)
RID Pak Kret, THAILAND
wmd_cm@yahoo.com

Noppadon Kowsuvon
Senior Professional Engineer,
Irrigation Development Institute (IDI)
RID Pak Kret, THAILAND
PrinceThai@gmail.com

Keywords— Automatic Flap Gate Weir, Structural Irrigation Water Management, Water Management Best Practice (key words)

ABSTRACT

Severe floods in Thailand affecting life, causing economic damaged including millions of hectares of agricultural area. According to the flooded area surveys, the main causes of severe floods are riverbanks encroachment, and ineffective structural flood management caused by lack of maintenance or damaged. To enhance and easing up the mentioned problems, various type of flap gate weirs were alternative structures of interest as best practices solution to such problems as structural irrigation water management.

The development of automatic folding flap gates Type III-A for mounting on the ridges of reservoir's spillway were carried on as the continuing research of flap gates type I-A and Type II-A . and the mobile floating Type III-B prototype demonstrated at Irrigation Development Institute (IDI) with ability to be carried in the river were designed as the continuing research of flap gates type I-A ,Type II-A and Type III-A.

To enhance the flap gate weir, the industrial grade technology sensor, Programable Logic Control (PLC), and Encoder were installed as a locator in the flapping system which enable Type III to operate automatically. Encoder installed for Z-axis ridge positioning reference which has the advantage under electrical outrages situation. The Encoder will point to the position of the door before the electrical outrages and automatically re-configure the door to its correct position every time, or as the controller requires the sudden shutter to be positioned above or below the reference point as needed.

After laboratory designed, RID by former Director General Sanchai Ketwarahai launched the LOOKING BACK campaign to enhance the capacity of reservoirs throughout THAILAND. The storage increment for Prasae Reservoir via Flap Gates installation on it's spillway ridge is the first project constructed and completed in 2015 in Wang Chan, Rayong.

Prasae is a large-scale reservoir with a capacity of 248 million cubic meters. After the installation of type III-A flap gates on the spillway ridges to increase height of 1.00 meter by 4 flap gates width 17.28 meters, the reservoir can hold additional 47 million cubic meters of water storage (Diagram. 1)

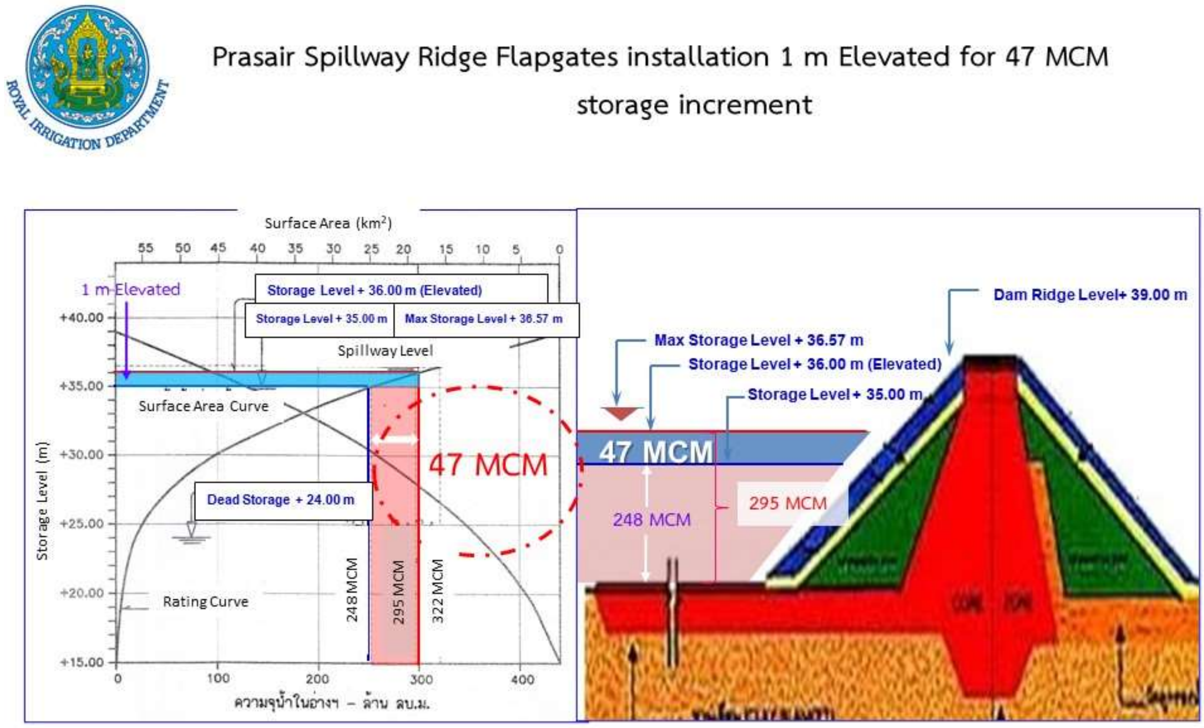


Diagram. 1 Elevated Storage via Flap Gate Weir type III-A installation on the dam's spillway of Prasair Reservoir, Wang Chan, Rayong

In dry season, water management is shifted to limited water supply. With 47 million cubic meters additional water reserved during wet season, the flap gates weir can be controlled in fine tuning degree up or down until optimum level reached to comply with Reservoir Operation Study (ROS). In future, the gates system can also be controlled via mobile phone or over the Internet.

Under sudden flood situation, the flap gates can automatically fold down by itself for upstream control via pre-programmed automated command system. In addition, the differential pressure sensors are installed to monitor water level in real-time accurately under high or low ambient gauge pressures

The development of automatic folding flap gates Type III-A for mounting on the ridges of reservoir's spillway was designed under the Building Information Modeling (BIM) technology. Three main elements needed to operate the Type III A flap gate weir are 1) the control unit, 2) the power unit, and 3) the flap gate weir system illustrated in figure 5.

The sensor and air tube package were installed toward water level measurements called the absolute pressure sensor. The absolute pressure sensor were named after the original sensor were modified to correct the inaccuracy flaws caused by ambient pressures error. The absolute pressure sensor can be located in water level monitoring system. The following figures 6 illustrate the type III-A flap gates components, control room and electricity back up system.

In addition, more advantages experienced onsite, the Type III-A can also drain sediment effectively resulted in budget saving on dredging sediment cost. Each steel gate of type III-B is designed to be floatable for ease of transport and installation where cranes cannot be carried down to the middle of the river. Floating gates are alternative option with no-cranes needed which allow construction work to be carried on. In case the designed gate is very long in length, the flap gates can be separated for ease of transport and installation.

Fig. 1 Hydraulic system of Flap Gate Weir type III

Fig. 2 Automatic Type III-A Flap Gate Weir

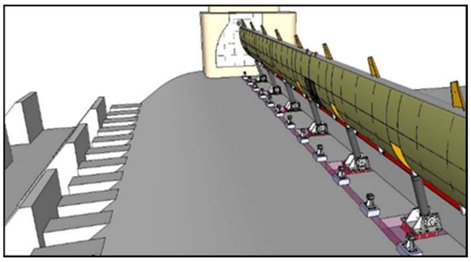


Fig. 3 Hydraulic System of Type III-B flap Gates

Fig. 4 Type III-B flap gates designed to Be Floatable for ease of transportation

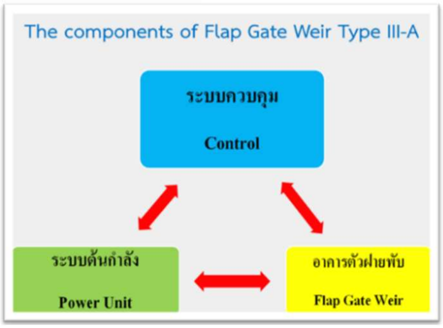


Fig 5. Three main elements needed to operate the Type III A flap gate

Fig 6. The type III-A flap gates components, control room and electricity back up system.

SUMMARY AND ACKNOWLEDGMENTS

In conclusion, both Type III-A and Type III-B multi purposes flap gates weirs can be installed to replace damaged irrigation structures toward more efficient water management. The key features of both Type III-A and Type III-B are parts and components that can be easily manufactured and installed, suitable to serve numbers of irrigation applications including wide range flood preventions form residents to industrial estates. The flap gate weirs are easy to manage and easy to maintain, and the domestic overall cost from manufacture to installation are more affordable.

Finally, we would like to thank Ms. Arunmanee Naraviriyakul and Ms. Janjira Thongsuk of Irrigation Development Institute for their hard work in coordinating this paper.

REFERENCES

(1) Phoungphotisop, 2011. Automatic Flap Gate Weir Type III-A & III-B

TB-220L

ESTIMATION OF CROP WATER REQUIREMENT AND IRRIGATION EFFICIENCY USING CLOUD–BASED IRRISAT APPLICATION IN THE LOWER PING RIVER BASIN, THAILAND

Paphanin Phutonglom[1], Areeya Rittima[2*], Yutthana Phankamolsil[3], Allan Sriratana Tabucanon[4], Wudhichart Sawangphol[5], Jidapa Kraisangka[6], Yutthana Talaluxmana[7], Varawoot Vudhivanich[8], and Assada Kijpayung[9]
[1, 2*]Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Thailand
[3]Environmental Engineering and Disaster Management Program, Mahidol University, Kanchanaburi Campus, Thailand
[4]Faculty of Environment and Resource Studies, Mahidol University, Thailand
[5, 6]Faculty of Information and Communication Technology, Mahidol University, Thailand
[7]Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Thailand
[8]Department of Irrigation Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Thailand
[9]Royal Irrigation Department, Thailand
*Corresponding author's e–mail: areeya.rit@mahidol.ac.th

Keywords— Crop Water Requirement, Reference Crop Evapotranspiration, Irrigation Effiency, Cloud–Based IrriSAT Application, Normalized Difference Vegetation Index (NDVI)

ABSTRACT
Estimation of crop water requirement (ET_c) is certainly essential for canal operators to evaluate the current status of irrigation water use and roles of irrigation in supplying water to meet crop requirements and improving the irrigation efficiency (IE) at the field scale. ET_c can be obtained based upon the reference crop evapotranspiration (ET_o) and crop coefficient (K_c). This study presented the K_c values generated from Cloud–Based IrriSAT application which is a satellite–based supportive tool for irrigation scheduling. The dynamic values of K_c of three irrigation schemes located in the Lower Ping River Basin namely; Tortongdang (TD), Wangbua (WB) and Wangyang–Nongkwan (WY–NK) during 2000–2020, were obtained and monitored using updated satellite imagery data of planting areas over growing seasons during an entire year for ET_c and IE estimation. K_c–IrriSAT were accordingly verified and adjusted with average K_c–RID which were calculated as a function of K_c from field observation for the different types of crops and accumulated area size monitored by GISTDA. The results after the calibration procedure revealed the similar patterns of average K_c generated by IrriSAT corresponding to the average K_c–RID and the high correlations between K_c–IrriSAT adjusted and average K_c–RID for TD, WB, and WY–NK irrigation projects were found. The irrigation efficiency can be principally obtained based upon the Net Irrigation Water Requirement (NIR) and Gross Irrigation Water Requirement (GIR). The results of ET_c were applied and seepage losses and effective rainfall were calculated to find NIR for estimating irrigation efficiency. It could be drawn from the results that the irrigation efficiency of TD, WB, WY–NK irrigation projects are 72.16%, 80.33%, and 56.49%, respectively which are relatively high particularly in TD and WB, indicating that the water supplying to the irrigated area was limited and consistent with estimated values of ET_c.

INTRODUCTION
Thailand's economic development has been mostly driven by the agricultural sector. Enhancing agricultural productivity in large–scale irrigation schemes plays an important role to raise the economic growth of the country. Therefore, water supply facilities and irrigation technologies should be potentially provided to farmers for raising agricultural productivity and modernizing the irrigation systems. Evaluating crop water requirement (ET_c) and irrigation efficiency (IE) in irrigation areas requires the crop coefficient (K_c) as an important parameter. The values of K_c are mainly subject to the crop types and dynamic growth periods of crops. This leads to the difficulty in estimating the certain amount of water to be delivered in irrigated areas. Cloud–IrriSAT application can also predict ET_c by referring to the strong relations between the Normalized Difference Vegetation Index (NDVI) in the cultivated area and Kc [1]. Accordingly, this study aims at tracing the dynamic values of ET_c by using cloud–based IrriSAT application to find crop water requirement and irrigation efficiency of three irrigation schemes in the Lower Ping River Basin including TD, WB, and WY–NK with the service areas of 992, 1,336, and 1,129 km^2, respectively.

METHODOLOGY

Cloud–based IrriSAT application was taken to estimate K_c for three main irrigation schemes; TD, WB, and WY–NK during 2000–2020 by identifying the crop growing area as input data. To evaluate the dynamic values of K_c, the GIS shape files of these three irrigation schemes must be converted into Keyhole Markup Language (KML) files. Various forms of K_c were generated through the cloud–based IrriSAT application. However, K_c(average) was only used to validate with those average values of crop coefficient (average K_c–RID) performed by using observation data from the Royal Irrigation Department (RID) and Geo–Informatics and Space Technology Development Agency (GISTDA) during 2018–2019. Validating process of K_c–IrriSAT values was conducted using least square criterion to visualize the good correlation between K_c–IrriSAT and average K_c–RID and to find the adjusted factors corresponding to the specific growing periods. The reference crop evapotranspiration (ET_o) was computed based upon the FAO Penman–Monteith equation and the yearly crop water requirement (ET_c) was quantified using K_c–IrriSAT. The Net Irrigation Water Requirement (NIR) and Gross Irrigation Water Requirement (GIR) were then provided to estimate the irrigation efficiency of each scheme in the last step. Irrigation efficiency (IE) can be computed as the ratio of the amount of water consumed by crops or “Net Irrigation Water Requirement (NIR)” to the amount of water supplied through irrigation or “Gross Irrigation Water Requirement (GIR)”.

RESULTS AND DISCUSSIONS

The results show that the maximum K_c(average)–IrriSAT values are 0.6698, 0.6760, and 0.6841 for TD, WB, and WY–NK irrigation schemes, respectively which are much lower than those received from K_c(average)–RID with 1.3942, 1.3412, and 1.3415, respectively. However, it shows the similar patterns of average K_c generated by IrriSAT corresponding to the average K_c–RID over the growing seasons in a year. In addition, correlations between Kc–IrriSAT and average Kc–RID for TD, WB, and WY–NK irrigation schemes are relatively higher with R^2 of 0.8304, 0.8466, and 0.8314, respectively after the validation process was successfully done. The yearly estimated values of NIR are 406.25, 382.83, 247.00 MCM for TD, WB, and WY–NK irrigation schemes, respectively and the yearly measured values of GIR are 562.54, 476.56, and 437.06 MCM for TD, WB, and WY–NK irrigation schemes as illustrated in Fig 1. This indicates that the amount of irrigation water supplied to these three irrigation schemes are still sufficient to crop water requirements. However, high irrigation efficiency were definitely found in the TD and WB irrigation schemes with IE of 72.16% and 80.33%, respectively reflecting the possibility of experiencing the physical water scarcity in this region. Irrigation efficiency of WY–NK irrigation scheme was 56.49% considering as good in term of irrigation performance.

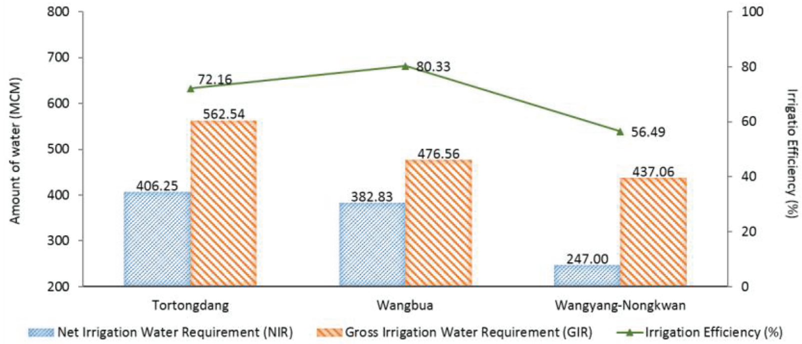


Fig.1 Comparison of yearly NIR and GIR and irrigation efficiency of three irrigation schems

SUMMARY AND ACKNOWLEDGMENTS

This research revealed the estimation of crop water requirement and irrigation efficiency of three irrigation schemes in the Lower Ping River Basin using the cloud–based IrriSAT application. It could be drawn that IrriSAT application can be a useful tool to trace the dynamic values of crop water demand particularly in the small to large irrigation areas. In addition, it is very helpful for the canal operators to specify affordable amount of water delivery and to improve the irrigation efficiency at the field scale.

Authors would like to acknowledge the Agricultural Research Development Agency (Public Organization) for providing financial support.

REFERENCES

[1] Hornbuckle, J., Vleeshouwer, J., Ballester, C., Montgomery, J., Hoogers, R., Bridgart, R. (2016). Estimating the crop coefficient. IrriSAT Technical Reference, 5–7.

SESSION C:
WATER MANAGEMENT TOWARDS SDGS

TC-301S

The New National Water Law for Improving Water Management Problems in Thailand, Focused on Water Allocation and Water Resources Conservation

Araya Yotmongkol
Department of Water Resources
Bangkok, Thailand
araya17233@gmail.com

ABSTRACT

Thailand encounters water problems annually. Water demand still increases continuously for supporting population growth, economic expansion, and urbanization. Water becomes a limited resource. Water conflict between upstream and downstream areas is intense and it expands widely. Therefore, water management efficiently is an essential issue for Thailand. In 2019, the Thai government established the Act on Water Resources B.E. 2561 (2018). They expected this law to improve water management problems sustainable. The research aims to analyze the new water law to improve the water management problems, focused on water allocation and water resources conservation. The author starts the research by gathering water management problems in Thailand. The problems will be connected to the new national water law by separating into four groups include 1) the equal water allocation 2) the management of water crisis 3) the management of water resources conservation, and 4) the integrated water resources management. After that, the provision of the new national water law is analyzed to present the concept and sensitive aspects that correspond to the improvement of the problems. The author will focus on water allocation and water resources conservation. The provision in chapter IV and chapter VI of the law will be analyzed. Finally, the author proposes the economic instrument mentioned in Water Framework Directive (WFD) to guideline water management improvement in Thailand. The result of this research can encourage the Thai government for using the new water law to improve water management. Incentive measures such as Non-Monetary Voluntary Agreement, Payment for Ecosystem Service (PES), and Water Tax Reduction can solve the sensitive aspects when the government implements the new national water law. Furthermore, the measures can be applied to improve the problems of water allocation and water resources conservation.

Keywords Water; Law; Allocation; Conservation

INTRODUCTION

Thailand encounters water problems annually. The primary source of water is rain. Thailand is located in the Southeast Asia continent, which is a tropical zone near the equator. The influence of stormy winds brings the rain in Thailand moreover El Nino and La Nina phenomenon can be the critical factor for the variable rainfall.[1] The consequences are water shortage and flooding in various areas. Currently, Thailand faces a water imbalance. Water use in Thailand still increases continuously for supporting population growth, economic expansion, and urbanisation. Water becomes a limited resource. Water conflict between upstream and downstream areas is intense and it expands widely. Therefore, water management efficiently is an essential issue for Thailand.

Thailand manages water resources which are divided into surface water and groundwater. The State Irrigation Act B.E. 2485 (1942) and People Irrigation Act B.E. 2482 (1939) provide the regulation of surface water for irrigation areas. In contrast, the Groundwater Act B.E. 2520 (1977) indicates the protection of groundwater resources, the licensing of groundwater exploitation, and groundwater utilisation control.[2] For the last decade, surface water outside irrigation areas was not covered by a specific law. Over 48 agencies manage water in a different direction and lack connectivity. It is the cause of budget loss and disintegrated water problem-solving.[3]

Thailand attempts to achieve the sustainability of water security by reforming water management. In January 2019, the Thai government adopted the Act on Water Resources B.E. 2561 (2018) to be the leading law for national water management. This new water law was adapted from involved laws and improved by related water organizations, including water specialists, government agencies, business representatives, and communities both upstream and downstream. It is a challenging aspect that this new national water law is expected to improve water management problems in Thailand sustainable.

METHODOLOGY

The research aims to analyze the new water law to improve the water management problems, focused on water allocation and water resources conservation.

The methodology of research is a qualitative method by analysing secondary data and interviewing. The research comprises three parts including 1) Problems of Water Management 2) Concept of Water Resource Act and Sensitive Aspect 3) Guideline of Water Resources Management.

The author reviews the water management characteristics of Thailand to find the gaps which are possibly the cause of water problems in the country. Moreover, the literature review covers the process of the new national water law establishment to ensure the quality of the law involved with water users in every part. The author studies the economic instrument mentioned in the Water Framework Directive. The concepts of the economic instrument and incentive measures will be analysed to adapt to water management in Thailand.

After understanding water problems and the gaps which are the cause of water management issues in Thailand, three parts of the research will be scrutinised.

The first part, it starts with addressing the problems of water management in Thailand. The author collects the issues of water management from the Thai government reports include the Office of the National Water Resources, the Department of Disaster Prevention and Mitigation, and the Department of Water Resources. Furthermore, the author joins with the online conference in the topic “The Project of Water Management which relevant to the Development of Thailand’s Economic and Social”. The discussion is presented by specialists from the University of Thammasat and Thailand Science Research and Innovation. They examine water management criteria by considering the balance of water demand and water supply in different river basins of Thailand.[4] Besides, the author searches academic articles and books with the keyword “problems of water management in Thailand”. The author separates water resources problems into 4 groups following the new national water law.

The second part will diagnose the concept of the new national water law to analyse the water rights mentioned and the sensitive aspect of the law in a practical process. The author studies the new water law from the Act of Water Resources B.E. 2561 (2018). After that, the author collects the recommendation of sensitive aspects in the law for the practical process from the online conference and academic articles.

In the third part, the international policies and water management of other countries will be adapted for proposing a water management guideline. The researcher chooses “the equal water allocation” and “the management of water resource conservation” from the second part and advances them with a water management guideline. “Economic Instrument” mentioned in the Water Framework Directive of EU becomes the keyword of this part. Moreover, the author also uses interview methodology in this part.

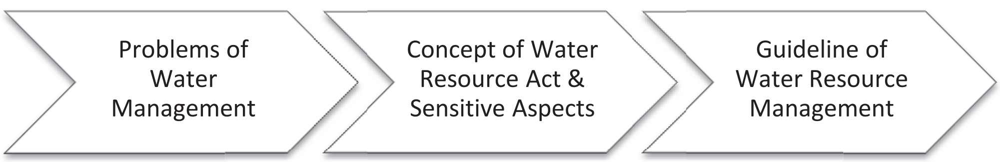


Figure 1 Process of Research Methodology

RESULT AND DISCUSSION

1. PROBLEMS OF WATER RESOURCES MANAGEMENT

The author examines water resources management problems in Thailand for addressing the cause of water problems. Nine issues mentioned as follow;

1. Water demand increases whereas water use prioritization are still lack control.[5]
2. Wastewater from the leakage of the agricultural chemical and household activities is ignored especially in the upstream areas.[6]
3. Illegal deforestation causes severe landslides and floods in the monsoon season.[7]
4. Land-use change affects biodiversity loss.[8]
5. Most of the building structure obstructs water flow in urban areas.[9]
6. Insufficient control of water use is the cause of water shortage in the dry season.[10]
7. Water users do not concern about water value because it is free.[11]
8. There is a conflict between water users in the upstream and downstream areas in the biophysical and social dynamic.[12]
9. Institution complexity of water administrators bring the overlapping implementation.[13]

Nine issues are combined into four groups for diagnosis in the next part of the research. They include 1) water allocation issue 2) water crisis management issue 3) water quality and water resources conservation issue and 4) integrated water resources management issue.

2. CONCEPT OF WATER RESOURCES MANAGEMENT IN THE ACT OF WATER RESOURCES

2.1 EQUAL WATER ALLOCATION

The problems of water management, which lack of prioritisation control and lack of awareness to save water, can improve by promoting equally water allocation and advocating the value of water. People can reach water and pay for it in a reasonable case. The concept in the Water Resources Act will support the actions and recover these issues.

Section 7 of the law formulates the basic rights of people to access public water resources. People have the right to use or keep public water resources in necessary volumes without causing damage to other people. Water allocation is identified in chapter 4, which classified the use of shared water resources into three types.

The law is established to be the primary water management law in public water resources. It is an important feature that the practical process will be diagnosed for achieving equally water allocation under this law. The researcher presents the sensitive aspects of the practical approach in this part as follow;

1. The conflict between water users in a different economic sector can occur. There is a diversity of water quantity, water quality, and geography related to the level of gravity. People who live in upstream areas have more occasions to reach water sources than downstream people. Suppose downstream areas require a majority of freshwater. In that case, they must approach the negotiation with people in upper areas for saving water, treating water sources, and launching more water to down areas.
2. The explicit criteria of water payment must be expressed. If water users in type two and type three are required for licence permission and water charge, the government must show the definition and differentiation between type one, type two, and type three. Moreover, the government must explain the method to manage fees from water charges for transparency of payers.
3. Some businesses invest by paying more money for using more water. It is not a target of the law. The law determines water payment to increase awareness of water users and stimulate them to save water.
4. Charging water can be the cause of product price raise. The producer must pay more for water because it is an essential material. If the cost of the product increases, the burden of indirect

water payment owned by general people will increase. The government should concern about this issue.

2.2 MANAGEMENT OF WATER QUALITY AND WATER RESOURCES CONSERVATION

Wastewater from the leakage of the agricultural chemical and household activities, illegal deforestation in the watershed area, and land-use change are the problems of management of water quality and water resources conservation. The Water Resources Act determines the provision to control and improve these issues.

Chapter 6 of the law is the conservation and development of public water resources. It focuses on prescribing and regulating for conserving and developing public water resources. The actions, which are the causes of pollution, danger, or damage to shared water resources, will be prohibited. Section 73 of the law concerns the environmentally protected area. The exploitation of the land, which affects public water resources, will be controlled. Section 78 advocates water users to preserve the ecology in their area. Any action causing water resources deterioration will be prohibited, such as releasing toxic substances in the river and discharging untreated water to public water resources. Water users are prerequisites for installing equipment or measures to examine water quality harm, prevent water resources damage, and resolve destroyed water sources in their area. The structure affecting public water resources will be required to be removed.

A sensitive aspect of managing water's quality and water conservation is the conflict between government officer who uses the law and people who take advantage of the area for their livelihood. The law provides the right for a government organization to determine the environmentally protected area. It can affect original people who use that area for their agriculture and habitat. For instance, there is a conflict of local people in Ka-Ching Swamp Forest, Chumporn Province, Thailand who disagree with the enforced legislation for managing and conserving this swamp forest. They think the ruling will obstruct the locals in terms of habitat and generating income. They ignore the law and still continuous destroy swamp forests for their demand.[14]

3. Guideline of Thailand's Water Management

Author proposes the measures for improving problems of water allocation and water resources conservation. Water Framework Directive (WFD) is the tool that the author uses for finding the guideline for water management.

WFD is a common framework for water management in Europe. It operates within river basin districts. The purpose of WFD is the protection of inland surface water, transitional waters, coastal water and groundwater. "Environmental good status" is the goal of WFD. Article 5 of WFD prescribes the economic analysis of water use and the environmental impact of human activities. Furthermore, article 9 of the directive determines the cost of water service. Water price will ensure efficient water use and contribute to the environmental objective.[15]

The economics of water use and environmental impact will be considered by using an economic instrument. Moreover, incentive measures are promoted to support equal water allocation. Besides, pollution control and water infrastructure are important factors for water resources conservation. There are instruments for achieving equal water allocation and water resources conservation as follows;

Non – monetary voluntary agreement is the process that water users support the management with willingness without enforcement. Water users in different areas set the voluntary agreement to allocate water from upstream to downstream.[16] For example; sharing water from Klong Wang Tanote supports the EEC area. This process can reduce the conflict of water users between different sectors. Moreover, the government can provide the agreement for farmers to motivate them to grow organic plants and avoid chemical fertilizer. It can decrease water contaminated with a chemical substance.

Payment for Ecosystem Service (PES) is an incentive measure that government uses for motivating water users to conserve water resources. This measure can encourage the cooperation of water users in the different sectors by supporting the compensation. The compensation can be a convenient infrastructure or money for supporting the community's activities. PES is not only decreasing the conflicts; but it also increases awareness of water users in the long term. Furthermore, ecosystem will be conserved by water use.

Product evaluation is the instrument to check and control the balance between water use and the value of goods. The instrument considers water use efficiency. The local government has to concern about water footprint and water use efficiency in each region.[17] Each crop requires a different quantity of freshwater. Some areas use water for their plants that have less value in the area, and they cause water stress. Product evaluation will support the government to control the prioritization for allocating water to the suitable part which gives more value.

Water tax reduction can reduce the production cost. Government should support industries by reducing the water cost for an industry that uses innovative processes or improving the procedure for saving water, treating wastewater, and producing products to encourage the awareness of water value.[18] This instrument can motivate the industries to provide efficient water use in the production process and produce more water-saving products. Besides, this measure can improve the problem of product price raise because of the production cost increase.

Subsidisation is the instrument by which government supports subsidisation to industries, farmers, or entrepreneurs who suffer from water scenarios. When the country faces a water crisis, subsidies are adapted to reduce the production cost, shift downward supply trend, reduce price, and increase the number of goods in the market. It can be price support, subsidised loan, direct payment, and tax or charges relief.[19] The process of subsidisation can reduce the side effect of water payment in water allocation which is possible to affect product price raises.

Other incentive measures include encouragement of 3R. The government will support the measure of reducing reuse and recycling continuously. Furthermore, government convince entrepreneurs to build water resource in their area.[20]

Polluter pay stimulates the responsibility of contamination sources. Industries or activities which are the cause of pollution have to pay for polluted treatment. The industries have to get the licences and establish a plan to treat the wastewater before releasing them to the public water sources.

CONCLUSION

As the first and second parts of the research, water allocation and water resources conservation are the essential water management problems in Thailand. Water will have more value by promoting equally water rights and efficiently water allocation in the Water Resources Act. The law reveals water users, who use more water, have to pay more money and present their water management plan. Moreover, the law determines the conservation and development of public water resources. The ecosystem of water sources will be concerned and water quality will be prevented. However, there are sensitive aspects of the law that governments have to consider when using the law in a practical process. Economic instrument concept and incentive measures in part three are adapted to improve water management and complete the sensitive areas of the law. It corresponds to the Water Framework Directive (WFD) which mentioned about economic analysis of water use and the environmental impact of human activities. Non – monetary voluntary agreements and PES can reduce conflict of water users and they can increase water awareness. Product evaluation can support the government to prioritize water use. Water tax reduction and subsidization can motivate industries to provide efficient water use. They can reduce the side effect of water payment which is possible to affect product price raises. Besides, Pollution pay can control water quality. The author recommends that there are not only economic and environmental parts that will be concerned for improving water management problems; the social impact has to be considered.

REFERENCES

[1][10][11] Franzetti, Francesca, Pezzoli Alessandro, and Bagliani Macro (2017), Rethinking Water Resources Management under a Climate Change Perspective: From National to Local Level. The Case of Thailand in M. Tiepolo and others (eds), Renewing Local Planning to Face Climate Change in the Tropics (Green Energy and Technology, 2017), pp. 193.

[2] Sukhsri, Chaiyuth (1999), Water Resources Law in Thailand. Faculty of Engineering, Chulalongkorn University and Department of Energy Development and Promotion (DEDP), Japan International Cooperation Agency (JICA) and The Japanese Institute of Irrigation and Drainage (JIID), pp. 3.

[3] Office of the National Water Resources (2018), the Management of Water Resources in Thailand, pp. 17.

[4][17] The University of Thammasat and TSRI (2020), *Project of Water Management which relevant with the development of Thailand's economic and socia*l, Seminar to disseminate study results.

[5] OECD (2021), Chapter 3 towards better management of water security in Thailand's Northern Region. [Online] Available: www.oecd-ilibrary.org/sites/5c065631-en/index.html?itemId=/content/component/5c065631-en. 2021, January 5.

[6] Huang, Guangwei and others (2019,) Duality Seasonal Effect and River Bend in Relation to Water Quality in the Chao Phraya River, 11(4) Water, pp. 671.

[7] Trisurat, Yongyut, Shirakawa, Hiroaki and Johnston, John M (2019), Land-Use/ Land-Cover Change from Socio-Economic rivers and Their Impact on Biodiversity in Nan Province, Thailand, 11(3) Sustainability, pp. 650.

[8] Akber, Md. Ali. and Shrestha, Rajendra Prasad (2013), Land use change and its effect on biodiversity in Chiang Rai province of Thailand, Journal of Land Use Science, http://dx.doi.org/10.1080/1747423X.2013.807315.

[9] Poaponsakorn, Nipon (2013), Impact of the 2011 Floods, and Flood Management in Thailand, 34 ERIA Discussion Paper Series, pp. 6.

[12] N.Becu et.al. (2003), Agent Based Simulation of a Small Catchment Water Management in Northern Thailand: Description of the Catchscape Model. 170/2 Ecological modelling, pp. 331.

[13] Friend, Richard and Thinphanga, Pakamas (2018), Urban Water Crisis under Future Uncertainties: The Case of Institutional and Infrastructure Complexity in Khon Kaen, Thailand, 10 Sustainability (Basel, Switzerland), pp. 2935.

[14] Suwandee, Poomchai and Thammathikul, Akkara (2020), The Problems of Law Enforcement for the Wetlands Management and Conservation: The Case Study of Ka-ching Swamp Forest, Patew, Chumpon Province, NRRU Community Research Journal 95, Vol.14, No.2, pp. 103.

[15] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000.

[16] Carmona, Maria and others (2017), Assessing the effectiveness of Multi-Sector Partnerships to manage droughts: The case of the Jucar river, Research Gate, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017EF000545.

[18][20] Interview with Mr. Nirut Koonpol, Director of Bureau of Water Management, Department of Water Resources

[19] Ray, Dolores and others (2019), Role of economic instruments in water allocation reform: lessons from Europe, International Journal of Water Resources Development, Vol.32, No. 2, pp. 228.

TC-302S

Nature Based Solutions for Sustainable Urban Storm Water Management in Global South: A Short Review

Fahad Ahmed[1,2], Shashwat Sharma[1], Ho Huu Loc[1,*], Ming Fai Chow[3]
[1] Water Engineering and Management, Asian Institute of Technology (AIT)
Klong Luang, Pathum Thani, 12120, Thailand
[2] Department of Civil Engineering, University of Sargodha
Sargodha, 40100, Pakistan
[3] Discipline of Civil Engineering, School of Engineering, Monash University Malaysia
*Corresponding author's E-mail: hohuuloc@ait.asia

ABSTRACT

Rapid urbanization in the Global South exacerbates urban water management challenges such as urban flooding and water pollution, rendering many areas water-insecure. Our reliance on grey infrastructures to combat these water management challenges is not sustainable in the long run, due to which a better alternative must be sought. Nature-based Solution (NBS) promote ecosystem services and enhance climate resiliency along with flood control and improvement of water quality by utilizing natural elements including green spaces and water bodies within the urban environment. In the past few decades, NBS have been adapted for urban drainage in Global North and evolved by means of various terms based on geographic location, practices and applications. Some of these well-known terms include Low Impact Development (LIDs), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD) and Best Management Practices (BMPs). The transition towards a resilient and sustainable environment has been made possible through the application of NBS. Recently, countries in the Global South such as Singapore, Malaysia, Vietnam, and Thailand are trying to alter urban storm water management strategies through conversion of grey infrastructure to green infrastructure by employing various NBS techniques. The findings of this study show how NBS has influenced the Global South's urban water management.

***Keywords*—**Nature Based Solutions; Sustainable Urban Water Management; Global South

1. INTRODUCTION

The global population is growing at such a rapid rate that by 2050, over 2600 million new people will be living in cities (a 68 percent increase) (UNDESA, 2012). Rapid and unplanned urbanizations, mainly in large urban areas, have led in increased impervious surfaces and, as a result, greater runoff volumes and rates. Climate change is anticipated to raise the frequency and severity of rainfall events, putting additional strain on urban hydrology and escalating the dangers of flooding (Revi et al., 2014).

The discharge of various contaminants from point and non-point sources into surface waterways in considerable volumes is triggered by heightened anthropogenic activity along with changes in land use and cover (Kabir et al., 2014). Due to washout and the deposition of various contaminants, the quality of receiving waters deteriorates during storm events. Stormwater runoff transfers and accumulates a wide range of contaminants into bodies of water, from heavy metals and pathogens to organic debris and suspended particles (Muerdter et al., 2018).

Traditional stormwater management focuses on reducing flood danger by directing surface runoff to drains and stream discharge. Although it aids in the reduction of ponding and flooding, it lacks sufficient water quality management, preventing the application of stormwater for both non-potable and potable uses (Spahr et al., 2020).

Through natural processes involving vegetation and soil, non-conventional or alternative stormwater runoff management systems have evolved with the goal of improving runoff quality, promoting evapotranspiration, and reducing surface runoff amount (Dagenais et al., 2018).

These approaches have experienced wide–ranging adoption in the Global North under various names, including SUDS (sustainable urban drainage system) in the United Kingdom (CIRIA, 2015), Water Sensitive Urban Designs (WSUD) in Australia (Water by Design, 2014), LID (low impact development) and best management practice (BMP) in North America (Fletcher et al., 2015), and Green and Blue Infrastructure in European countries (Fletcher et al., 2015; European Commission, 2019). For Global South only few countries have adapted these approaches including Sponge Cities in China (Ren et al., 2017), Singapore (ABC Waters Programme) (PUB, 2018) and Malaysia (MSMA) (DID, 2012).

The growth in usages of urban drainage terminologies like NBS, GI, BMP, SUDs, LIDs, WSUDs, and SCMs etc. has been exponential in recent times. This growth is clear evidence of a heightened social interest in urban stormwater management over recent decades. It also demonstrates the increasingly integrated nature of urban drainage as a discipline, historically part of civil engineering, with a growing focus on the ecology of receiving waters and the delivery of multiple benefits (USEPA, 2013).

BMPs in North America and SuDS in the United Kingdom–all have local roots, and only a few have gained widespread attention. For example, Australia and Europe accounted for 93 of the 352 annual citations for BMP literatures related to stormwater from 2005 to 2009. Similarly, the Australian phrase WSUD was referenced on 335 instances annually between 2010 and 2012, with 75 of those citations connected to European approaches.

As a result, urban drainage has evolved substantially in recent years, shifting from a focal point of flood protection and health security to one that considers a wide-ranging domain of environmental, sanitary, and socioeconomic considerations. Therefore, new terminology has arisen to better depict these new technologies, and as the world progresses toward a more sustainable and integrated approach, this trend is projected to continue in the near future (Fletcher et al., 2015).

The Global South is facing challenges which include aging infrastructure, depleted resources, and changing precipitation patterns in the face of growing and competing demands. Furthermore, climate change raises the likelihood of higher and more erratic precipitation, which might result in severe floods and long-term droughts. Furthermore, through producing changes in hydrological systems, urbanization has an impact on the quality and quantity of water supplies (IPCC, 2014). As a result, certain alternative solutions, or what we can term Nature-based solutions, must be adopted in order to alleviate the repercussions of the grey infrastructure gap. This will necessitate the employment of NBS to pay off for the dwindling quantity and quality of citizens' water sources, which rely on environmentally sensitive "natural" processes for their urban water security.

Several "sustainable" phrases for urban water management have emerged, particularly in industrialized countries with temperate climates. Consequently, we're seeing waves of paradigm shifts as these schools of thought are conveyed to developing countries, either through scientific research conducted by graduate students from these countries or through ODA-funded consultancy projects. Despite the fast growing literature, real application of those terminologies in poor countries of the Global South remains limited due to a range of ground-level constraints like as limited resources and changing hydrometeorological conditions. As a result of this research, it may be possible to make a more informed decision about which terminology to adapt, as well as get a better understanding of various terminologies. It would also help city planners and developers make more educated judgments about which urban water management terminologies to utilize.

2. METHODS

The "Scopus" database was searched for articles describing the application of Nature-based Solutions for urban water management in the Global South. "Nature based Solutions" or "Low Impact Development" or "Green Infrastructure" or "Urban water Management" or "Water Sensitive Urban Design" were the keywords we used in our "Scopus" search. The publication period was limited from 2000 to 2021. Following the receipt of search results, we narrowed the search by limiting articles about the application of nature-based solutions for urban water management in the Global South. In China, Hong Kong, Thailand, Malaysia, Brazil, and Africa, we looked at 20 NBS applications for urban water management.

Furthermore, different NBS techniques are discussed in Table 1 and compared with each other.

TABLE 1: COMPARISON OF DIFFERENT NBS TECHNIQUES WITH BENEFITS

SN	NBS Technique	Description	Benefits
1	Rainwater harvesting / Rain Barrels	Rain barrels are the containers which collect stormwater from roofs and the water can be reused for potable or non-potable purposes in dry periods.	i. Additional water supply source ii. Prevent urban flooding
2	Green roofs	Green roofs have soil layer and a special drainage mat material which convey surplus stormwater from the roof to the drainage system	i. Reduced runoff peaks and volumes ii. Lower flood risks iii. Insulation of heat transfer iv. Low cost for air-conditioning v. Reduced heat island effect vi. Reduced Air pollution vii. Increased biodiversity
3	Rain Gardens/ Bioretention systems	Rain Gardens or Bioretention systems are depressions in soil that contain vegetation in an engineered soil above a gravel / sand drainage bed. It provides storage, evaporation and infiltration.	i. Reduced runoff peaks and volumes ii. Improved water quality iii. Lower flood risks iv. Reduced Air pollution v. Prevent urban flooding vi. Increased biodiversity
4	Pervious pavements	Permeable pavements are the pavements made by gravel and paved by porous concrete or paving block or porous bricks which can infiltrate rainwater and convey water to drainage system.	i. Reduced runoff peaks and volumes ii. Lower flood risks iii. Improved water quality iv. Prevent urban flooding
5	Infiltration trenches	Infiltration trenches are the narrow ditches filled with gravel to intercept runoff from the impervious area present at upslope.	i. Reduced runoff volumes ii. Lower flood risks iii. Prevent urban flooding
6	Vegetative swales	Vegetative swales are the channels with sloping sides covered with vegetation or grass. It collects the stormwater and conveys and infiltrates it.	i. Reduced runoff peaks and volumes ii. Lower flood risks iii. Improved water quality iv. Prevent urban flooding

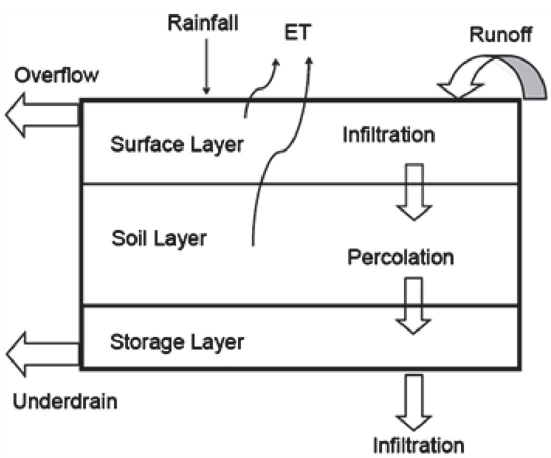


Fig. 1. Typical Structure of vertical layers in Bioretention system (Adapted from USEPA., 2000)

3. RESULTS AND DISCUSSIONS

3.1 THE LITERATURE

The list of noteworthy research on sustainable water management techniques in the global south is presented in Table 2. It should be noted that the list presented is nowhere near exhaustion since this paper is intentionally position as a "short review". China, including Hong Kong, has the most studies, with ten, followed by Malaysia, which has four, and Thailand and Brazil, which each have two. Ethiopia (East Africa) and South Africa are the other countries with one study each. Modeling, which consists of 13 investigations that are either physical or numerical in nature, is the predominant approach of the methodology. Field-based monitoring paired with social surveys is another noteworthy strategy. The most popular types of NBS and the associations are bioretention cells. Moreover, different terminologies have been used and followed in the studies; among them for China and Hong Kong mostly LID and Sponge city were used. Whereas, for Malaysia the emphasis was on MSMA and BMP as the guidelines for MSMA have been developed from BMPs. For Thailand, the term NBS is mostly used as it is a new and evolving term there for urban water management. For South Africa no specific term was found while for South America (Brazil) LID term was utilized.

TABLE 2: APPLICATIONS OF NBS IN GLOBAL SOUTH.

SN	Documents	Study aims	Geographical region	Methods	Terminologies	Type of NBS	Key Findings
1	Yang and Chui., 2018	To propose a method for formulating suitable sizing criteria for multi-objective stormwater management.	Hong Kong	Numerical modelling	LID	Bio-retention system	Lowered runoff volume and peak flow
2	Gao et al., 2021	To simulate the effect for the combinations of LID facilities.	China	Numerical modelling	LID	Rain garden, Green roof, Permeable pavement	i. Improved runoff control rate ii. Improved SS load reduction rate iii. Combined NBS facilities have better regulatory effects than single NBS facility
3	Zhang et al., 2020	To evaluate the Sponge City strategy's control of stormwater runoff volume and quality.	China	Numerical modelling	Sponge City and LID	Rain Garden, Bioretention, Grass pitch	i. Reduced flooding risks ii. Maintained water quality iii. Improved ecosystem services
4	You et al., 2019	To evaluate the performance of bioretention systems with alkaline solid wastes	China	Physical Modelling	BMP	Bio-retention system	Enhanced removal of nutrients (Phosphorus and Nitrogen) in a simulated stormwater runoff
5	Luo et al., 2020	To investigate the performance of bilayer media bioretention system	China	Physical Modelling	Sponge City	Bio-retention system	i. Higher Nitrogen removal efficiency ii. Longer hydraulic residence
6	Mai and Huang.,2021	To investigate the performance of biochar-amended bioretention facilities	China	Physical Modelling	Sponge City and LID	Bio-retention system	NBS can effectively control runoff volume and remove rainfall-runoff pollutants
7	Zhang et al., 2019	To examine the performance of a mixed-flow bioretention system	China	Physical Modelling	LID	Bio-retention system	The mixed-flow bio-retention can effectively improve TN and COD mass removal.
8	Song and Song., 2018	To evaluate the performance of an artificial bioretention system	China	Physical Modelling	LID	Bio-retention system	Bio-retention systems have favorable removal effect on

SN	Documents	Study aims	Geographical region	Methods	Terminologies	Type of NBS	Key Findings
							Phosphorus in rainwater runoff.
9	Wan et al. 2018	To evaluate the performance of wood-chip bioretention system	China	Monitoring / Analysis	LID	Bio-retention system	For the field performance, wood-chip bio-retention system effectively removes nitrogen.
10	Li et al., 2021	To assess the performance of inverted bioretention	China	Physical Modelling	LID	Bio-retention system	i. Increased efficiency for the total runoff reduction and peak flow reduction by inverted bio-retention system. ii. Good performance on nitrate removal was exhibited
11	Liew et al., 2012	Evaluation of detention pond for stormwater quantity control	Malaysia	Numerical modelling	MSMA	Dry detention pond	The detention pond achieved the goal by catering the flow and protecting against flooding
12	Ayub et al.,2015	Green roof tested for high intensity stormwater runoff for quantity and quality of metals (Lead and potassium)	Malaysia	Physical Modelling	BMP, SUDs and MSMA	Green roof	The results showed that reduction in the runoff for high intensity stormwater was very promising.
13	Shaharuddin et al.,2014	To use constructed wetlands for stormwater quality control	Malaysia	Monitoring / Analysis	MSMA	Constructed wetland	The concentration of nutrients such as nitrogen, phosphate nitrite, nitrate, ammonia was significantly reduced
14	Sim et al., 2008	To use constructed wetland to treat surface runoff from developed urban area	Malaysia	Monitoring / Analysis	MSMA	Constructed wetland	The removal efficiency of nutrients was satisfactory for Total nitrogen, nitrate and phosphate.
15	Vojinovic et al.,2021	To examine the efficacy of different types of NBS (i.e., small- and large-scale NBS) and their	Thailand	Interviews / Numerical	NBS and EBA	Small-scale and Large-scale NBS	i. The effectiveness of small-scale NBS is limited to smaller rainfall events

SN	Documents	Study aims	Geographical region	Methods	Terminologies	Type of NBS	Key Findings
		hybrid combinations with grey infrastructure		modelling			ii. The extreme events require combinations of different kinds of measures (hybrid measures)
16	Majidi et al.,2019	To assess the effectiveness of small-scale urban nature-based solutions to reduce flooding and enhance human thermal comfort	Thailand	Numerical modelling	BMP and NBS	Green roof, Pervious pavement, Bioretention, Rain garden	The usage of a variety of various solutions at different sites can lead to effective flood mitigation and thermal comfort increase.
17	Haddis et al.,2020	To evaluate the performance of constructed wetland in a tropical climate under suboptimal conditions of flow	Ethiopia (East Africa)	Monitoring / Analysis	Others	Constructed wetland	i. Constructed wetlands can function well under irregular flow conditions ii. Can be the technology of choice in low income countries (particularly in tropical climates).
18	Belle et al.,2018	To investigate the effectiveness of NBS to reduce drought, veld fires and floods using wetlands	South Africa	Questionnaires / interviews / field observations.	Others	Wetlands	Healthy wetlands are effective buffers in reducing disaster risks such as drought, veld fires and floods
19	Filho et al., 2021	To assess the performance of constructed wetland for the Greywater treatment under Tropical Conditions	Brazil	Monitoring / Analysis	Others	Constructed wetland	The outputs of the study: i. Will contribute to optimal design and operation of a Constructed wetlands ii. Will contribute with empirical data to Constructed wetlands guidelines in Brazil

SN	Documents	Study aims	Geographical region	Methods	Terminologies	Type of NBS	Key Findings
20	de Macedo et al.,2019a	To assess the performance of a bioretention basin in a subtropical climate area	Brazil	Monitoring / Analysis	LIDs	Bio-retention system	i. Delayed and reduced peak flows. ii. Retained greater volume of runoff

3.2. THE "OLD" CONCEPTS

i. LOW IMPACT DEVELOPMENT (LID)

The phrase "low impact development" (LID) is generally used in North America and New Zealand. Barlow et al. (1977) are credited with being the first to make use of the term in a land use planning report in Vermont, USA. The LID can be defined as the approaches for reducing impervious cover and maintaining/retaining natural areas through site design. In recent years, low-impact development approaches have been applied in several studies for numerous nations in the Global South. In two studies conducted by Macedo et al. (2019a and 2019b) for stormwater management in Brazil, bioretention systems (a technology of Low Impact Development practices) were shown to postpone and reduce peak flows, and the system retained a greater amount of runoff volume. Furthermore, the peak flow attenuation was significant.

ii. BEST MANAGEMENT PRACTICE (BMP)

The term "best management practice" (BMP) indicates a systematic method to pollution avoidance that was developed in North America, specifically the United States of America and Canada. It also refers to stormwater management strategies that address one or both of the water quality and quantity concerns.

In the context of stormwater management, BMPs link non-structural interventions (such as good housekeeping and preventive maintenance) with structural deployments (such as bioretention systems or green infrastructure) to achieve the overall goal of pollution control. Individual and combined LID-BMPs for urban stormwater management were examined in Malaysia.

Goh et al., 2017 used enhanced bioretention with carbon source additive in a Mesocosm study (Engineering Campus Universiti Sains Malaysia USM, Nibong Tebal, Penang, Malaysia) to investigate nutrient removal efficiency and found that bioretention has a potential application for nutrient rich stormwater in mixed land.

Furthermore, Chang et al., 2018 conducted a field study in Kwasa Damansara, Selangor, Malaysia, using an engineered channel ecological swale and a detention pond to investigate the use of a treatment train for stormwater issues such as flooding and runoff quality control. They discovered that the treatment train was the long-term solution for stormwater issues i.e., floods and runoff quality control.

iii. SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

The term "sustainable urban drainage systems" (SUDS) was described in an extensive set of standards published in 2000, which included design manuals that were equivalent but not identical for England, Scotland, Northern Ireland, and Wales (CIRIA, 2000).

SUDS are a collection of technologies and methods for draining stormwater/surface water that are more environmentally friendly than traditional approaches. SuDS in England and Wales are more concerned with water quantity control than with water quality control.

iv. WATER SENSITIVE URBAN DESIGN (WSUD)

Mouritz (1992) was the first practitioner in Australia to use the phrase "water sensitive urban design" (WSUD), which was swiftly followed by Whelans et al. in a report for the Western Australian Government (1994). The Water Supply, Sewerage, and Stormwater Management (WSUD) initiative covers all aspects of integrated urban water cycle management, including water supply, sewerage, and stormwater management. The United Nations' World Summit on Sustainable Development sparked a slew of related concepts, including climate-sensitive urban development (Coutts et al., 2013).

3.3. THE "NEW" WAVES

i. NATURE BASED SOLUTIONS (NBS)

Approaches to developing new transdisciplinary knowledge and applications in urban ecosystems have evolved and integrated a number of metaphors throughout the previous half-century. In roughly chronological order, ecosystem services (ES), green infrastructure (GI), and, more recently, nature-based solutions are presented (NBS).

The International Union for Conservation of Nature (IUCN) is a prominent supporter of NBS, and in 2020, it will launch the Global Standard for NBS. NBS is defined by the IUCN as "activities to protect, sustainably manage, and restore natural and modified ecosystems in ways that effectively and adaptively solve societal concerns, providing both human welfare and biodiversity benefits." The necessity of recognizing the necessity to create mutual benefits for people and the ecosystem is emphasized in the concept.

According to the authors of the 2018 UN World Water Development Report (WWAP 2018), NBS can help in three areas: enhanced water availability, improved water quality, and reduced water-related risks.

There are numerous researches that address the advantages of adopting NBS. Cui et al., 2021, for example, relates the narrative of two cities, describing Singapore and Lisbon's paths toward developing adaptive and resilient urban water management strategies utilizing NBS. Through NBS, these cities have been transitioning from concrete "grey" infrastructure to "blue and green" infrastructure, despite their historical, climatic, economic, and cultural differences. These cities have shown how to turn ecological challenges into opportunities by implementing NBS, changing urban environments into healthy and enjoyable places to visit, live, and work. Figure 2 shows the ecosystem services provided by nature-based solutions.

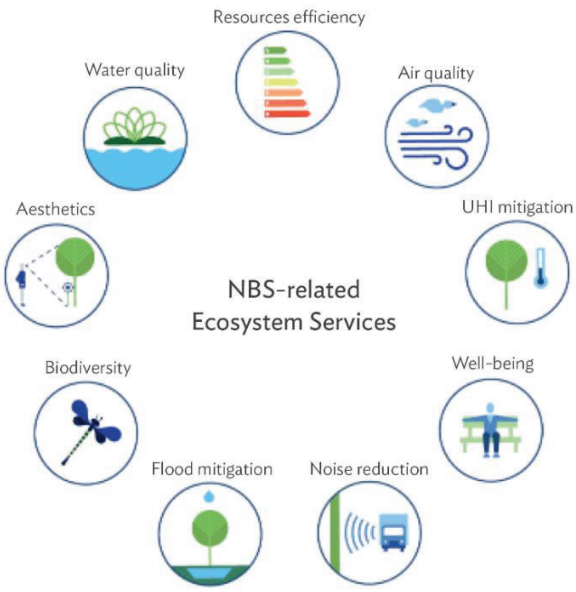


Fig. 2. NBS = nature-based solution, UHI = urban heat island (Adopted from Bozovic et al., 2017)

ii. ECOSYSTEM BASED ADAPTATION (EBA)

Ecosystem-based adaptation (EBA), which is defined as methods that leverage natural or managed biophysical systems (ecosystems) and processes to achieve adaptation goals, is gaining popularity as a useful tool for improving soil and water conservation strategies and agricultural development. EBA provides a broad array of advantages that concentrate on ecosystem repair, conservation, and long-term management. By restricting nutrient and sediment input in rivers and streams, EBA measures have a significant impact on sustaining surface water quality (Gathagu et al., 2018).

Filter strips, sediment ponds, grassed rivers, grade stabilization structures, stream stabilization structures, and agricultural management methods are examples of EBA structural measures. No-tillage and nutrient management strategies are examples of non-structural EBA measures.

Many scholars have recently discovered EBA to be a beneficial strategy for addressing water-related challenges in the Global South. Babel et al., 2021, for example, discussed the value of incorporating EBA measures into sediment management strategies to combat watershed deterioration in Thailand. Despite the growing adoption of EBA around the world, there is little research on its efficiency and efficacy in countries like Thailand and the rest of the Global South.

iii. NATURE BASED SOLUTIONS PROJECTS IN KINGDOM OF THAILAND

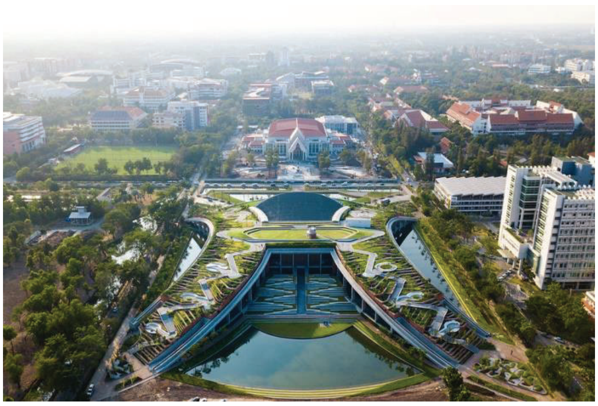
In Thailand, nature-based solutions are becoming more popular. Many NBS developments have been completed, including the Puey Ungphakorn Centenary Hall and Park and the Chulalongkorn University Centenary Park. The following is a brief explanation of the above-mentioned NBS projects and their goals.

Puey Ungphakorn Centenary Hall and Park

The Puey Ungphakorn Centenary Hall and Park is located in Thammasat University, Pathum Thani Province of Thailand with an area of approximately 60,000 square metres. The park is designed to tackle issues like climate change and urbanization. The main concern of the project is to manage and alleviate the risk of food and water scarcity. The park consists of a Green Roof Urban Farm" is the largest of its kind in Asia and the third largest in the world. The park's motto is to contribute to society and its residents in the form of clean air and reduced temperature inside the Puey Ungphakorn Centenary Hall.

Chulalongkorn University Centenary Park

This NBS projects is located in the heart of Bangkok with an area of about 44,800 square meters. The main concept of this project is to reduce risks of urban floods in surrounding areas. The design capacity of the park is approximately a million gallons of water. The components of this NBS project include a water retention pond, a constructed wetland, green roof, water retention lawn and rain garden. The park provides to the society in the form of urban flood mitigation, air pollution control and other services to the people like relaxing and exercise in its leisure area.



Puey Ungphakorn Centenary Hall and Park

Chulalongkorn University Centenary Park

iv. SPONGE CITY STRATEGY

The Chinese central government launched the Sponge City Initiative in 2014 to address stormwater issues (MOHURD, 2014). LIDs (Li et al., 2020), WSUDs, and SuDS are all techniques related to Sponge City. It does, however, have distinct regional characteristics due to rapid and expanded development, which has resulted in serious flooding and pollution challenges. Sponge City intends to employ NBS to execute stormwater management, with multi-functional goals such as reducing urban flood risk, capturing, purifying, and storing more rainwater for potable and non-potable uses, and providing additional ecological advantages through shared green areas (Chan et al., 2018).

3.3. FUTURE OUTLOOKS

Engineering and architecture must act together to design systems for urban water management that are centered on natural solutions. Because engineers are more concerned with managing water quantity and end up with grey infrastructure that ignores water quality, while architects are more concerned with aesthetics, other aspects such as biodiversity, economics, and social welfare are overlooked.

Consequently, a system that can provide all of the aforementioned benefits while still being low-maintenance is desirable. Many regions in the global south have been plagued by calamities such as floods and droughts for decades, and because they are economically weak, the above-mentioned structure for urban water management is essential.

The Covid-19 pandemic has shown how vulnerable many of our city systems are. As the globe concentrates on economic recovery initiatives, which are likely to involve water management infrastructures and better water services, NBS for creating resilient, livable, affordable, and equitable cities should receive special emphasis. The Covid-19 recovery plans provide a fantastic opportunity to expand NBS in Global South countries, with the objective of better protecting, conserving, and rebuilding ecosystems and their services.

4. CONCLUSIONS

Given the global rise in urbanization, changing climate, and urban stormwater repercussions on human and marine habitats, urban water management is a crucial topic. The urban water cycle and drainage management have seen significant changes throughout time. LIDs, SUDs, WSUDs, and BMPs, among other techniques, have been accepted by the Global North to solve challenges (especially urban floods and water pollution) connected to urban water drainage and management, and these strategies have shown to be beneficial in resolving the aforementioned difficulties.

Considering the Global South, there has been a favorable tendency in the past decades to adapt nature-friendly approaches such as sponge cities in China and EBA in various locations of the Global South. These approaches and strategies have mostly been adapted from the Global North to countries in the Global South. However, due to climate differences (temperate climate in the Global North vs. mostly tropical climate in the Global South), it is difficult to achieve fruitful results (due to changes in meteorological and hydrological conditions) by implementing those approaches in many regions of the Global South (i.e., Thailand, Malaysia, Singapore, Brazil, African countries etc.).

Because the region we're concerned about is mostly made up of poor countries with weak economies, there are barriers to implementing new policies like NBS and EBA, such as associated costs and local people's desire.

Therefore, the study concludes that public awareness and collaboration from local government entities are needed to implement NBS for urban drainage. As the globe faces numerous issues, such as changing climate, overpopulation, and rapid urbanization, anomalies in the hydrologic cycle result in floods and droughts, among other things; on the other side, dirty water disrupts aquatic ecosystems and biodiversity. There is a critical need to use efficient initiatives such as NBS.

REFERENCES:

(1) Ayub K R., A A Ghani., N A Zakaria. (2015). Green Roof: Vegetation Response towards Lead and Potassium, 1st Young Sci. Int. Conf. Water Resour. Dev. Environ. Prot. no June. 5–7.

(2) Babel, M.S., Gunathilake, M.B., Jha, M.K. (2021). Evaluation of Ecosystem-Based Adaptation Measures for Sediment Yield in a Tropical Watershed in Thailand. Water, 13 2767. https://doi.org/10.3390/w13192767.

(3) Belle, J.A., Collins, N. & Jordaan, A. (2018). Managing wetlands for disaster risk reduction: A case study of the eastern Free State, South Africa, Jàmbá: Journal of Disaster Risk Studies 10 1 a400. https://doi.org/10.4102/jamba.v10i1.400.

(4) Bozovic, R., C. Maksimovic, A. Mijic, M. Van Reeuwijk, K. Smith, and I. Suter. (2017). Blue Green Solutions, A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development. Imperial College London. Blue Green Dream project, Climate-KIC, European Institute for Innovation and Technology.

(5) Chan, F.K.S., et al., (2018). “Sponge City” in China—a breakthrough of planning and flood risk management in the urban context. Land Use Policy 76, 772–778.

(6) Chang C K., N A Zakaria., M R Othman. (2018). MATEC Web Conf. 246 01112.

(7) CIRIA, (2000). Sustainable urban drainage systems - design manual for Scotland and Northern Ireland. Dundee, Scotland: CIRIA Report No. C521.

(8) CIRIA. (2015). The SuDS manual. https://www.ciria.org.

(9) Coutts, A.M., Tapper, N.J., Beringer, J., Loughnan, M., and Demuzere, M., (2013). Watering our cities the capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. Progress in Physical Geography, 37 (1), 2–28.

(10)Cui, M.; Ferreira, F.; Fung, T.K.; Matos, J.S. (2021). Tale of Two Cities: How Nature-Based Solutions Help Create Adaptive and Resilient Urban Water Management Practices in Singapore and Lisbon. Sustainability, 13, 10427. https://doi.org/10.3390/ su131810427.

(11)Dagenais, D., Brisson, J., Fletcher, T.D. (2018). The role of plants in bioretention systems; does the science underpin current guidance? Ecol. Eng. 120 532–545.

(12)De Macedo, M.B., Ambrogi Ferreira do Lago, C., Mendiondo, E.M., M, H.G. (2019a). Bioretention performance under different rainfall regimes in subtropical conditions: a case study in Sao Carlos, Brazil. J. Environ. Manag. 248 109266.

(13)De Macedo, M.B., do Lago, C.A .F., Mendiondo, E.M., (2019b). Stormwater volume reduction and water quality improvement by bioretention: potentials and challenges for water security in a subtropical catchment. Sci. Total Environ. 647, 923-931.

(14)Department of Irrigation and Drainage Malaysia (DID). (2012). Urban Stormwater Management Manual for Malaysia (MSMA). Kuala Lumpur, Malaysia.

(15)European Commission. (2019). Natural Capital Accounting: Overview and Progress in the EuropeanUnion, 6th Report. https://ec.europa.eu.

(16)Fletcher, T. D., et al. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7) 525–542. https://doi.org/10.1080/1573062X.2014.916314.

(17)Gathagu, J.N.; Sang, J.K.; Maina, C.W. (2018). Modelling the Impacts of Structural Conservation Measures on Sediment and water yield in Thika-Chania Catchment, Kenya. Int. Soil Water Conserv. Res. 6, 165–174.

(18)Goh H W., N A Zakaria ., T L Lau., K Y Foo., C K Chang., C S Leow. (2017). Urban Water J. 14 2 134–142.

(19)Haddis A., Bruggen B V d., Smets I. (2020). Constructed wetlands as nature based solutions in removing organic pollutants from wastewater under irregular flow conditions in a tropical climate, Ecohydrology & Hydrobiology. 20 38–47.
(20)Jiayu Gao, Jiake Lia, Yajiao Li, Jun Xia, Peng Lv. (2021). A Distribution Optimization Method of Typical LID Facilities for Sponge City Construction, Ecohydrology & Hydrobiology 21, 13–22.
(21)Kabir, M.I., Daly, E., Maggi, F. (2014). A review of ion and metal pollutants in urban green water infrastructures. Sci. Total Environ. 470–471, 695–706.
(22)Li, L., Collins, A.M., Ali Cheshmehzangi, A., Chan, F.K.S., (2020). Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China. Urban For. Urban Green. 54, 126770.
(23)Liew Y S., Z Selamat., A A Ghani ., N A Zakaria. (2012). Performance of a dry detention pond: case study of Kota Damansara, Selangor, Malaysia, Urban Water J. 9 2 129–136.
(24)Luo, Y., Yue, X., Duan, Y., Zhou, A., Gao, Y., Zhang, X., (2020). A bilayer media bioretention system for enhanced nitrogen removal from road runoff. Sci. Total Environ. 70 5 135893. https://doi.org/10.1016/j.scitotenv.2019.135893.
(25)Magalhães Filho, F.J.C.; de Souza Filho, J.C.M.; Paulo, P.L. (2021). Multistage Constructed Wetland in the Treatment of Greywater under Tropical Conditions: Performance, Operation, and Maintenance. Recycling, 6, 63. https:// doi.org/10.3390/recycling604006.
(26) MOHURD (2014) (Ministry of Housing and Urban-Rural Development of the People’s Republic of China), Technical Guidelines for Sponge City Construction (in Chinese).
(27)Mouritz, M., (1992). Sustainable urban water systems; policy & pofessional praxis. Perth, Australia: Murdoch University.
(28)Muerdter, C.P., Wong, C.K., LeFevre, G.H. (2018). Emerging investigator series: the role of vegetation in bioretention for stormwater treatment in the built environment: pollutant removal, hydrologic function, and ancillary benefits. Environ. Sci.: Water Res. Technol. 4 (5) 592–612.
(29)PUB. (2018). Active, Beautiful, Clean Waters Design Guidelines, fourth Ed. https:// www.pub.gov.sg/Documents/ABC_Waters_Design_Guidelines.pdf.
(30)Ren,N., Wang, Q., Wang, Q., Huang, H., Wang, X. (2017). Upgrading to urban water system 3.0 through sponge city construction. Front. Environ. Sci. Eng. 11 9. Retrieved from http://water. epa.gov/infrastructure/greeninfrastructure/index.cfm.
(31)Revi A, Satterthwaite D.E., Aragón-Durand F., Corfee-Morlot D., Kiunsi R.B.R., Pelling M., Solecki W., Urban areas: Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., White (Eds.) L.L. (2014). Climate Change: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change., Cambridge University Press, Cambridge, UK and New York, NY, USA
(32)Shaharuddin S., N W Chan., N A Zakaria., A A Ghani., C K Chang., R Roy. (2014). Constructed Wetlands as a Natural Resource for Water Quality Improvement in Malaysia Sci. Res. 05 07 292–298.
(33)Sim C H., M K Yusoff., B Shutes., S C Ho., M Mansor. (2008). Nutrient removal in a pilot and full scale constructed wetland, Putrajaya city, Malaysia. J. Environ. Manage. 88 2 307–317.
(34)Song, Y., Song, S. (2018). Migration and transformation of different phosphorus forms in rainfall runoff in bioretention system. Environ. Sci. Pollut. Res, 3 1–8. https://doi. org/10.1007/s11356-018-2405-4.
(35)Spahr, S., Teixid O, M., Sedlak, D.L., Luthy, R.G. (2020). Hydrophilic trace organic contaminants in urban stormwater: occurrence, toxicological relevance, and the need to enhance green stormwater infrastructure. Environ. Sci. Water Res. Technol. 6 15-44.
(36)UNDESA. (2012). World Urbanization Prospects: the 2012 Revision.

(37)USEPA. (2000). Low-Impact Development (LID): A Literature Review (Report), 35.
(38)USEPA. (2012). Green infrastructure.
(39)Vojinovic Z., Alves A, Gómez J P, Weesakul S, Keerakamolchai W., Meesuk V., Sanchez A. (2021). Effectiveness of small- and large-scale Nature-Based Solutions for flood mitigation: The case of Ayutthaya, Thailand. Science of the Total Environment. 789 147725.
(40)Wan, Z.X., Li, T., Liu, Y.T. (2018). Effective nitrogen removal during different periods of a field scale bioretention system. A. Environ. Sci. Pollut. Res. 25 17855 – 17861. https://doi.org/10.1007/s11356-018-1954-x.
(41)Water by Design. (2014). Bioretention Technical Design Guidelines.
(42)WWAP (United Nations World Water Assessment Programme)/UN-Water. (2018). The United Nations World Water Development Report 2018: Nature-Based Solutions for Water; UNESCO: Paris, France.
(43)Yang, Y., Chui, T.F.M. (2018). Optimizing surface and contributing areas of bioretention cells for stormwater runoff quality and quantity management. J. Environ. Manag. 206 1090–1103.
(44)Yang, Y., Chui, T.F.M. (2018). Optimizing surface and contributing areas of bioretention cells for stormwater runoff quality and quantity management. J. Environ. Manag. 206 1090–1103.
(45)Yepeng Mai, Guoru Huang. (2021). Hydrology and rainfall runoff pollutant removal performance of biochar amended bioretention facilities based on field scale experiments in lateritic red soil regions, Science of the Total Environment. 76 143252.
(46)Yuqing Li, Yu Zhang, Heng Yu, Yuan Han, Jiane Zuo. (2021). Enhancing nitrate removal from urban stormwater in an inverted bioretention system. Ecological Engineering. 170 106315.
(47)Zhang, W., Sang, M., Che, W., Sun, H. (2019). Nutrient removal from urban stormwater runoff by an up-flow and mixed-flow bioretention system. Environ. Sci. Pollut. Res. 26 17731–17739. https://doi.org/10.1007/s11356-019-05091-4.
(48)Zhang, Y.; Zhao, W.; Chen, X.; Jun, C.; Hao, J.; Tang, X.; Zhai, J. (2021). Assessment on the Effectiveness of Urban Stormwater Management.Water 13 4. https://doi.org/10.3390/w13010004.
(49)Zhaoyang You, Li Zhang, Shu-Yuan Pan, Pen-Chi Chiang, Silu Pei, Shujuan Zhang. (2019). Performance evaluation of modified bioretention systems with alkaline solid wastes for enhanced nutrient removal from stormwater runoff, Water Research 161 61-73.

TC-303S

Assessing the Sustainable Development of Oil Palm Industry in Thailand

A Life Cycle Assessment Approach

Jun-Jun Ma
Department of Environmental Science and Technology
Saitama University
Saitama, Japan
ba.g.227@ms.saitama-u.ac.jp
Takeshi Fujino
Department of Environmental Science and Technology
Saitama University
Saitama, Japan
fujino@mail.saitama-u.ac.jp
Wilailuk Niyommaneerat
Environmental Research Institute
Chulalongkorn University
Bangkok, Thailand
Orathai Chavalparit
Department of Environmental Engineering
Chulalongkorn University
Bangkok, Thailand

Abstract

In 2018, the global palm oil production and consumption were 70.6 million tons and 66.4 million tons, respectively. Thailand is the third largest palm oil producer, accounting for 3.9% of the global palm oil production. In 2018, the total area of oil palm plantation in Thailand reached 922,000 ha, and it has grown by about 4.5% over the past 10 years (2009-2018). In the same period, the output of fresh fruit bunch (FFB) reached 15.39 million tons. About 240,000 workshops on the production and processing of this product have been established. As the oil palm plantation area has been continuously increasing since 2009, greenhouse gas (GHG) emissions have increased yearly, global palm oil inventories are high, and oil palm prices would continue to be pressured by oversupply. In 2016, Thailand's per capita ecological footprint (EF) was 2.5 global hectares (gha), and its per capita biocapacity (BC) was 1.2 gha. Its biocapacity is less than 1.3. In this research, we aim for a sustainable development of Thailand's oil palm industry. System boundaries were formulated for the four oil palm plantation regions in Thailand, namely, the northern, northeastern, central, and southern regions. The life cycle inventory (LCI), a global greenhouse gas calculation model, and an EF calculation method were used to determine the GHG emissions palm oil in each of these regions in Thailand and Thailand's EF. GHG emissions are expressed in terms of carbon dioxide equivalent (CO_2eq) and net value. Thailand's oil palm plantations and palm oil processing areas are mainly distributed in the south. The CO_2eq per ton of FFBs in Thailand's oil palm plantations is 113.8 kgCO_2eq. The CO_2 eq per ton of CPO produced by a palm oil processing plant is 1000.4 kgCO_2eq, excluding biogas recovery equipment. The average EF of Thai oil palm is 21.6 gha/ha-year. The ratio of income to EF is 53.9 USD/gha. The ratio of income to EF in the southern area is 69.3 USD/gha. Although the total amount of GHG emissions in southern Thailand is high, the CO_2eq harvested per ton of FFBs is the smallest and the ratio of revenue to EF is the highest. Compared with the southern region, the northern and eastern regions need to invest more fertilizers and energy in oil palm cultivation. The cost is higher, and the market price of CPO is less competitive.

Keywords: GHG emission, Sustainable development, Ecological footprint

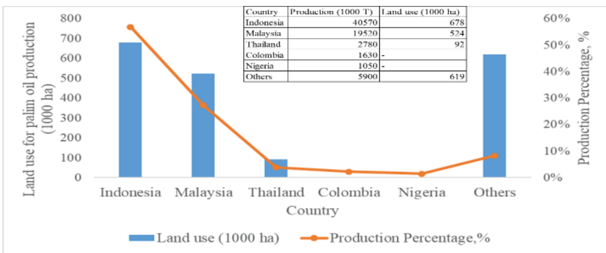
Introduction

At present, the main producers of palm oil are the members of the Association of Southeast Asian Nations (ASEAN). In 2018, the global palm oil production and consumption were 70.6 million tons and 66.4 million tons, respectively. Palm oil accounted for 35.7 and 38.6% of global vegetable oil production and consumption, respectively. Fig. 1 shows the Land use for palm oil production and production in 2018. Currently, Malaysia and Indonesia are the world's biggest palm oil producers where the production of both countries is 84% of the world palm oil production. Thailand is the third largest palm oil producer, accounting for 3.9% of the global palm oil production [1].

With the continuous expansion of the palm oil industry in Thailand, primary forests are often logged to establish oil palm plantations. Fig. 1 shows that land use for palm oil production was 922000 hectares in 2018, and it has grown by about 4.5% over the past 10 years (2009–2018). The rapid development of the palm oil industry has negative effects on sustainability, especially the impact of land use changes and greenhouse gas (GHG) emissions on the environment [2,3].

Thailand's palm oil production chain is complete, including oil palm plantations, crude palm oil extraction, edible oil refining, and biodiesel production. The production of crude palm oil (CPO) is mainly divided into the wet and dry extraction processes. Our survey showed that the wet extraction process is generally used to convert FFBs into CPO in Thailand. To promote the sustainable production of CPO, good system management is required to reduce the impact of solid waste, wastewater, and GHG emissions on the environment. International organizations, such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC), which contribute to decreasing national GHG emissions, and clean development mechanism projects, developed a method that takes into account GHG emissions. In 2016, the per capita EF in Thailand was 2.5 gha, whereas the per capita BC was 1.2 gha. Its biocapacity deficit was 1.3 gha. The lack of biocapacity mainly comes from the carbon footprint component in the ecological footprint assessment. This result shows that Thailand must use resources elsewhere to maintain the lifestyle of the country's current population [2,4].

In this paper, we characterize the current Thai palm oil industry by formulating the research system boundary on the basis of oil palm planting and palm oil production using the GWAPP method to calculate greenhouse gas emissions. Then we discuss oil palm planting and palm oil production, and the main greenhouse gas emission process. The greenhouse gas emissions were quantified for every ton of FFBs harvested, every ton of CPO processed and produced in the Thai palm oil industry. Combined with the carbon footprint analysis model of oil palm planting, the economic benefits in terms of net oil palm income were determined. When calculating the ratio of revenue to EF, the EF of oil palm plantations was used. The purpose of this study is to determine the EF of palm plantations, evaluate the EF of FFBs of oil palm plantations, and determine the ratio of oil palm plantation revenue to EF [4].



Country	Production (1000 T)	Land use (1000 ha)
Indonesia	40570	678
Malaysia	19520	524
Thailand	2780	92
Colombia	1630	-
Nigeria	1050	-
Others	5900	619

Figure 1: Land use for palm oil production and production in 2018

1 Oil palm planting and palm oil production

1.1 Oil palm cultivation, geographical and climatic factors

Thailand is located between latitudes 5°37'N to 20°27'N and longitudes 97°22'E to 105°37'E, with a total area of 513,115 km^2. Thailand has a tropical monsoon climate. There are three seasons a year. The annual temperature is no lower than 18°C, the average temperature is about 28°C, and the average annual precipitation is about 1,000 mm. The precipitation is relatively abundant, but it is affected by the topography and monsoon [5]. Because oil palms have certain requirements in climate and soil fertility, the current palm production is divided into four regions in Thailand, according to geographical environmental factors and planting and processing conditions: the north, northeast, central, and southern regions. Figure 2 shows the oil palm plantation areas and harvested areas in Thailand in 2012,2018. The Thai oil palm plantations are mainly distributed in the central and southern regions and their areas are increasing yearly [2,5].

1.2 Production, harvesting, and processing

Thailand's palm oil processing industry chain is complete, mainly including oil palm plantations, CPO extraction and processing, CPO refining, and biodiesel production. Thailand has about 240,000 family workshops participating in oil palm plantation (upstream), CPO processing mills (midstream), and palm oil extraction facilities (downstream). Among the family workshops, 79% are small [6]. The production cost of palm oil in Thailand is higher than those in Indonesia and Malaysia, sometimes as high as 110%. Therefore, Thailand's palm oil export has no advantage.

1.3 System boundary of the study

In this study, we combined two environmental sustainability assessment tools, namely, life cycle greenhouse gas (LC-GHG) emission assessment and ecological footprint assessment, to assess the environmental sustainability of oil palm cultivation in different regions of Thailand. In this study, we calculated the total greenhouse gas emissions from the production, transportation, processing, and waste disposal in the palm industry, as well as the ecological footprint of the palm planting process. Figure 3 shows the scope of the greenhouse gas and ecological footprint assessments, including the 25-year economic life and raw material transportation of palm nursery plants and palm plantations. We also investigated the types of land use before the conversion to new oil palm plantations and the areas planted after 2006[1,2,4].

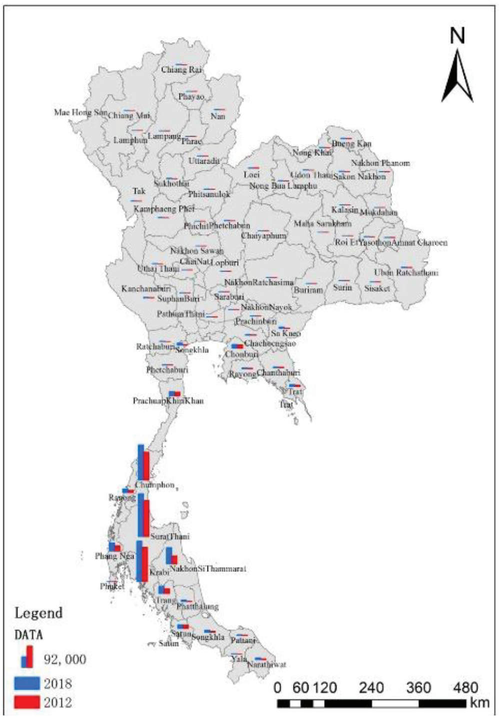


Figure 2. Palm plantation areas and harvested areas in Thailand in 2012,2018

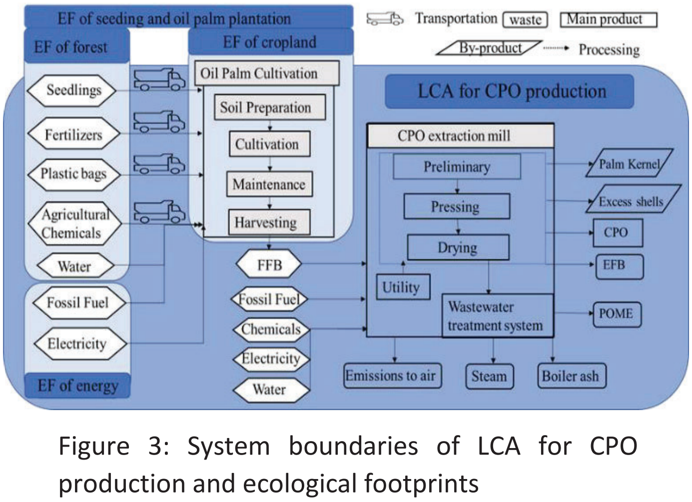


Figure 3: System boundaries of LCA for CPO production and ecological footprints

2 Methodology

2.1 Technology

The oil palm cultivation system is mainly composed of seedling cultivation and oil palm cultivation. The economic life of oil palm is about 25 years, and the frequency of a harvest cycle is about 10–15 days or 2–3 times a month. In this research, 32 mills using a wet extraction process with a production. The EFBs and palm oil mill effluent (POME) produced by the wet extraction process are classified as waste, as shown in Fig. 3. The wastewater generated by wet extraction is discharged to wastewater treatment equipment [7].

In this study, the ecological footprint (EF) evaluation index is combined with the greenhouse gas emissions during an oil palm life cycle to evaluate the sustainable development of the Thai oil palm industry. In our study, we considered the environmental impacts using the ecological footprint evaluation index. This work is the first to combine the environmental impacts of oil palm plantation nursery and oil palm cultivation on the total land and water ecosystem demand for providing resources and absorbers of emissions with greenhouse gas emissions. The total EF is the sum of energy, forest, and arable land EFs, as shown in Fig. 3. In this study, EF was selected for evaluating oil palm plantations because it can be used as an independent indicator of life-cycle environmental impact, as well as a screening indicator of environmental performance [2,7]. The system boundaries are shown in Fig. 3.

2.2 EF of oil palm plantation

The method of calculating EF is shown in Eq. (1). EF is defined as the sum of the EFs of direct and indirect land, water, fuel, and power applications, CO_2 emissions, and chemical and material use.

$$EF = EF_{direct} + EF_{indirect} \qquad (1)$$

EF_{direct} is the EF for direct land occupation, and $EF_{indirect}$ is the EF for indirect land occupation.

2.3 GHG emitted sources and calculation

In this study, we established a "global warming assessment of palm oil production" model based on the obtained data, and we determined the system boundaries of the model calculation, as shown in Fig.3. The standard Intergovernmental Panel on Climate Change (IPCC) conversion factors was used to convert GHGs into carbon dioxide equivalent (CO_2eq). The crop cycle length is fixed at 25 years. In this study, we assessed in detail various factors involved in the production of palm oil, including transportation, fertilizer use, and the amount of CH_4 generated from palm oil plant wastewater, and we linked the amount of nitrogen fertilizer used with the output of FFBs. The net amount of carbon dioxide per hectare per ton of palm oil and the net amount of overall CO_2 emissions from the Thai palm oil industry were calculated [4,7].

E_{FFB} come from FFB production and FFB transport, as shown in Eq. (2).

$$E_{FFB} = E_{FFB,production} + E_{FFB,transport} \qquad (2)$$

The greenhouse gases emissions from the wastewater treatment system were calculated in this study by the UNFCCC method [8]. In this study, we mainly calculated for the situation where there is no biogas recovery device in the wastewater treatment system. Therefore, in this case, only $E_{Wastewater\ treatment}$ is calculated as

$$E_{Wastewater,treatment} = \sum_i Q_{ww,i,y} \times COD_{removed,i,y} \times MCF_{ww,treatment,BL,i} \times B_{O,ww} \times UF_{BL} \times GWP_{CH4} \quad . \qquad (3)$$

The conversion formula of the greenhouse gas carbon equivalent is

$$e_p\left[\frac{kgCO_2eq}{ton}\right] = \frac{(E_{Energy} + E_{FFB} + E_{Chemical} + E_{Wastewater})\left[\frac{kgCO_2eq}{yr}\right]}{yield\ product\left[\frac{ton}{yr}\right]}. \quad (4)$$

2.4 Data collection

In this study, we analyzed the CPO production capacity of 32 palm oil processing plants in Thailand. When calculating greenhouse gas emissions of palm oil processing, we used the numbers of inputs and outputs involved in the transportation process and waste disposal. EFs represent the value of converting these quantities into greenhouse gas emissions. These data were from the Thai National LCI database, Ecoinvent database [9], and literature. In the calculation of the ecological footprint, the life cycle inventory (LCI) data of oil palm plantations were from Thailand's national LCI database. In this study, we merged the data of eastern Thailand and central Thailand.

3 Results and discussion

3.1 CPO extraction process

In the palm oil mill the inputs used for the production of CPO were composed of FFB, diesel oil, electricity and water supply as shown in Table 1. The averaged FFB of 6.04 T (32 mills) was required to produce 1 ton of CPO. For the electricity consumption, two important sources of electricity were supplied to the mills. Firstly, the major supply was produced from the steam turbine generator in the mill in which fibers were used as biomass fuel for the boiler. Secondly, it was supplied from the grid connection.

The CPO production caused a large amount of wastewater. Processing 1 ton of FFB generated average wastewater of about 0.65 m^3 (32 mills). The wastewater treatment plants of the palm oil mills had an average chemical oxygen demand (COD) of raw wastewater, wastewater inflow, wastewater outflow, and treated wastewater from the final pond of 102607, 69984, 13697 and 3157 mg/L, respectively (Table 2).

Table 1: Production of 1 ton CPO

Parameter	Unit	Average [a] GHG emission (32 mills)
Inputs		
Fresh fruit bunches (FFB)	ton	6.04
Water consumption	m^3	7.09
Energy consumption from EGAT	kWh	8.76
Diesel oil consumption	L	3.73
Outputs		
Main product		
-CPO	ton	1
Solid waste		
-EFB	ton	1.33
Wastewater		
-Palm oil mill effluent (POME)	m^3	3.96

[a] Weighted average

Table 2: Characteristics of wastewater from the palm oil mills

Parameter	Unit	Range	Average [a] GHG emission (32 mills)
Palm oil mill effluent (POME)	m^3	9086-206908	102607

COD inflow wastewater	mg/L	62743-114782	69984
COD outflow wastewater	mg/L	3150-29432	13697
COD final pond	mg/L	327-19797	3157

[a] Weighted average

3.2 Greenhouse gas emissions from the palm oil industry

3.2.1 Greenhouse gas emissions from seed cultivation, FFB harvest and CPO production

Table 3 shows the greenhouse gas emissions the four major palm growing regions in Thailand. Greenhouse gas emissions are expressed as CO_2 equivalents emitted per ton of harvested FFBs. The CPO production and processing conditions in the four palm plantation regions are same (the CPO processing plant in the south is closer to the plantation, and the amount of greenhouse gases emitted during transportation is approximately 0). In all these regions, there is no biogas recovery. The amount of greenhouse gases emitted by producing 1 ton of CPO is shown in Table 4.

Table 3: Weighted average life cycle GHG emissions major oil-palm-growing regions

	North	Northeast	Central	South
GHG emissions (kg CO_2eq/t FFB)	141(114-167)	189(126-231)	112(69-149)	93(77-102)

Table 4: Comparative GHG emissions 1 ton of CPO with biogas emissions and without allocation

Output	Boiler emissions	Electricity from grid	Diesel	Mill consumption	Transportation of diesel to mill	Biogas	Total
GHG emissions for 1 ton CPO (without allocation) kg CO_2eq	64.01	0.50	-	12.19	12.11	911.62	1000.43

According to calculations based on available data, palm planting in Southern Thailand has the highest greenhouse gas emission (CO_2 equivalent per ton FFBs), 189 kg CO_2eq/t FFBs. The southern region has the smallest emission of 93 kg CO_2eq/t FFB. From table 4, we can see that for CPO production and processing, the CO_2 equivalent of each ton of CPO produced is 1,000.43 kg, and the greenhouse gas equivalent emitted from the biogas is relatively high. The table also shows the CO_2 eq from by boiler combustion.

3.3 EF in Thailand's palm oil industry

3.3.1 EF of palm plantation (FFBs)

The EF of palm plantation is shown in Table 5. The EF of palm plantations in southern Thailand is the smallest, about 17.58 gha/ha-year. For plantations in northern Thailand, the EF is determined to be 24.59 gha/ha-year. Planted forests in northern Thailand consume the most resources per unit area. The oil palm plantations in northern Thailand have the highest EF, which may be related to water consumption and fuel and chemical use. Planted forests per unit area in the northern provinces require large amounts of water, especially irrigation water. Large amounts of chemicals are used in the central region because cultivators prefer to use herbicides to remove weeds instead of manually removing them in Chonburi Province [2]. The southern provinces consume the lowest resources. The soil and climatic environment in southern Thailand are more conducive to palm tree planting than the northern areas. Therefore, in terms of palm planting, the EFs of plantations from north to south in Thailand are gradually decreasing.

Table 5: EFs of oil palm plantations

Regions	EF of oil palm plantation (gha/ha-year)			
	EF of energy	EF of forest	EF of cropland	Total
North	0.987	23.2	0.402	24.59
Northeast	0.843	21.1	0.402	22.35
Central	0.703	20.8	0.402	21.9
South	0.21	16.97	0.402	17.58
Weighted average	0.686	20.52	0.402	21.6

3.3.2 EF and greenhouse gas emissions FFBs

The maximum EF used for FFB production in Thailand's four palm growing regions was determined. The production of FFBs per unit area in northern Thailand requires relatively larger amounts of fertilizers and irrigation water, whereas that in other regions requires smaller amounts. As shown in Fig. 4, in the palm cultivation and FFB harvesting in Thailand, the southern region has a high overall greenhouse gas emission owing to the extensive planting areas. However, as shown in Table 3, the greenhouse gas emission for every ton of FFBs harvested in southern Thailand is 93 kg, and the EF value per hectare of plantations in the southern region is also the smallest. Overall, the oil palm plantation in southern Thailand requires the least ecological resources and emits the least amount of greenhouse gases per unit area.

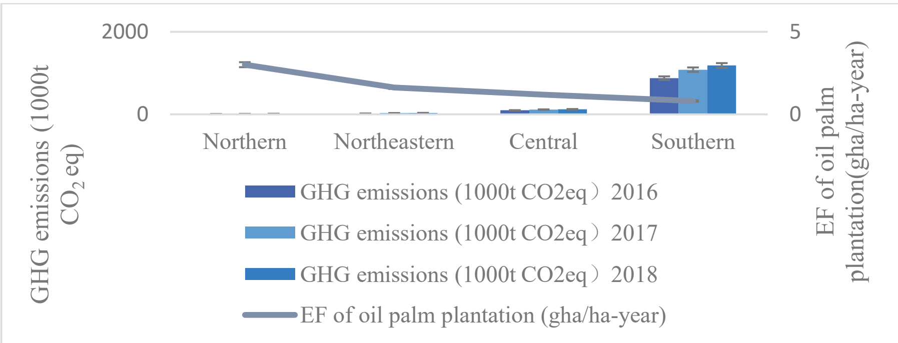


Figure 4: GHG emissions and EF of Thailand's four major oil palm plantation regions (FFB harvested)

3.3.3 Ratio of plantation forest income to EF

The ratio of the economic benefits of plantations to EF represents the benefits of using the land and water ecosystems obtained from oil palm plantations to provide resources and absorb emissions. Table 6 shows the ratio of economic benefits of Thai oil palm industry to EF.

Table 6: Ratios of economic benefits to EF

Plantation	USD/gha (2009-2018)		
	Minimum	Maximum	Average
North	20.7	83.1	39.7
Northeast	23.1	86.4	46.9
Central	25.2	91.1	59.4
South	30.4	107.2	69.3
Average	24.9	115.0	53.9

Table 6 shows the average ratios of economic benefits of oil palm plantations to EF in the northern, northeastern, central, and southern regions from 2009 to 2018, which were 39.7, 46.9, 59.4, and 69.3 USD/gha, respectively. It can be said that the oil palm plantations in the southern region have brought the greatest benefits to planters, because compared with other regions, the ratio of economic benefits to EF of plantation in the southern region is higher, and FFB production is also high. The plantation in the northern region has the lowest profit per hectare and the lowest yield, considering that plantation in the northern region requires large amounts of water and fertilizer. Because the soil and climatic environment in southern Thailand are more conducive to palm tree planting than those in the north, Thailand's water and fertilizer inputs from the north to the south are gradually decreasing. The economic value of palm planting basically conforms to this frond, that is the economic value per unit area increases from the north to the south.

4 Conclusions

Thai oil palm plantations are mainly distributed in the southern region, followed by the central region. The northern and northeastern regions are relatively small, accounting for only 13.6% of the total area. The CO_2 equivalent per ton of FFB harvested in Thailand's plantations is about 133.8 kgCO_2eq, and those in the north, northeast, center, and south are 141, 189, 112, and 93 kgCO_2eq, respectively. The CO_2 equivalent per ton of CPO produced by the palm oil processing plant in Thailand without using a biogas recovery device is 1000.43 kgCO_2eq. The total CO_2 equivalent of the oil palm industry in Thailand is about 4.342 million tons, accounting for about 1.44% of Thailand's annual carbon emissions, of which 29,800 tons is in the north, 71,000 tons in the northeast, 355,300 tons in the center, and 3,886,100 tons in the south. Although the total palm plantation area in the southern region is relatively large, the southern region produces the lowest unit CO_2 equivalent during palm tree planting and harvesting palm fresh fruit bunches. The average EF of Thai oil palm plantations is 21.6 gha/ha-year. The ratio of earnings to EF is 53.9 USD/gha. The ratio of revenue to EF in the southern region is 69.3 USD/gha. The EF of oil palm plantations in the southern region is relatively small, and the ratio of income to EF is the highest. This means that the southern region of Thailand has lower investment in oil palm planting than the other regions in Thailand. Palm planting requires greater investments on chemical fertilizers and energy, its cost is higher, and its CPO price is not competitive.

References

(1) Muhammad, J.I., Azizah, B., Farah, H. A., Rizafizah, O., (2018), Palm oil industry in Southeast Asia and the effluent treatment technology—A review, Environmental Technology & Innovation, 9,169–185.
(2) Charongpun, M., Shabbir, H. G., (2017), Ecological footprint assessment towards eco-efficient oil palm and rubber plantations in Thailand, Journal of Cleaner Production,140,581-589.
(3) OAE, (2009-2018), Agricultural Statistics of Thailand, Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.
(4) Roihatai, K., Aran, H.K., Charongpun, M., (2012), Greenhouse gas emissions of palm oil mills in Thailand, International Journal of Greenhouse Gas Control, 11,141-151.
(5) Thapat, S., Shabbir, H.G., Patcharaporn, P., Piyanon, K.et al., (2017). Environmental sustainability of oil palm cultivation in different regions of Thailand: Greenhouse gases and water use impact, Journal of Cleaner Production, 167,1009-1019.
(6) Chaiwat S., (2020), Palm Oil Industry Outlook 2020-22 in Thailand. Krungsri Research, Thailand.
(7) Nabila, F. J., Zarina, A. M., Haslenda, H., (2019), An integrated carbon footprint accounting and sustainability index for palm oil mills, Journal of Cleaner Production, 225,496-509.
(8) UNFCCC, (2010), Project Search. United Nations Framework Convention on Climate Change, Bonn.
(9) Ecoinvent, (2012) Swiss Centre for Life Cycle Inventories, Ecoinvent Data v3.0. Swiss Centre for Life Cycle Inventories.

TC-305S

Understanding multi-actors'dimensions for urban water security in armed conflicting areas of Rakhine State, Myanmar

INTRODUCTION

Makhanu & Nakagawa (2018) highlighted that the relationship between water management and conflict is one of three major linkages between conflict and water. It is not because of access to water but more related to the way people manage the system of water supply. Good governance to water policy and laws always reflect to sound water resources management system and that leads to sustainability of water resources and well beings of the people in the country (Westley et al., 2002).

According to the literature review, previous research findings show that "weak water management system in conflicting areas (Negenmen, 2001)", "armed conflicts directly or indirectly affect to water management system (Alkhafaji, 2018)", "lack of coordination and participation in implementation of top down water management structure in conflict areas (Qureshi, 2012)", and "water institutional structure formation is not very common in conflicting areas management (Mohorjy & Grigg, 1995)".

Water resources in Myanmar are in a favorable situation as its water per capita is more than all surrounding countries however the availability of freshwater supply depends on reservoirs, communal ponds, private collection of rainwater and groundwater therefore, Myanmar National Water Policy (2014) stated that there is large disparity between stipulations for water supply in urban areas and in rural areas and also many agencies are engaging in water supply and management without proper cooperating and coordinating each other.

Although Myanmar is rich in water resources. Myanmar possess 12% of the whole Asia's freshwater resources and 16% of the ASEAN nations, the growing pressure on the existing water resources uneven temporal and spatial distribution of water resources create further challenges for water allocation (Kovar et al, 2009). In addition to that, the current policy and administration of water resources in Myanmar is scattered and unfocused, and overlapping interests lead to unclear jurisdiction (MNWP, 2014).

As mentioned by Weiwei, et al (2020), Rakhine State is located in the tropical area with an abundant and concentrated rainfall during the rainy season, while the dry seasons last long with a considerable evaporation rate, resulting in a disproportional temporal distribution of water quantity in natural ponds which are main sources of urban drinking water supply while salt water intrusion into surface water from many river networks within basin.

Although there might be previous researches on water supply governance and many documents have been published stating good water governance is a prerequisite to improve water management (Akhmouch & Correia, 2016) in the world, there are still some following knowledge gaps to know when assessing urban water security in armed conflicting areas of Rakhine State.

1) Who are the actors in the governance network influencing the implementation of town water supply service in the most armed conflict affected areas of Rakhine State? Which actors are influencing the current conflict situation? 2) What are the institutions related to the governance of the urban water supply and their relationships during armed conflicting period? and 3) How is the power relationship and dynamic among key stakeholders engaging in urban water supply governance in Rakhine State? How is the role of community in self-regulated water supply system in Rakhine State?

In the light of such knowledge gaps, the main research problem raised to know whether the pattern of interactions between actors (state & non state) and institutions (formal & informal) along with dynamic of stakeholders' power are positively contributing or not to urban water security in the context of armed conflict.

Towards solving the main research problem, the decision model was set as "If and when the two factors of ; 1) Good Institutional Arrangements by Water Supply Key Actors and 2) High Stakeholders' Power Dynamic are positive, it is likely to achieve the high level of adaptive and good urban water supply governance".

Thus, it was useful to do an actor analysis to understand who is involved, what are their interests and motivations, and which resources and means do they possess to influence the issue and the objective of this research was set to: 1) Analysis the actors (State & Non-State) and institutions (Formal & Informal) for urban water supply governance in armed conflicting areas of Rakhine State, Myanmar, and 2) Analysis the stakeholders' power dynamics in urban supply governance of armed conflicting areas in Rakhine State, Myanmar.

This research findings will support to achieving of SDG Goal (6) and its detail targets and indicators in Myanmar, particularly for Rakhine State which is prone to natural disasters along with armed conflict and ethnic riot. In addition to that, this study will contribute the policy recommendations to decision makers in Government of Myanmar as well as to the similar ongoing armed conflicting countries around the world.

1 METHODS

1.1 Study Site

This research study area of Rakhine State in Myanmar is geographically located in the coastal area where facing the issue of salt water intrusion into surface water from many river networks within basin. In terms of socioeconomic development, the Rakhine State is the 2nd poorest state in the country while there are ongoing major armed conflicts during 2018 to 2020. This study focused on the most armed conflicts affected Townships of; Kyauktaw, Mrauk U, Rathedaung, and Buthidaung among the total of (17) Townships in the Rakhine State. The study area map was presented in Figure 1.1.

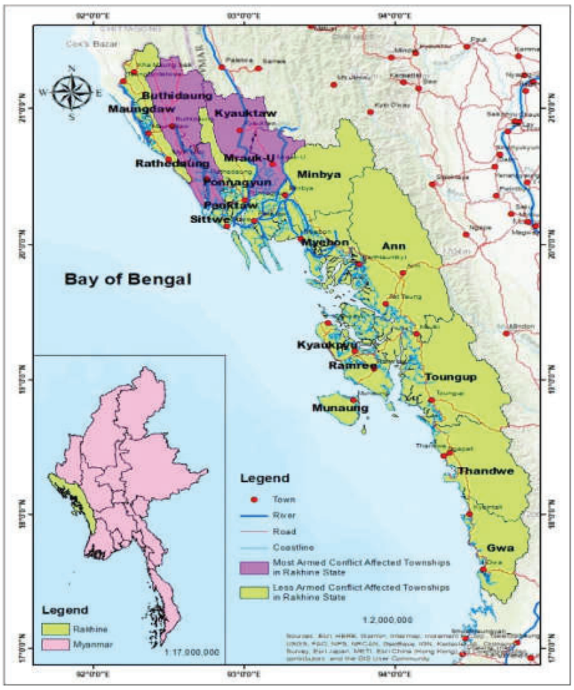
In Rakhine State, the freshwater resources are mainly from rain water as surface water storage natural ponds and man-made small dams for providing the Urban/Town water supply services by Department of Municipal/Development Affairs with the support of elected Town Municipal Affairs Committees in each Township. However, depending on the rain water storage capacity and the number of population and households, the supply and demand of public water supply service can be different.

Current public water supply system in the study area is gravity flow system and combination with pumping system from natural water resources of ponds and small dams to the water collection tanks/ponds located to cover the town wards. Then, by using pipe water distribution system from the water collection tanks to individual tap stands located in user households of urban area town wards. As the provided town water supply service is "schedule based' and "rotation basis" to cover minimum 50% to maximum 85% of households, there are also private hand-dug wells and deep tube wells established by own arrangement in order to complement the distributed pipe water with individual home yard groundwater sources.

This research study is built on the theoretical background of "Management and Transition Framework (MTF)" in which Institutional Analysis and Development Framework (IAD) by Ostrom (2005) is part of basic concept. For objective (1) of actors and Institutions analysis, IAD framework is applied to conceptualize the operational outcomes of institutions which are affected by the armed conflicts as the result of how water governance actors organize the institutional arrangements to be effective freshwater supply management.

The indicators applied for actors & institutions analysis were; Different actors' perceptions about their institutions' internal relationships and those with external actors, Town water supply related policy priorities, Causes and consequences of institutional policies, Staff, Relationship with government and non-governmental agencies, and relationship with local communities. Then Users' satisfaction with the Town water supply services and Opinion of actors on the quality of water supply service by using variables of; a) The staff's accountability, b) The capacity of staff to learn about local condition, c) The conditions for the exchange of important information were also applied.

For objective (2) of stakeholder power dynamic analysis was applied using combined SA (Stakeholder Analysis) & SNA (Social Network Analysis). The indicators applied for stakeholder power dynamic analysis were; Power, Interest, Satisfaction, Access to Information, and Institutional Relationship including Identification and classification of institutional relationships between key stakeholders.



Source: Author

Figure 1.1: Map of Study Area

1.2 Data Collection

The secondary data of; public water supply related structural, biophysical, and socioeconomic information including budget allocation and uses, pricing, water fee collection, maintenance cost for (4) most conflict affected Townships were collected from relevant Rakhine State Level Government Departments and Union Government Departments.

For the collection of primary data, (4) separate participatory workshops with multi-stakeholders were conducted in (4) study Townships. During these workshops, as the first part of workshop, the total number of invited participants (160) from (4) Townships i.e. (40) participants each from study Township, participated to present their involvement, responsibilities, interest and role in their respective Town Water Supply System and also identify the individual stakeholder' claims as attributes of power, legitimacy and urgency by answering the questions adapted from "Stakeholder Salience Theory" for classifying the different types of stakeholders and their saliency.

During the second part of workshop, total of (160) participants answered the structured interview questions which were designed with two major parts for; providing data for SA, and providing data for SNA. The first part of interview questions for SA was designed to describe their organization's role in the system, determine the power and the interest of their organization, the level of their satisfaction regarding the status quo of the system, and the level of their organization's access to information. Also, respondents were asked to ascertain all other stakeholders' powers and interests.

In the second part of structured interview question for SNA, respondents/participants were asked to characterize other stakeholders with whom they have the institutional relationship in freshwater quantity and quality management in order to determine the magnitude of those relationships as well as the nature of them.

1.3 Data Analysis

The qualitative information collected from secondary data sources were analyzed qualitatively with statement & content analysis. The collected statistical data such as; "The ratio of State government budget per capita", "The amount of available freshwater resources per capita", "The amount of collected water utilization fees were analyzed by using quantitative descriptive statistics.

The primary data related to causes & consequences of institutional policies collected from structured interview were analyzed qualitatively with narrative policy analysis (Roe, 1994) Stakeholder Identification and mapping by using “Stakeholder Salience Theory” (Mitchell et al., 1997), and Institutional Analysis (Ostrom, 2005) respectively.

For objective (1) of actors & institutions analysis, the primary data collected from structured interview were analyzed by using descriptive statistic including percentages, tables, frequencies, counts, and also WAI (Weighted Average Index) method.

For objective (2) of the data analysis for SA, in order to determine each stakeholder's power and interest, the weighted average index of all stakeholders' answers were used. The following equations indicating how power and interest indices for each stakeholder are calculated:

$$P_i = \frac{\sum_{j=1}^{N} P_{ij}}{N} \quad (1)$$

$$I_i = \frac{\sum_{j=1}^{N} I_{ij}}{N} \quad (2)$$

Where: Pi and Ii are the i^{th} stakeholder's power and interest indices respectively; P_{ij} and I_{ij} are power and interest amount that j^{th} stakeholder assigns to i^{th} stakeholder in their responses to survey respectively; and, N is the total number of stakeholders. Then, “power versus interest grid’ was applied to depict the comparative positions of stakeholders.

For objective (2) of the data analysis for SNA, after conducting survey, data were transferred into adjacent matrices in UCINET software to be analyzed. The magnitude of the ties were determined by Likert scale, exactly equal to respondents' answers (Likert, 1932). For conflictive and collaborative relations, there was only positive answers although the amounts have to be assumed to be negative and positive respectively.

Four different indicators were calculated using UCINET. Out-degree, In-degree, Betweenness, Beta Centralities, considering the absolute amounts of the ties (since according to equations (3) to (6), examining positive and negative ties simultaneously leads to misleading and meaningless results). In equation (7), the denominator is the maximum eigenvalue of the network's adjacency matrix.

$$IC_j = \sum_{i=1}^{N} R_{ij} \quad (3)$$

$$OC_i = \sum_{j=1}^{N} R_{ij} \quad (4)$$

Where: IC_j and OC_i are the In-degree Centrality of the j^{th} node, and Out-degree Centrality of the i^{th} node respectively. N in the number of nodes (here, stakeholders), and R_{ij} is the element of the i^{th} row and the j^{th} column of the adjacency matrix which is an N × N matrix.

For calculating the betweenness centrality, equation (5) was used in this study (Freeman, 1978).

$$B_i = \sum_{i \neq j \neq k} \frac{\delta_{jk}(i)}{\delta_{jk}} \quad (5)$$

If σ_{jk} equals to the total number of geodesic paths between nodes j and k, and $\sigma_{jk}^{(i)}$ equals to the number of these paths which pass through node i, the betweenness centrality of node i (i.e. B_i) when i, j, and k are distinct.

Beta centrality was calculated by the following equation (Bonacich, 1987).

$$C_i = \sum_{j=1}^{N} R_{ij}(\propto + \beta C_j) \quad (6)$$

Where: Ci and C_j are beta centralities of the ith and the j^{th} nodes respectively.

The amount of parameter β was calculated by the below equation (7).

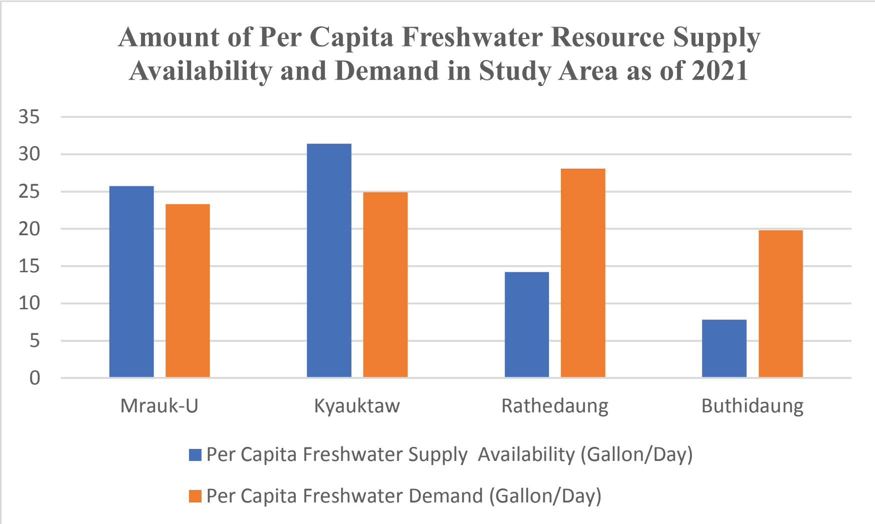
$$\beta = \frac{0.995}{MaxEigenvalue} \quad (7)$$

After calculating all the equations using the results of the survey and adjacency matrices, social networks were drawn using NETDRAW (Borgatti, 2002).

2 RESULTS

2.1 Secondary Data Analysis Results

The quantitative secondary data analysis results showed that during all (5) consecutive fiscal years, the budget allocation for freshwater supply in Rakhine State was always fully utilized and also the amount of allocated budget for each year was different and not growing regularly . As shown in Figure 2.1, the result of analysis on current freshwater supply and demand indicated that it is still balancing in Kyauktaw and Mrauk U Townships while the demand in both Rahtedaung and Buthidaung Townships is increasing almost double amount of supply. The result also showed that the amount of collected water utilization fees per annum has been increasing year by year in all (4) Townships.



Source: Field Survey, 2021

Figure 2.1: Per Capita Freshwater Resource Supply Availability and Demand in Study Area, 2021

2.2 Primary Data Analysis Results

During the Multi-stakeholder workshop, eight key stakeholder groups were identified first by using stakeholder salience theory. Out of total (7) types only (4) types of key stakeholder groups were classified while there were high salience level of government stakeholders & low salience level of non-government stakeholders in this study. The classification of key stakeholder types and their saliency was presented in Table 2.1.

TABLE 2.1:

Classification of Key Stakeholder Types and Saliency by Using Stakeholder Salience Theory

Type of Stakeholders	Possessed Attributes	Saliency	Stakeholder Groups
Dormant	Power	Low	Nil
Discretionary	Legitimacy	Low	Department of Rural Development, Private Sector
Demanding	Urgency	Low	Water Users
Dominant	Power, Legitimacy	Moderate	Nil
Dangerous	Power, Urgency	Moderate	Nil
Dependent	Legitimacy, Urgency	Moderate	Civil Society Organizations,
Definitive	Power, Legitimacy, Urgency	High	TMAC/Town Elders, Department of Municipal/ Development Affairs, Local Authorities, Political Parties

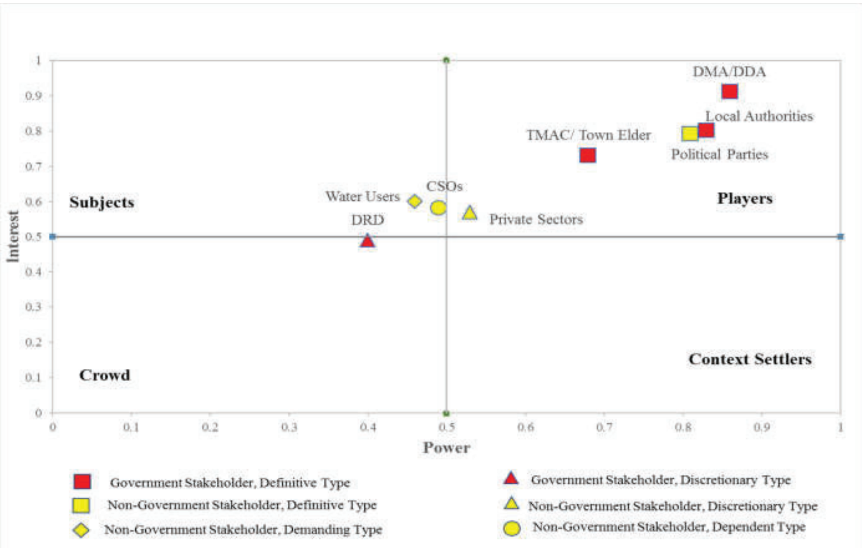
Source: Field Survey, 2021

Then, identified key stakeholder groups' general information, causes consequences of policies changes on freshwater supply, water pricing, and maintenance during armed conflict period. The qualitative primary data analysis result related to causes & consequences of institutional policies showed that the causes of Increasing IDPs (Internally Displaced Persons) during armed conflict along with COVID-19 Pandemic in 2020 and Lack of rule of law during armed conflict made the consequences of prioritizing Institutional policy to provide water supply service to IDPs so that the existing water users have to be faced with irregular and insufficient water supply. In addition to that due to the COVID -19 pandemic, the policy priority has also been emphasized to supply freshwater to COVID -19 Quarantine Centers. It was also found that the consequences of Institutional policy particularly rules and regulations on water tax collection were not able to apply during armed conflict as well as water pricing was increased made water tax were unable to collect fully due to the lack of law enforcement for taking actions to those who do not regularly pay the water tax during armed conflict. Apart from that due to the cause of armed conflict and COVID-19 pandemic, the institutional policy, plan and projects related to freshwater supply system maintenance for sustainability were also delayed.

The results for objective (1) of actors & institutions analysis showed that actors' perception on their internal relationship and those with external actors are almost positive. Freshwater users' satisfaction level is positive on services from local government and departmental authorities although services from informal institutions is only the neutral level of satisfaction. Opinion of actors showed as positive agreement on the quality of water supply services provided during 2018 to 2020 by Town water supply system while the current status of freshwater supply management is satisfied by majority. Many actors responded that their level of access to freshwater supply related information is only at normal level.

The results from the data analysis for objective (2) of SA showed that; DMA/DDA and Local Authorities determined themselves as very significant power and very significant interest in Town Water Supply System while Political Parties have strong power and both TMAC/ Town Elders and Political Parties have strong interest. Other institutions determined that the power of DMA/DDA, Local Authorities, and Political Parties is very significant while TMAC/ Town Elders has significant power in Town Water Supply System in Rakhine State. Again, other institutions determined that DMA/DDA, has very significant interest while TMAC/ Town Elders, Local Authorities, and Political Parties have significant interest in Town Water Supply System in Rakhine State.

As shown in below Power Vs Interest Grid, DMA/DDA, TMAC/Town Elders, Local Authorities, Political Parties, and Private Sectors have high power with high interest so that they are called as "Players" while DRD, Water Users, and CSOs have low power with high interest so that they are called as "Subjects". Figure 2.2 was presented the power versus interest grid of Public Water Supply Stakeholder Groups in Rakhine State.



"Players" have High Power with Hight Interest,.

"Subjects" have Low Power with high Interest.

"Context Settlers" have High Power with Low Interest.

"Crowd" have Low Power with Low Interest.

Figure 2.2: Power Versus Interest Grid of Public Water Supply Stakeholder Groups in Rakhine

The UCINET calculated value of (4) criteria and (2) Attributes data were presented in Table 2.2 Based on the UCINET calculated value, NETDRAW diagram showing overall relationship was visualized as the results from data analysis for objective (2) of SNA of magnitude and nature of relationship between eight key stakeholder groups for urban water supply in Rakhine Sate.

TABLE 2.2:

UNINET Calculated Value 4 Criteria and 2 Attributes for NETDRAW Visualization

ID	Betweenness	Outdegree	Indegree	Beta Centrality	Nature of Stakeholders	Type of Stakeholders
TMAC/ Town Elder	0.367	7	6	6000.242	0	1
DMA/DDA	1.033	6	7	6947.138	1	1
DRD	0.167	4	7	6947.138	1	2
Local Authorities	1.2	7	7	6947.138	1	1
Water Users	0.5	6	6	6000.242	0	3
CSOs	0.367	7	6	6000.242	0	4
Private Sectors	0.167	7	5	5182.291	0	2
Political Parties	1.2	7	7	6947.138	0	1

Source: UCINET Rakhine Dataset, 2021, Nature of Stakeholders; 0= Non-Government, 1= Government, Type of Stakeholders; 1= Definitive , 2= Discretionary, 3= Demanding, 4= Dependent

3 DISCUSSION

The current situation of freshwater supply and demand for urban water security in Rakhine State is critical and the causes of armed conflict and COVID-19 pandemic in Rakhine State have some negative consequences of urban water supply institutions' policy priority in water supply, water tax collection and maintenance for sustainability directly or indirectly.

Out of eight key actors/stakeholders identified for urban water supply in Rakhine State, the non-government actors/stakeholders of; Water Users, CSOs, and Private Sectors are identified as demanding, dependent and discretionary types with lower saliency level while government actors/stakeholders of DMA/DDA, Local authorities, TMAC, and Political Parties are identified as definitive types with have high saliency. The findings resulted from 'Stakeholder Salience Theory" are consistent with the results shown in "Power Vs Interest Grid" where the same state actors/government stakeholders with definitive types showed their high power and high interest. Similar results of UCINET calculated value- "Betweenness", "Indegree" and "Outdegree" were also shown as relatively higher for those state actors/ government stakeholders as well as the resulted NETDRAW diagram clearly showing the stronger magnitude of relationship among those state actors only.

The scope of this study was focusing on public freshwater supply services using freshwater from surface water sources provided to the urban water users in most armed conflict affected (4) Townships in Rakhine State and did not cover to study on other informal water supply services from other available sources.

4 CONCLUSION

Finally, the results from this study supported to understand well on dynamic among different types of actors for urban water security in armed conflicting areas of Rakhine State, Myanmar by showing the significant findings of; High salience level of government stakeholders & low salience level of non-government stakeholders, Higher value of Beta Centrality with stronger magnitude of relationship for government stakeholders & lower value of Beta Centrality with weaker magnitude of relationship for non-government stakeholders.

Thus, all these results alarm to water governance practitioners and local government policy makers to strengthen the roles of non-state actors who are demanding, dependent, discretionary types with lower saliency and weaker magnitude of relationship towards resolving issues of urban water security in armed conflicting areas of Rakhine.

REFERENCES

(1) Makhanu, S. K. & Nakagawa, H. (2018). 21st century water challenges in Kenya. Loughborough University Conference contribution, https://hdl.handle.net/2134/31669
(2) Westley, F. & Carpenter, S. & Brock, W.A. & Holling, C. & Gunderson, L.H.. (2002). Why systems of people and nature are not just social and ecological systems. Panarchy: Understanding Transformations in Human and Natural Systems. 103-119.
(3) Negenmen, T. (2001). Evolution of water resources in Yemen. Ground water management: sharing responsibility for an open access resource.
(4) Alkhafaji, H. (2018). Iraq's Water Crisis Challenges and Solutions. Al-Bayan Centre for Planning and Studies Series of Publications.
(5) Qureshi, A.S. (2002). Water Resources Management in Afghanistan: The Issues and Options, WORKING PAPER 49, Pakistan Country Series No. 14, International Water Management Institute.
(6) Mohorjy, A. M. & Grigg, N.S. (1995). Water resources management system for Saudi Arabia. Journal of Water Resources Planning and Management, 1995, 121(2): 205-215.
(7) Kovar P., Maca P., Redinova J. (eds.) (2009). Water Policy 2009, Water as a Vulnerable and Exhaustible Resource. Proceedings of the Joint Conference of APLU and ICA, 23 – 26 June 2009, Prague, Czech Republic.
(8) MNWP, (2014). Myanmar National Water Policy, Myanmar Water Portal.
(9) Weiwei, Y. &Qingke, Y. & Weidong, W. & Ye, H. & Chundong, Z. & Yanhua, Y. & Ying, M. & Dayong, X. & Fubo. L. (2020), Current status and safety strategies of drinking water provision in the rural area of Rakhine State, Myanmar[J]. Chinese Journal of Environmental Engineering, 2020, 14(8): 2112-2122. https://doi.org/10.12030/j.cjee.202006071).
(10) Akhmouch, A., & Correia, F. N. (2016). The 12 OECD principles on water governance–When science meets policy. Utilities Policy, 43, 14-20.
(11) Ostrom, E. 2005. Understanding Institutional Diversity. Princeton, NJ: Princeton University Press.
(12) Roe, E.M. (1994). Narrative policy analysis: theory and practice. Durham/London: Duke University Press.
(13) Mitchell, R.K., Agle, B.R., & Wood, D.J. (1997). "Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts", Academy of Management Review, Vol. 22 No. 4, pp. 853-886.
(14) Likert, R. (1932). A technique for the measurement of attitudes. Archives of psychology 22 (140), 55.
(15) Freeman, L.C. (1978). Centrality in social networks conceptual clarification, Social Networks, Volume 1, Issue 3, 1978, Pages 215-239, ISSN 0378-8733, https://doi.org/10.1016/0378-8733(78)90021-7.
(16) Bonacich (1987): Power and Centrality: A Family of Measures. In: Holzer B., Stegbauer C. (eds) Schlüsselwerke der Netzwerkforschung. Netzwerkforschung. Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-21742-6_14
(17) Borgatti, S.P. (2002). NetDraw: Graph Visualization Software. Analytic Technologies, Harvard.

TC-310S

Development of Framework to Evaluate Current State of Groundwater Governance under Urbanization and Climate Change

Saurav KC*, Sangam Shrestha, Thi Phuoc Lai Nguyen, Ashim Das Gupta and S. Mohanasundaram
Asian Institute of Technology (AIT)
P.O. Box 4, Klong Luang, Pathum Thani, 12120, Thailand
* er.saurav.kc@gmail.com

Keywords— water governance framework; groundwater governance index; multiple stresses

ABSTRACT
Groundwater, a shifting environmental resource below the earth's surface, exhibits both water and mineral resources characteristics and is the most dependable source of freshwater withdrawals among agricultural, domestic, and industrial sectors. As this resource is linked with the atmosphere and surface water resources, its safe yield mainly depends on the hydro-geologic environment and the area's physical and geographical factors. Furthermore, human-induced dynamics also play a vital role in its safe yield and sustainability. The exponential expansion of urban centres and increased demand for infrastructures have drastically altered the perviousness of land surfaces, impacting both the quantity and quality of groundwater resources. The rapid urbanisation, on the one hand, has increased the imperviousness of the cities reducing the city's infiltration capacity for groundwater recharge, while the increased demand for freshwater resources has raised its abstraction lowering existing groundwater level and making it more vulnerable to availability and contamination. Moreover, climate change and climate variability further exaggerate water demand and potential recharge. In addition to its vulnerability to availability and quality, the dual impact of urbanisation and climate change on groundwater resources have pressurised the common-pool resource in its effective management leading to unfair access to the resource and unequal representation in planning and decision-making of all related actors creating increased possibilities for sectoral and right based conflicts.

Thus, this study develops an indicator-based framework that consists of 4 dimensions and 30 indicators, and each of these indicators shall be rated from 0-3 based on two variables, namely "adequacy of provision" and "institutional capacity for implementation" (Fig. 1). The weights of the dimensions or indicators can be assumed contributing equally or allocated according to prioritised issues or statistically determined loads. The aggregation of the variables within each indicator (eq.1) and aggregation of the indicators within each dimension (eq.2) is done using,

$$I_{xy} = \frac{V_1 + V_2}{2} \tag{1}$$

$$D_x = \frac{\sum_{y=1}^{n} W_y * I_{xy}}{\sum_{k=1}^{n} W_y} \tag{2}$$

And finally, the GGI is calculated by using the formula,

$$GGI = \frac{\sum_{x=1}^{n} W_x * D_x}{\sum_{x=1}^{n} W_x} \tag{3}$$

where, D = Dimensions; I = Indicators; V = Variables; W = Weightage; and x, y represents number of dimensions and number of indicators within in each dimensions respectively.

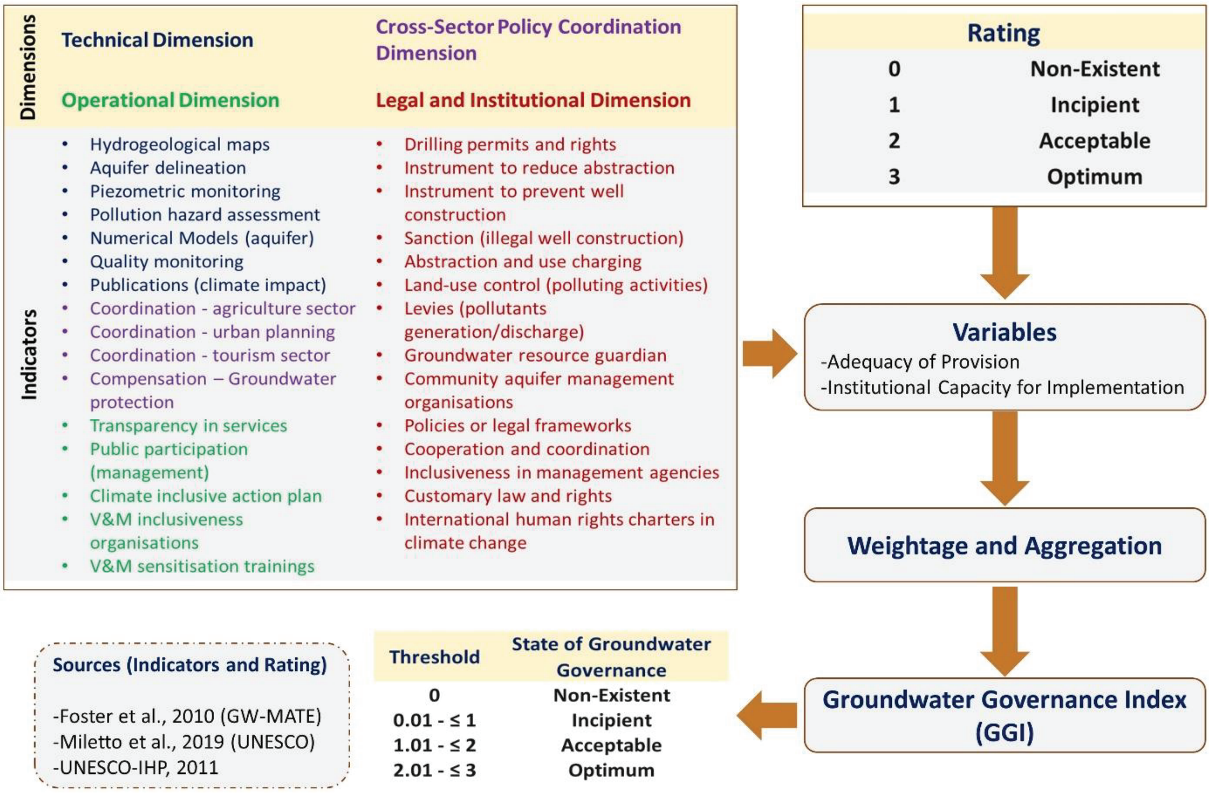


Fig. 1. Framework to evaluate groundwater governance

The aggregation of all the elements within the framework quantitatively indicates the existing state of groundwater governance known as the Groundwater Governance Index (GGI). The range of the GGI threshold (Fig. 1) denotes the baseline state ranging between non-existence to an optimal state of groundwater governance in the context of urbanisation and climate change. The results obtained from the assessment shall be validated qualitatively with the relevant actors and stakeholders for develop suitable recommendation strategies under multiple stresses. The individual and combined impact of climate change and urbanisation on groundwater resources have threatened the resource; thus, its assessment is a soft approach for sustainable management. The evaluation of the current state of its governance is the first step for the approach, and this developed framework shall be useful in appraising the current provisions and needs in groundwater governance in the study area. Furthermore, it shall be handy to policy, decision-makers, and related actors to visually understand and interpret the current state of groundwater governance in terms of extraction, quality, climate change, urbanisation, and inclusion of vulnerable and marginalised groups in the governance mechanism. Ultimately, this shall facilitate developing the right strategies for strengthening governance through equal access, opportunities, and the water right, leaving no one behind.

ACKNOWLEDGMENTS

The authors would like to extend sincere thanks to the "Strengthening Groundwater Governance in Rapidly Urbanising Areas of the Lower Mekong Region (GIRA)" project funded by Stockholm Environment Institute (SEI) under the SUMERNET 4 All Programme which is funded by the Swedish International Development Cooperation Agency (Sida).

REFERENCES

(1) Foster, S, Garduno H, Tuinhof A, and Tovey C (2010), Groundwater governance: conceptual framework for assessment of provisions and needs, The World Bank, No. 57555, pp. 1-16.

(2) Miletto, M, Pangare V, and Thuy L, (2019), Gender-responsive indicators for water assessment, monitoring and reporting, UNESCO Publishing, Vol. 1.

(3) UNESCO-IHP, (2011), Methodology for the GEF Transboundary Waters Assessment Programme, Methodology for the Assessment of Transboundary Aquifers, UNEP, Volume 2, pp. vi + 113.

TC-312S

Towards Sustainable Groundwater Management of Transboundary Aquifers in the Lower Mekong Region

A. Das Gupta
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120, Thailand
adasgupta.05@gmail.com

S. Shrestha
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120, Thailand

TPL. Nguyen
Department of Development and Sustainability, School of Environment, Resources and Development
Asian Institute of Technology
Pathum Thani, 12120, Thailand

S. KC
Water Engineering and Management, School of Engineering and Technology
Asian Institute of Technology
Pathum Thani, 12120 Thailand

ABSTRACT
The management of a transboundary aquifer shared by two or more countries is quite complex and is a challenging task. A pragmatic action plan to develop and implement sustainable groundwater development and management of a transboundary aquifer system is proposed. An Institutional system in the form of a Coordinating Council or a Multi-Country Consultative Body at the Government Level is recommended for the management of TBA. Adequate knowledge and in-house capacity with the know-how and expertise is imperative at different administrative levels to address development and management issues.

Keywords—Transboundary aquifers; Sustainable groundwater management; Framework-action plan

INTRODUCTION

In the Lower Mekong Region (LMR), groundwater from underlying transboundary aquifers (TBAs) is increasingly being used to supplement the shortage of surface water in areas where surface water is the predominant source of water supply, to meet the demand for water in areas where surface water is not easily accessible as well as to meet the demand during the dry season when a shortage of surface water availability is imminent. Groundwater also plays an important role in supporting natural river water flows and relevant ecosystems. Following the mission of the Mekong River Commission (MRC), the transboundary cooperation in surface water management in the region has progressed quite satisfactorily in recent years; however, there is no common approach or even modest recognition and cooperation for groundwater resources.

Sustainable development and management of TBAs require a rational approach in analysing and assessing groundwater from multi-disciplinary and multi-dimensional viewpoints in an interdisciplinary and integrated way. It should include scientific and hydro-geological understanding, understanding of socio-economics, institutional constraints, the frameworks of international law (if any), and needs to address wide-ranging environmental issues. These transboundary groundwater resources underlying the riparian countries merit closer attention with regards to their current use, which may not be intensive all over the region, but increasing demands on these resources will result in their intensive use in the near future. It is therefore imperative that a collaborative initiative by the Member Countries (MCs) of the LMR is undertaken to gather information about the status of TBAs, their use and the future perspectives of development for the benefit of communities in riparian countries.

This paper deals with an overview of a pragmatic action plan to develop and implement sustainable groundwater development and management of a TBA system. Goals of sustainable groundwater development and management along with measurable objectives to achieve the goals, are discussed. The comprehensive plan goes through a set of processes, conducted in coordination by the MCs working together sharing the TBAs, to come up with the operational guidelines in terms of water withdrawal on a long-term basis to maintain sustainable development of TBAs. An elaboration of implementation phases and scope of work of the pragmatic action plan is provided. Adequate institutional capacity is needed to execute all functions for implementing the sustainable development plan through long-term evaluation and monitoring of the state of the groundwater system. An Institutional system for the management of TBA in the form of a Coordinating Council or a Multi-Country Consultative Body at the Government Level is recommended. Finally, the in-house capacity requirement at different administrative levels is highlighted to provide the know-how and expertise to address development and management issues.

1 TBAs IN LOWER MEKONG BASIN (LMB)

As per the global inventory of TBAs by IGRAC and UNESCO-IHP (1), four TBAs are identified in LMB. These are Cambodia-Mekong River Delta Aquifer (AS89), Khorat Plateau Aquifer (AS90), Lower Mekong River 2 Aquifer (AS91) and Lower Mekong River 1 Aquifer (AS118), listed in Table 1. The first three are considered as the major aquifer systems with area coverage ranging from 100,000 to 200,000 km^2 shared by two or three countries in the basin.

TABLE 1 TBAs in Lower Mekong Basin (LMB) [derived from Table 1, (2)]

Code	Aquifer Name	Countries Sharing	Area (km^2)	Major Aquifer Formation
AS89	Cambodia-Mekong River Delta Aquifer	Cambodia, Vietnam	204,077	Sediment – sand, gravel, silt
AS90	Khorat Plateau Aquifer	Lao PDR, Thailand	108,529	Sedimentary rock – sandstone/siltstone
AS91	Lower Mekong River 2 Aquifer	Lao PDR, Thailand, Vietnam	122,216	Sedimentary rock – sandstone/siltstone
AS118	Lower Mekong River 1 Aquifer	Lao PDR, Myanmar, Thailand	36,769	Sedimentary rock - limestone

A number of recently published articles and reports dealt with the overview of TBAs in the Mekong River Basin on the regional scale and highlighted the need for comprehensive assessment and collaborative efforts in the development of this resource [(3), (4), (2)]. The upper part of the Mekong River Basin in China is characterised by the fissured rocks or karst aquifer, whereas the delta region (Mekong Delta) is extensively covered by unconsolidated alluvial sediments, extending from the coast to the northwest in Cambodia, including the Tonle Sap Lake. In the delta region, the thickness of the alluvial sediment is large, and these units are characterised as the primary aquifer. Along the central part of the basin, consolidated rock units (basalt, limestone, fissured sandstone, etc.) serve as localised aquifers with high potential groundwater yield. In the lower basin of Mekong, groundwater provides water for approximately 60 million people. Frequent water shortage problems are normally managed by increasing the supply from groundwater, particularly in the dry season.

2 SUSTAINABLE GROUNDWATER DEVELOPMENT AND MANAGEMENT (SGWDM)

Traditionally, 'Safe Yield' concept, as used in the operation of the surface water reservoir system, has been applied for groundwater resources and is defined as the amount of water that can be withdrawn from a groundwater basin annually on a long-term basis without producing any undesirable result (5). A common misperception has been that the development of a groundwater system is 'safe' if the average annual rate of groundwater withdrawal does not exceed the average annual rate of natural recharge. The concept of 'sustainable development', which emerged in the early 1980s, centred on the idea of limiting resource use to levels that could be sustained over the long term. The concept of sustainability in relation to groundwater resources is closely aligned with safe yield, but defined in a broad context as the development and use of groundwater resources in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (6). Sustainability of groundwater development is a function of the type of aquifer system, the climate, the recharge rate, and the type and scale of groundwater development.

Sustainable groundwater development is defined here as a groundwater pumping regime (spatial and temporal variations) determined for a specific physical system from the dynamic balance of inflow, outflow and change in storage using specified withdrawal rates, well-field locations, drawdown limits and a defined planning horizon. The withdrawal rate patterns that meet the constraint on drawdown and/or any other environmental concerns (like minimum outflow, limit on quality deterioration, land subsidence, seawater intrusion) will indicate the level of sustainable groundwater development. The analysis has to be based on proper identification and estimation of the following four elements of the groundwater system, including their states and inter-relationship: (1) *Available Groundwater Resource,* (2) *Groundwater Development and Use,* (3) *Groundwater Dependent Ecosystems, and* (4) *Governance and Management.* The first three elements are interrelated, giving the state and response of the physical system; however, the operational guidelines and regulations can only be implemented when there is adequate governance and management system in practice.

For a transboundary aquifer system, the development of sustainable groundwater use and management plan is much more crucial as the resource is shared by two or more countries having a unique mandate in resource use and management in their respective country's perspective. However, the principles and concepts applied for the national aquifer system are also applicable for a transboundary aquifer and they need to be adopted in practice in an amicable manner, ensuring equitable sharing of the resource among the countries. The ultimate goal would be to achieve a sustainable level of development of transboundary aquifer resources within an agreed period of time of operation. Groundwater development and use in the Lower Mekong Basin has been mostly unregulated. Water levels have been continually declining, particularly in the delta areas associated with water quality problems and seawater intrusion in the coastal areas. It has been reported in the published literature [e.g. (4), (2)] that the national stakeholders, including regional organisations, scientists, intergovernmental agencies and local communities, have recognised the significance of transboundary aquifer resources and their efforts are expected to institutionalise necessary management plan.

2.1 SGWDM: principles and concepts

The concept of groundwater sustainability should encompass five interrelated goals: three that involve primarily the physical sciences and engineering domain, and two that are mainly socio-economic in nature. These goals are stated as follows (7):

- ***Protection of groundwater supplies from depletion***: where sustainability requires that withdrawals be maintained indefinitely without creating significant long-term declines in regional water levels.
- ***Protection of groundwater quality from contamination***: where sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.
- ***Protection of ecosystem viability***: where sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supply and the support of ecosystem.
- ***Achievement of economic and social well-being***: where sustainability requires that allocation of groundwater maximises its' potential contribution to the social well-being (interpreted to reflect both economic and non-economic values).

- ***Application of good governance***: where sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with the full account of the ecosystem needs, intergenerational equity, and the precautionary principle.

In practice, attaining groundwater sustainability is difficult due to the long timescales of groundwater processes and impacts and depends on how we use, manage, and value groundwater. At a global scale, mean residence times of groundwater are much longer than the residence times of other parts of the hydrologic cycle. For individual aquifers, mean residence times of groundwater cover a wide spectrum from <10 years to >1,000,000 years (8). However, groundwater policy horizons, typically 5 to 20 years, are often inconsistent with natural groundwater time scales, and this inconsistency creates hindrance for long-term groundwater sustainability. Impacts of aquifer depletion and groundwater contamination are often only observed after long periods of time. Likewise, renewal of a depleted aquifer and remediation of contaminated groundwater may demand measures over several generations. Three practical approaches for groundwater sustainability are advocated (9): setting long-term sustainability goals, back-casting, and management that is integrated, adaptive, inclusive, and local. It was suggested setting groundwater sustainability goals for aquifers on a multigenerational time horizon (50 to 100 years) while acknowledging longer-term impacts. Alternatively, mean residence times are a useful indicator of planning horizons because the mean residence time of an aquifer, defined as the average time for groundwater to flow from recharge to discharge areas, is an approximation of the aquifer renewal time. For groundwater systems with short mean residence time, the mean residence time can be used directly or as starting point for discussion of the planning horizon. For groundwater systems with long mean residence time, cyclic planning with adaptive management should be used to achieve the long-term sustainability goals.

Specific measurable objectives are required to avoid a series of “undesirable results”, like the negative impacts caused by continual lowering of groundwater levels, water quality degradation and land subsidence. Measurable objectives are essential as it is impossible to achieve sustainability without defining what it means and how it will be measured. The purpose of a measurable objective is to be a guide to achieving management goals; therefore, monitoring the status of a measurable objective so that it can be directly related to triggers and thresholds is important. Monitoring is the cornerstone of adaptive management. The importance of monitoring, and of learning from information collected, is what fundamentally differentiates adaptive management from trial and error. In order to guide the development process without having any undesirable consequence of the groundwater pumping, countries sharing the resources of TBAs need to define some “measurable objectives” to achieve “the sustainability goal for the basin”.

2.2 SGWDM: how to implement in practice?

The riparian countries sharing the transboundary aquifer system need to agree on “measurable objectives” to avoid “undesirable results” and to achieve “sustainability goals for the basin”. This is to be accomplished through a collaborative process of investigation, analysis and arriving at a consensus through dialogue by the professionals and designated representatives of riparian countries.

First, an understanding of the present level of groundwater utilisation of TBAs and its associated impact on the state of groundwater in terms of groundwater level change and groundwater quality is needed, whereby ‘defining clear baseline’. In case if the groundwater level has been declining on long-term basis, then the ‘allowable groundwater overdraft’ over the planning horizon can be taken as the measurable objective. This target depends on many factors ranging from hydrologic and hydraulic conditions of the aquifer system to allowable pumping lifts used for water withdrawal and the pumping cost. The riparian countries need to agree on this and the ‘quantitative threshold’ is set in terms of maximum allowable groundwater level drop; as well as they need to indicate ‘protective triggers’ for the management authorities to take necessary steps in order to contain measurable objective within a quantitative threshold. On the other hand, if groundwater quality is an issue, then the permissible level of water quality content would be set as a measurable objective, and the ‘quantitative threshold’ would be maximum permissible values for specific water quality parameters.

With an understanding of the hydro-geological system of TBAs and proper characterisation of the aquifer system, in the second step, the dynamic behaviour of the aquifer system is simulated when subjected to different scenarios of water withdrawal pattern in order to identify the window of pumping patterns in future over the years that will meet the requirement of measurable objectives over the planning horizon. This is interpreted as back-casting procedure to determine the simulated feasible pumping patterns in future that will meet the requirement of maintaining the aquifer response within the set threshold values. The actual pumping in future can then be regulated following a pattern within the window of back-casting options. Proper guidelines are then provided for the respective country's groundwater agency to understand what is required to achieve sustainability and what would be the guiding pattern of water withdrawal in future. As well, regular measurement and monitoring, and evaluation are to be carried out to ensure that the defined, measurable objective is within the threshold value, otherwise adjustment to management option (e.g. in terms of withdrawal pattern) is to be applied as part of adaptive management.

3 PRAGMATIC ACTION PLAN NEEDED FOR SGWDM

The mission of MRC is to promote and coordinate the sustainable management of water resources for the countries' mutual benefit. Although MRC includes groundwater in its mandate, the activities so far have mainly focused on surface water or integrated water resource management (IWRM) and bilateral agreements only exist under the IWRM framework. Activities focusing on shared groundwater resources management have not been adequately implemented. Management of the resources in transboundary aquifers broadly follow the same principles as those for any national aquifer resource, driven by the national priorities. However, for a shared resource, the national priorities may have to be adjusted to ensure equitable distribution. Different interests in utilising groundwater resources between countries have also restricted to undertake any initiative to utilise the resources on shared basis. Furthermore, data and information derived for hydro-geological conditions in respective countries may not be compatible to carry out a shared assessment of transboundary aquifer resources. Some form of international/regional initiative is therefore needed for the assessment of TBAs based on a sound scientific foundation.

The transboundary groundwater resources underlying the Lower Mekong Region merit closer attention with regards to their current use, which may not be intensive, but increasing demands on these resources will result in their intensive use in the near future. It is therefore imperative that the MRC takes initiative to institutionalise a collaborative initiative among the sharing countries to gather information about the status of TBAs, their use and the future perspectives of development for the benefit of communities in riparian countries. A pragmatic action plan is required to guide the process, starting with data collection, data harmonisation and aggregation, all through the analysis and evaluation leading to sustainable management of transboundary aquifer. An overview of the action plan with specific elements is provided in Fig. 1. This action plan is recommended considering the long-term need for a system to be in place to address the sustainable use of groundwater of TBAs. It comprises of the following steps: (1) Secondary Data Collection and Appraisal, (2) Identification of Data Gap, (3) Harmonisation and Aggregation, (4) Selection of Pilot Study Area(s) in TBA, (5) Establishment of Monitoring Network, (6) Aquifer Characterisation, (7) Assessment and Evaluation, (8) TBA Information Management System, and (9) Multi-Country Consultative Body.

3.1 Implementation stages and scope of work

The implementation of activities with the goal of attaining SGWDM can be phased in three stages. Stage I is on secondary data collection, documentation and preliminary assessment, Stage II is on detailed analysis and development, and Stage III is on implementation, operation, management and monitoring. The scope of work of each stage requires discussion and agreement among the water users and stakeholders of riparian countries sharing the groundwater resources. The suggested scope of work under each stage is as follows:

Stage I: Preliminary Assessment - The major scope of work planned during Stage I deals with collection of secondary data available on hydro-meteorology, geology, hydro-geology, groundwater use, socio-economic aspect and institutional system; their preliminary analysis and evaluation to develop an understanding of the state of the groundwater system of TBAs in the respective sharing country. Also, identification of pilot study area (s) through discussion and deliberation of sharing countries for detailed data collection and analysis would be an important outcome of this stage.

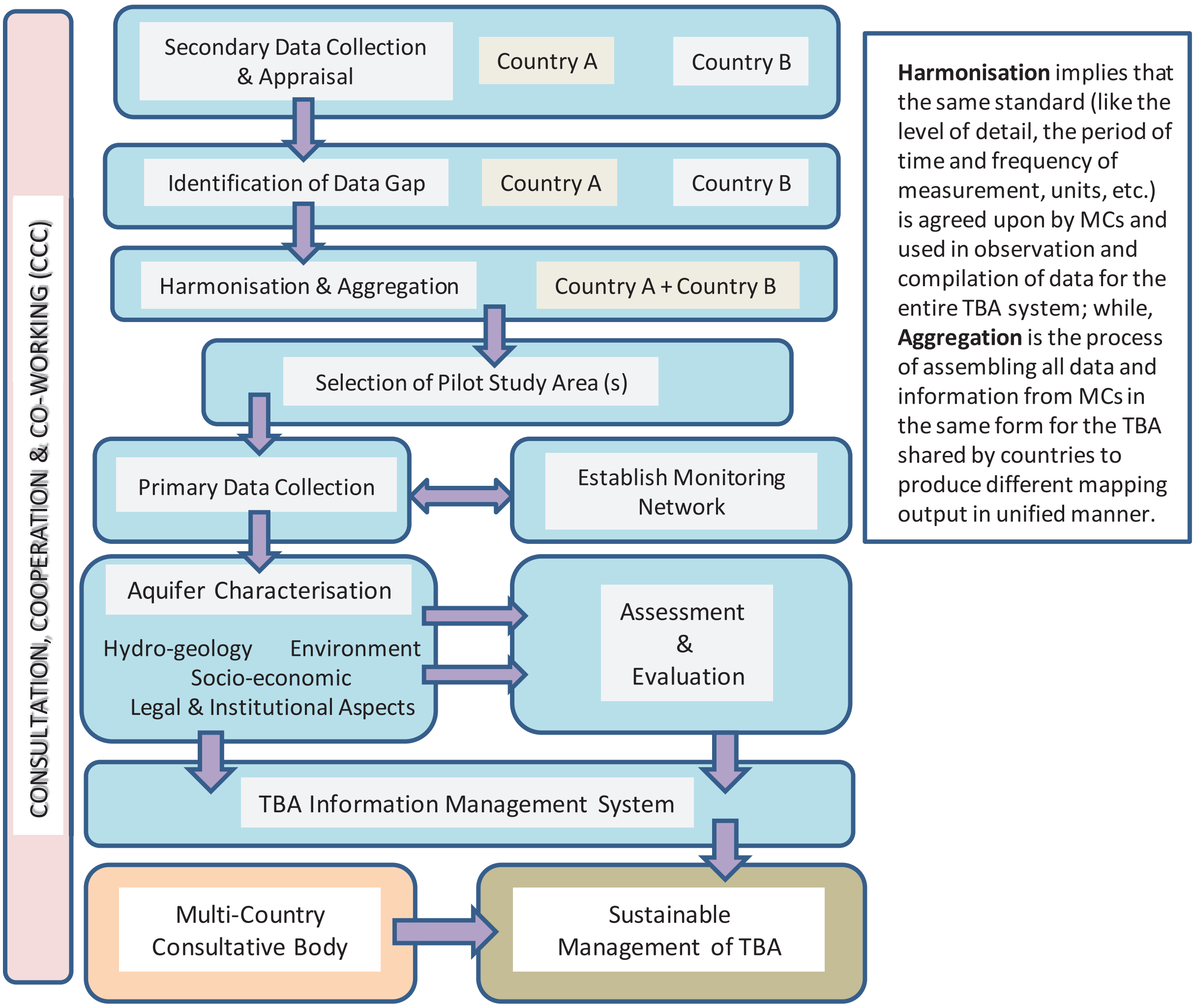


Fig. 1. Elements of Action Plan to achieve long-term objective of sustainable management of TBA: hypothesised 1 TBA shared by two countries (Country A & Country B)

Stage II: Detailed Analysis and Development - Once the pilot study area (s) have been identified, the main scope of this stage is to conduct a more detailed evaluation following a multidisciplinary approach. The hydro-geological analysis that is needed for the management of transboundary aquifers should run in parallel with and close relationship to the socio-economic, legal, and institutional analyses. Unless these components of the activities (indicated under Aquifer Characterisation in Fig. 1) are closely linked, the interrelationships may not be fully established and the final outcome may be weak. Following this**,** Assessment and Evaluation are done with the objective to understand the current state and future use of groundwater resources, to identify any environmental issues to be addressed in the development process, and to provide a sustainable development plan. One of the objectives of this stage of development is to evaluate the extent to which interregional harmonisation is needed in areas of data collection, data compilation, data analysis, and information dissemination and reporting. Stage II does not seek to change national approaches, rather to seek synergies and equivalences.

Stage III: Implementation, Operation, Management, and Monitoring - The sequence of activities in Stage III should be considered in the longer term. There are many reasons for this; mainly, that seeking finances and stakeholder support is generally a process that must not be hurried. Apart from this, a fundamental reason for this stage to extend to the long term is that aquifers respond more slowly than surface water systems. Consequently, the management and monitoring of transboundary aquifers are closely linked and have to be viewed from that perspective.

Finally, the overall aim of the action plan is to assess the current state of the resource, to identify current and potential transboundary issues and explore possibilities for common groundwater management. The outcomes of the assessment need to be easily understood and used by decision makers and even by the general public. For this, some effort needs to be put into producing an "Assessment Report" containing a clear and non-technical message, using thematic maps, tables and other graphical features accompanied with short explanations. An updating of this reporting would be a regular outcome of the joint management operation of TBA sharing countries. By considering the long-term perspective of resource use, assessment and evaluation, "TBA Information Management System (TBA-IMS)**"** is set up where all the compiled data, interpreted maps and results are stored. TBA-IMS is used during the recurring assessment and evaluation as development progresses. For proper functioning of the whole process a "Multi-Country Consultative Body" is formed to oversee the operation and management of TBAs.

3.2 Institutional system and capacity requirement

Each TBA has a unique feature from hydro-geological perspectives and the utilisation of its resource in respective sharing countries would be varying depending on the extent of its use in various development activities. Sharing countries have their institutional system for governance and management of groundwater that may not be compatible with each other. The overall scope of work to prepare the plan for sustainable groundwater use from transboundary aquifers requires discussion and agreed upon by the countries sharing the groundwater system. In order to facilitate this, a "Coordinating Council at the Government Level" is to be established to institutionalise a thorough consultation process and to take necessary actions for strengthening the collaborative process. This Coordinating Council is basically a "Multi-Country Consultative Body" as mentioned above. It is recommended that this "Coordinating Council" or "Multi-Country Consultative Body" consists of (1) A chair with strong leadership and communication skills, and (2) Three to Four independent members from sharing countries. These independent members should have collective expertise that would enable them to resolve all the legal, financial, hydrological, hydro-geological, environmental, groundwater management, and communication issues likely to come before them.

A proper organisational and institutional set-up with in-house capabilities has to be formed through joint effort and collaboration of countries sharing the groundwater basin. Expertise from outside and support of aid organisations will certainly assist in addressing key issues at the local and regional level; however, the long-term sustainable groundwater management will inevitably depend on the in-country professionals to provide the know-how and expertise. Sustainable use and management of groundwater resources require not only the technical and scientific skills in geology, hydro-geology but also the capability in socio-economics and the whole scope of water security to address issues of climate change. Groundwater is most effectively managed at the local and regional levels. Better authorities and tools at the local level are needed to support effective management. Capacity development needs are, therefore, to be assessed at different administrative levels in order to have well trained human resources and adequate financial resources at all levels to address groundwater resource development and management issues. All the stakeholders involved in groundwater development and use, and groundwater management need to have a basic knowledge and understanding of groundwater and the environment. Professionals with special expertise in different disciplines related to groundwater are to be in the institutional system all the way to the lowest possible level as measures are to be adopted at the local level to address development and management issues. Target group-oriented training programs are therefore required for in-house capacity development. The most important target groups are: Water Authorities; Water and Wastewater Associations; Engineers, Geologists and Hydro-geologists; and Community and Groundwater Users.

4 CONCLUDING REMARKS

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, aquifer boundaries are often very poorly known and many aquifers remain unknown or only partly recognised as separate, often unconnected, entities. This is particularly true for transboundary aquifers, which are often not recognised by countries as shared resources. This lack of recognition increases their vulnerability to anthropogenic pressures. Therefore, there is a need for a systematic effort to identify and delineate aquifers that are transboundary (Inventory) and to provide a standardised description of their main characteristics in terms of hydro-geology, environmental role and implications, socio-economic value and governance structure (Characterisation).

The management of a TBA shared by two or more countries is quite complex and is a challenging task as countries may have different forms of institutional and governance systems for management purpose. Adequate knowledge and understanding of the physical behaviour and functioning of the aquifer system, its state and extent of usage and their future trend are needed to plan for sustainable use and management of the resource. Implementation phases and scope of work of a pragmatic action plan are elaborated. It goes through a set of processes, conducted in coordination by the MCs working together sharing the TBAs, to come up with the operational guidelines of groundwater development on a long-term basis to maintain sustainable development of the TBA system. An Institutional system in the form of a Coordinating Council or a Multi-Country Consultative Body is recommended for the management of TBA. The in-house capacity and resources at different administrative levels to provide the know-how and expertise should be adequate to address development and management issues.

REFERENCES

(1) IGRAC (International Groundwater Resources Assessment Centre) and UNESCO-IHP (UNESCO-International Hydrological Programme) (2015), Transboundary aquifers of the world [map], Edition 2015, Scale 1:50 000 000, Delft, Netherlands, IGRAC.
(2) Lee, E., Jayakumar, R., Shrestha, S. and Han, Z. (2018), Assessment of transboundary aquifer resources in Asia: Status and progress towards sustainable groundwater management, Journal of Hydrology: Regional Studies, Vol. 20, pp. 103–115.
(3) Dam, R. and Jayakumar, R. (2017), Groundwater resources in the Greater Mekong Subregion: Collaborative resource management to increase resilience, Proc. of the Thematic Session "Geoscience for the Society", 52nd CCOP Annual Session, Bangkok, Thailand.
(4) Lee, E., Ha, K., Ngoc, N.T.M., Surinkum, A., Jayakumar, R., Kim, Y. and Hassan, K.B. (2017), Groundwater status and associated issues in the Mekong-Lancang River Basin: International collaborations to achieve sustainable groundwater resources, Journal of Groundwater Science and Engineering, Vol. 5, No. 1, 13p.
(5) Todd, D.K. (1959), Groundwater Hydrology, John Wiley, New York.
(6) Alley, W.M. and Leake, S.A. (2004), The journey from safe yield to sustainability, Groundwater, Vol. 42, No. 1, pp. 12-16.
(7) Canadian Council of Academies (2009), The Sustainable Management of Groundwater in Canada, Expert Panel on Groundwater, Ottawa, Canada.
(8) McMahon, P.B., Plummer, L.N., Bohlke, J.K., Shapiro, S.D., and Hinkle, S.R. (2011), A comparison of recharge rates in aquifers of the United States based on groundwater-age data, Hydrogeology Journal, Vol. 19, No. 4, pp. 779-800.
(9) Gleeson, T., Alley, W.M., Allen, D.M., Sophocleous, M.A., Zhou, Y., Taniguchi, M. and VanderSteen, J. (2012), Towards sustainable groundwater use: Setting long-term goals, backcasting, and managing adaptively, Ground Water, Vol. 50, No. 1, pp. 19–26.

TC-314S

Mapping Groundwater Resilience to Climate Change and Human Development in Bangkok and its Vicinity, Thailand

Sanjiv Neupane
PhD Candidate, Water Engineering and Management (WEM)
Asian Institute of Technology (AIT)
Bangkok, Thailand
mentosneupane26@gmail.com

Usha Ghimire
Research Associate, Water Engineering and Management (WEM)
Asian Institute of Technology (AIT)
Bangkok, Thailand
ushaghimire2820@gmail.com

Sangam Shrestha
Professor, Water Engineering and Management (WEM)
Asian Institute of Technology (AIT)
Bangkok, Thailand
sangam@ait.asia

S. Mohanasundaram
Asst. Professor, Water Engineering and Management (WEM)
Asian Institute of Technology (AIT)
Bangkok, Thailand
mohanasundaram@ait.asia

ABSTRACT

Groundwater is essential resource for various uses and have a great economic importance in Bangkok and its vicinity, Thailand. Groundwater resources in Bangkok and its vicinity is under immense pressure because of population growth, rapid urbanization, over exploitation and climate change. Mapping groundwater resilience under climate change and human development can be the effective tools to identify the area where the preventive measures are urgent which ultimately helps in the sustainability aspects of groundwater. We extend upon the results from Ghimire et al., 2021 on climate and land-use change impacts on spatiotemporal variations in groundwater recharge: A case study of the Bangkok Area, Thailand to include the effects of climate change and land use change on groundwater recharge. The future climate projected using the climate data of RCM's namely ACCESSCSIRO-CCAM, CNRM-CM5- CSIRO-CCAM and MPI-ESM-LR-CSIRO-CCAM for three future periods: near future (2010–2039), mid future (2040–2069) and far future (2070–2099) under RCP 4.5 and RCP 8.5 scenarios were bias corrected using quantile mapping technique. All RCMs projects that the temperature is continuously increasing in the study area, however, future precipitation is highly complex and uncertain and there was significant difference among various RCMs and both RCPs scenarios. An empirical land-use projection model (Conversion of Land-use and its Effects, Dyna-CLUE) was used. Future land-use scenarios of Low Urbanization Scenario (LU), Medium Urbanization Scenario (MU) and High Urbanization Scenario (HU) were developed in Dyna-CLUE focusing on increasing built-up area to generate land-use maps until 2099. A hydrological model WetSpass developed was used to estimate the water recharge and suggest that groundwater will be decrease in future for high and medium urbanization and the decrease in groundwater recharge ranges from 5.84mm/yr to 20.91mm/yr in RCP 4.5 scenario and 4.07mm/yr to 18.72 mm/yr in RCP 8.5 scenario. But, for low urbanization, the increase in future groundwater recharge ranges from 7.9 mm/yr to 16.66 mm/yr for RCP 4.5 scenario and 5.54 mm/yr to 20.04 mm/yr for RCP 8.5 scenario.

To estimate future groundwater level, GMS-MODFLOW model was set up using boundary conditions, recharge rates, pumping rates and hydraulic properties. The average groundwater level is projected to increase in first two pumping scenarios (S1 and S2), all land use scenarios and both RCPs scenarios. Whereas the average groundwater level is projected to decrease in pumping scenarios S3, all land use scenarios and both RCPs. Based on the result of GMS-MODFLOW, groundwater resiliency indicator was used to generate the resiliency map of Bangkok and its vicinity. The area classified as "very highly resilient" is projected to increase for pumping scenarios S1 and S2 in future. Whereas, for pumping scenario S3, the area under "very high resilient class" decreases and area under "not resilient" class increases in future.

Keywords: Climate change; Human development; GMS-MODFLOW; Groundwater resiliency

1. Introduction

In recent years, the world climate has been rapidly changing (Vijaya et al., 2011), and climate change has become a serious threat to water resources by affecting major long-term climate variables such as air temperature, precipitation, and evapotranspiration (Treidel et al., 2012). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), global temperatures have risen by 0.3-0.6°C since 1900 and will pick up to rise between 1.4 to 5.8°C by 2100.

Technological advancements have cleared the way for rapid growth and development. In most regions of the world, larger industries, jumbo infrastructures, and greater populations are quite communal. Human development, in terms of land use change and population growth, is occurring at an alarming rate, which has a direct impact on the water cycle's dynamics. According to United Nations Development Program (UNDP), Asia is the most vulnerable and scarce freshwater resources area in the world. It has been projected that freshwater resources will be more scare in the future due to climate change and augmented human demand (Wada et al., 2016; Veldkamp et al., 2017; Boretti and Rosa, 2019). Fresh water supply, both in terms of quality and quantity, will be a serious concern. Rivers, lakes, and streams, for example, may not be able to supply the ever-increasing demand of the growing population. Furthermore, the absence of infrastructure to harness freshwater resources means that groundwater will be used considerably more frequently. As a result, the reliance on groundwater is growing.

Groundwater is depicted as the world's hidden treasure, constituting 94% of its freshwater resources (Koundouri & Groom, 2010). Groundwater is the most preferable source of water supply since it is of good quality and requires less treatment than surface water (Shrestha et al., 2020). Groundwater plays a critical role in the long-term development of Asia's major cities. The importance of groundwater for the city's water supply will almost certainly increase in the future due to climate change and human development (population expansion, urbanization). As a result, for strategic planning and management of water resources in urban areas, it is critical to analyze the resiliency of groundwater under climate change and human development.

Bangkok is one of the megacities of Southeast Asia (Lorphensri et al., 2016) and it has been experiencing a noteworthy loss of groundwater since 1960s. Rapid population growth, urbanization, fast growing economy, tourism development and industrialization are the main drivers of groundwater over exploitations in Bangkok and its vicinity, Thailand (Lorphensri et al., 2016). Large scale groundwater degradation in Bangkok and its vicinity resulted in adverse environmental problems like continuous depletion of groundwater levels, land subsidence and groundwater contamination by sea water intrusion (Wattayakorn et al., 2016). The problem such as flooding, deterioration of infrastructure facilities, loss of properties, groundwater pollution and health hazards are associated with excessive groundwater extraction and land subsidence (Gupta and Babel, 2006). It is obvious that Bangkok city has experienced rapid change and development activities are still on advancement. Different human activities, imminent changing trends in climate and random extraction has a tremendous impact on groundwater resources. Therefore, there is an urgent need to implement policies to balance recharge according to withdrawal.

This study intends to assess the resiliency of groundwater system to climate change and human development in Bangkok and its vicinity, Thailand. We extend upon the results from Ghimire et al., 2021 on climate and land-use change impacts on spatiotemporal variations in groundwater recharge: A case study of the Bangkok Area, Thailand to include the effects of climate change and land use change on groundwater recharge.

2. Study area and data collection

2.1 Study area

The study area consists of Bangkok (13° 45' North, 100° 31' East) and its vicinity (Nonthaburi, Nakhon Pathom, Pathum Thani, Samut Prakan, Samut Sakhon, and Phra Nakhon Si Ayutthaya) (Figure 1). The Noi and Chao Phraya Rivers, as well as the Mae Klong, Pasak, Prachin, and Tha Chin Rivers, run through Bangkok and its surrounding provinces. The research area is located in a humid tropical climate with warm temperatures all year. Under the influence of the South Asian monsoon system, Bangkok has a tropical dry-and-wet climate with two seasons: dry (November to April) and rainy (May to October). The average annual temperature is 30 °C/year, with an average rainfall of 1500 mm. Bangkok and its environs have a total population of 11.3 million people, with a population density of 300–3,600 people per square kilometer, according to the 2010 census.

The study area covers the groundwater control areas of Bangkok and its six surrounding provinces, consisting of underlying unconsolidated sediment of the Chao Phraya-Tha Chin Basin which consist of alluvial and colluvial deposits and river terraces with a multiaquifer system. There are 8 aquifers layer in Bangkok and its vicinity; Bangkok aquifer (BK, 50m zone), Phra Pradaeng aquifer (PD, 100m zone), Nakhon Luang aquifer (NL, 150m zone), Nonthaburi aquifer (NB, 200m zone), Sam Kok aquifer (SK, 300m zone), Phaya Thai aquifer (PT, 350m zone), Thonburi aquifer (TB 450m zone), and Pak Nam aquifer (PN, 550m zone).

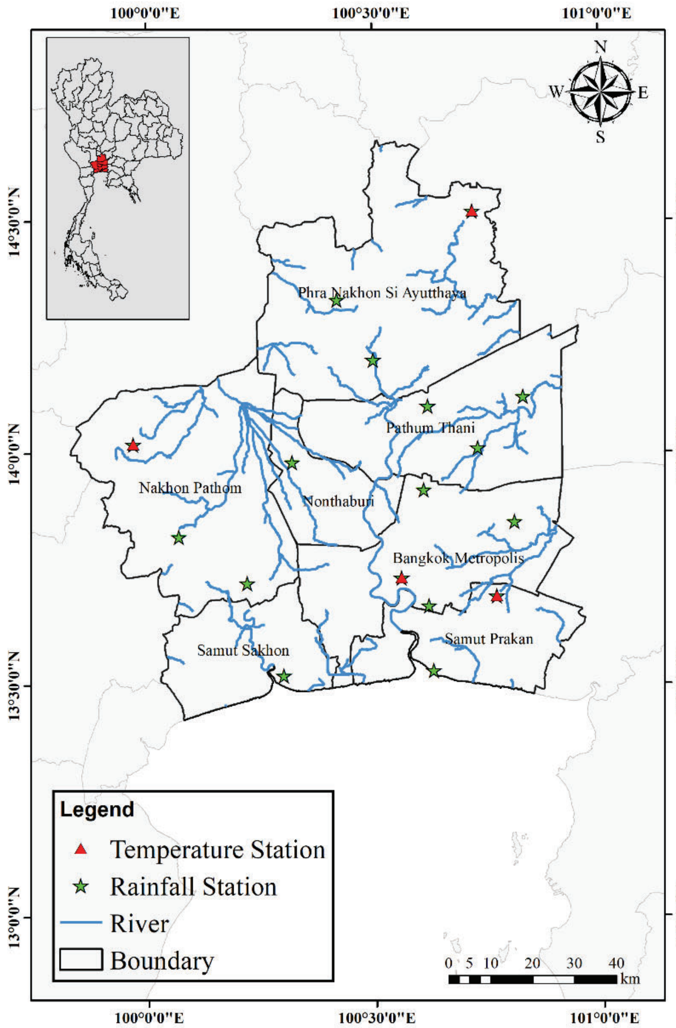


Figure 1: Location map of Bangkok and its vicinity with meteorological stations and the river network

2.2 Data Collection

Table 1: Data used in this study and corresponding sources of data

Data Type	Frequency/Time	Unit/ Format	Source
Observation/ Monitoring well data	Yearly/ 2001 and 2009	m	Department of Groundwater Resources (DGR), Thailand
Production/ Pumping well data	Yearly/ 2001 and 2009	m	
Hydrogeological properties	-	-	
River conductance and stage	-	m/sec and m	
Top and bottom elevation of each aquifers	-	masl	

3. Methodology

An overall methodology framework used in the study is stated in figure 2. The major objective of this study is to assess the resiliency of groundwater in Bangkok and its vicinity, Thailand, under climate change and human development scenarios. This process was be done through simulation using WetSpass model and Groundwater Model (GMS-MODFLOW). The climate data through baseline and future scenarios by climate models and land use change scenario created by Dyna-CLUE was fed into the WetSpass model to simulate future groundwater recharge. The effects of climate change and land use change on groundwater recharge is taken from the study by Ghimire et al., 2021 (Climate and land-use change impacts on spatiotemporal variations in groundwater recharge: A case study of the Bangkok Area, Thailand). The calibrated groundwater model MODFLOW from GMS (Groundwater Modeling System) was set up to estimate groundwater level of the study area. Finally, the groundwater resiliency indicator was developed based on the observed result which in-turn was used to develop the groundwater resilience map of the study area.

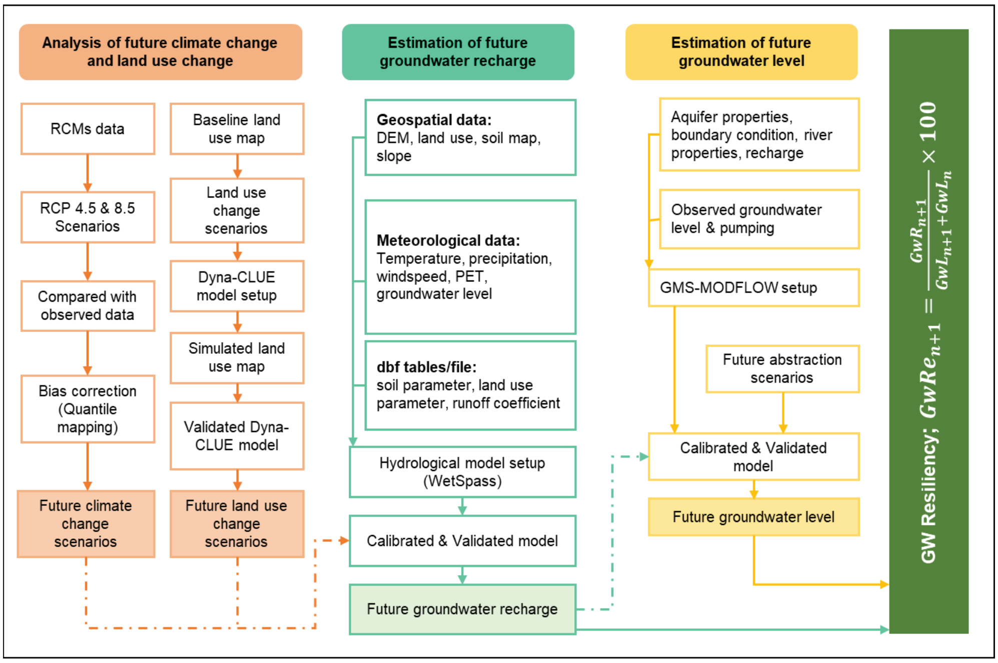


Figure 2: Groundwater resiliency mapping — Methodological Framework.

DEM is a digital elevation model; PET is potential evapotranspiration; RCM is a Regional Climate Model; GwRe is the groundwater resiliency; GwR is groundwater recharge; GwL is groundwater level; and n is the base year.

3.1 Groundwater flow model development

The groundwater level of Bangkok and its vicinity, Thailand, were simulated using the groundwater model MODFLOW from the Groundwater Modeling System (GMS). The purpose of this modeling method is to assess the temporal change in groundwater level caused by the disparity between groundwater recharge and expanding groundwater abstraction. This is one of the most extensively used groundwater models, and it may be used to investigate groundwater system dynamics and flow patterns in a variety of ways. This model can also be used as a tool for assessing recharge, discharge, and aquifer storage processes, as well as measuring long-term yields (Zhou et al., 2011). MODFLOW is also noted for its computational efficiency, accurate simulation of regional groundwater flow, and accurate representation of data. In addition, numerous academics and hydro geologists have employed the MODFLOW model to simulate groundwater flow in aquifers (Cheng et al., 2013; Lachaal et al., 2012; Yang et al., 2010; Ali et al., 2012; Maheswaran et al., 2016).

The three-dimensional groundwater flow through the porous medium is governed by the following equation:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial x}\left(K_z\frac{\partial h}{\partial z}\right)=S_s\frac{\partial h}{\partial z}-W \tag{1}$$

Where, K_x, K_y, K_z are the values of hydraulic conductivity along x, y and z axes [LT-1], h is the hydraulic head [L], W is flux per unit volume, representing sink and/or sources of water [T-1], S_s is the specific storage of the aquifer [L-1].

Equation 1 describes the transient flow when combined with both the initial and boundary conditions and steady state, while the term in the right-side of the equation is assumed to be zero. Flow area in the MODFLOW is represented by grids and layers. Each grid and layer is expected to have consistent properties and Equation 1 is used to calculate the head of the layer. For confined layers, the head can rise above the top elevation while the simulated head remains below the surface of the unconfined layer.

The GMS-MODFLOW model was setup by discretizing a groundwater basin of 10,199 km^2 into 138 rows and 123 columns with a cell size of 1000m×1000m enclosed in modified UTM coordinates of 590000 m east to 148500 m north. The inside grid of the groundwater border was set as an active area and the outside grid an indolent or inactive area. Vertically, the grids are alienated into 16 layers out of which 8 were aquifers (2,4,6,8,10,12,14 and 16) and remaining were aquitards (1,3,5,7,9,11,13 and 15). Model inputs include the elevation of each layer, hydrogeological properties, boundary conditions, initial groundwater levels, recharge and discharge. The groundwater level data for 139 observation wells and pumping data for 7,791 pumping wells were used in the model. Groundwater level data for 139 observation wells in 2001 was used for model calibration with 2009 used for model validation. The model simulation was conducted in the steady state condition to obtain future groundwater levels. The hydraulic properties, observation well and pumping well of the Bangkok aquifer system are summarized in Table 2.

Table 2: Hydraulic properties, observation well and pumping well details of the Bangkok aquifer system

Parameters /Aquifers	**Bangkok**	**Phra Pradang**	**Nakhon Luang**	**Nontha Buri**	**Sam Khok**	**Phaya Thai**	**Thonburi**	**Pak Nam**
K_x (m/day)	70	100	59	30	16.1	10.8	3.7	17.5
K_y (m/day)	70	100	59	30	16.1	10.8	3.7	17.5
K_z (m/day)	7	10	5.9	3	1.61	1.08	0.37	1.75
S_s (1/m)	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Number of pumping well	67	2091	3110	1774	415	236	68	30
Pumping rate (m^3/day)	1741.5	212586.1	610157.0	687788.8	249920.4	39455.8	21069.6	11190.2
Number of observation well	3	40	41	50	2	1	2	-

3.2 Groundwater resiliency mapping

The term resilience refers to an ecosystem's ability to withstand long-term damage as well as the time it takes to recover after a disturbance (Gunderson, 2000). In the context of climate change, resilience is defined as a system's ability to absorb disruptions while maintaining its core structure and ways of operating, as well as its ability to adapt to stress and change (IPCC, 2007). In an interconnected system, groundwater resiliency is defined as the aquifer's ability to withstand varied pumping stress while maintaining the same basic functionality in the context of variable surface water supply and recharge. According to Peters et al. (2004), resilience refers to "how rapidly a system is likely to recover from a failure, whereas vulnerability refers to the severity of the failure." Groundwater resilience, according to Sharma & Sharma (2006), is the "system's ability to retain groundwater reserves despite large perturbations."

In this study groundwater resiliency is defined as the percentage recovery from total depletion at a given time (Shrestha et al., 2020).

$$GwRe_{n+1} = \frac{GwR_{(n+1)}}{GwL_{(n+1)} - GwL_n} \times 100 \tag{2}$$

Where, n represents the base year, GwRe is groundwater resiliency, GwR is groundwater recharge (m/yr) and GwL is groundwater level (m/yr).

Groundwater resiliency (GwRe) was further divided into five different classes to develop a groundwater resiliency map of Bangkok and its vicinity (Table 3).

Table 3: Groundwater resiliency classification

Groundwater Resiliency (GwRe) or Percentage of Recovery (%)	Resiliency Class	Interpretation
0 to 1	Not resilient	Less groundwater recharge, higher reduction of groundwater level
1 to 3	Fairly resilient	Less groundwater recharge, fair reduction of groundwater level
3 to 5	Moderately resilient	Moderate groundwater recharge, moderate reduction of groundwater level
5 to 8	Highly resilient	Higher groundwater recharge, less reduction of groundwater level
>8	Very highly resilient	Higher groundwater recharge and very less reduction of groundwater level

3.3 Future abstraction scenarios

To analyze the impact of climate change and human development in groundwater level three pumping scenarios were assumed.

I. Pumping Scenario 1 (S1):

In this scenario, pumping rate was assumed to follow existing trend. After analyzing the pumping rate for 2001 and 2004, the pumping rate was decreased by 0.50% per year. Therefore, the pumping rate was assumed to decrease by 15% in 2030, by 25% in 2060 and by 35% in 2090. In this scenario, the pumping rate was assumed to be decreased by same rate as the baseline period. Thus, this scenario is the business as usual scenario.

II. Pumping scenario 2 (S2):

In this scenario, the pumping rate was assumed to be same as the study results of safe yield pumping model in the ground water critical area conducted by Department of Groundwater Resources, Thailand. The evaluation result on the potential groundwater consumption of 8 confined aquifers was found that the safe yield pumping rate of the whole area was 733,564 m3/day i.e. decrease of pumping rate than that of baseline pumping rate. This scenario is the optimistic scenario where the groundwater abstraction further decreases in future. Pumping rate was assumed to decrease by 20% in 2030, by 40% in 2060 and by 60% in 2090.

III. Pumping scenario 3 (S3):

In this scenario, the pumping rate was assumed to increase by same rate as of decrease rate in scenario 2. This scenario is the pessimistic scenario where the groundwater abstraction further increases in future. Pumping rate was assumed to increase by 20% in 2030, by 40% in 2060 and by 60% in far future 2090.

4. Results and discussion

4.1 Calibration and validation of groundwater model

A steady state groundwater model was developed for 2001. To achieve good agreement between the simulated and observed hydraulic heads, the values of hydraulic conductivities in each layer were adjusted within the acceptable limits. Model calibration was conducted by the trial and error method, and after several runs, the values of hydraulic conductivities in different layers were adjusted until a good match was achieved between observed and simulated heads. In addition, adjustments were also made to the river conductance and depth for model calibration. The model was validated for 2009, keeping the same calibration parameter and only changing the input data such as groundwater recharge, groundwater abstraction and observed groundwater levels. The model performance was evaluated using R^2 as a statistical measure. The R^2 value for the calibration period was found to be 0.80 and 0.75 for the validation period. This suggests that the overall performance of the model is fairly good. The relationship between observed and simulated heads for both calibration and validation periods are shown in Figure 3.

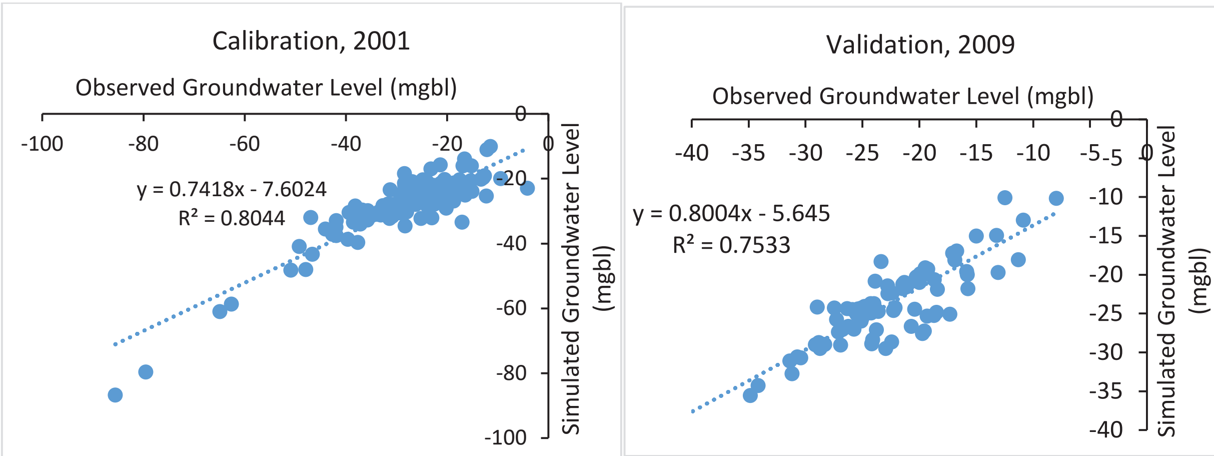


Figure 3: Relationship between observed head (mgbl) and simulated head (mgbl) in the steady state condition for calibration period (2001) and validation period (2009).

4.2 Impact of climate change and land use change in groundwater level

The impact of climate change and land use change on groundwater level was projected for three future periods: 2030, 2060 and 2090 under two RCPs scenario (RCP 4.5 and RCP 8.5) and three land use change scenarios (high, medium and low urbanization) after comparison with baseline (2001). Three pumping scenarios (S1, S2 and S3) were also analyzed to calculate future groundwater abstraction and subsequently used to calculate future groundwater level in all the aquifer layers. The results of three aquifer layers: Phra Pradaeng aquifer (PD, 100m zone), Nakhon Luang aquifer (NL, 150m zone), Nonthaburi aquifer (NB, 200m zone) is presented here as these layers are the most productive aquifer layers with good groundwater quality.

The result reveals that under all RCPs scenario and land use change scenario, groundwater level is projected to increase for pumping scenario S1 and S2. Whereas, for pumping scenario S3 it is projected to decrease in future. The maximum increase in average groundwater level is seen in low urbanization scenario and pumping scenario S2. The average increase in groundwater level ranges from 2.2m to 7.9m, 4m to 10.3m and 3.8m to 7.9m for PD, NL and NB aquifer and RCP 4.5 scenario respectively and 1.6m to 8.8m, 3.4m to 11.2m and 3.7m to 11.9m for PD, NL and NB aquifer and RCP 8.5 scenario respectively. The maximum decrease in average groundwater level is seen in high urbanization scenario and pumping scenario S3. The average decrease in groundwater level ranges from 2.9m to 5.6m, 2.8m to 6.7m and 3.2m to 7.6m for PD, NL and NB aquifer and RCP 4.5 scenario respectively and 3.3m to 4.9m, 3.2m to 5.9m and 3.7m to 7m for PD, NL and NB aquifer and RCP 8.5 scenario respectively (Figure 4).

The rate of change in groundwater level throughout the Bangkok city is not uniform. The central part of the city experience the decrease in groundwater level under all RCPs, land use and pumping scenarios. The maximum decrease in groundwater level was seen in NB aquifer by 28.4m and 27.7m for RCP 4.5 and RCP 8.5 scenario respectively under high urbanization and pumping scenario S3. The western and Eastern part of Bangkok city experience increase in groundwater level under all RCPs, land use and pumping scenarios and maximum increase in groundwater level was seen in NB aquifer by 27.6m and 26.7m for RCP 4.5 and RCP 8.5 scenario respectively under low urbanization and pumping scenario S2. The absolute change in future groundwater level with respect to observed groundwater level (2001) in 2030, 2060 and 2090 for PD, NL and NB aquifer layers under three land use scenario (low, medium and high urbanization scenario) and RCP 4.5 and 8.5 scenario for pumping scenario S3 is stated in figure 5. Whereas, for pumping scenario S1 and S2 it is presented in supplementary figure 1 and 2 respectively.

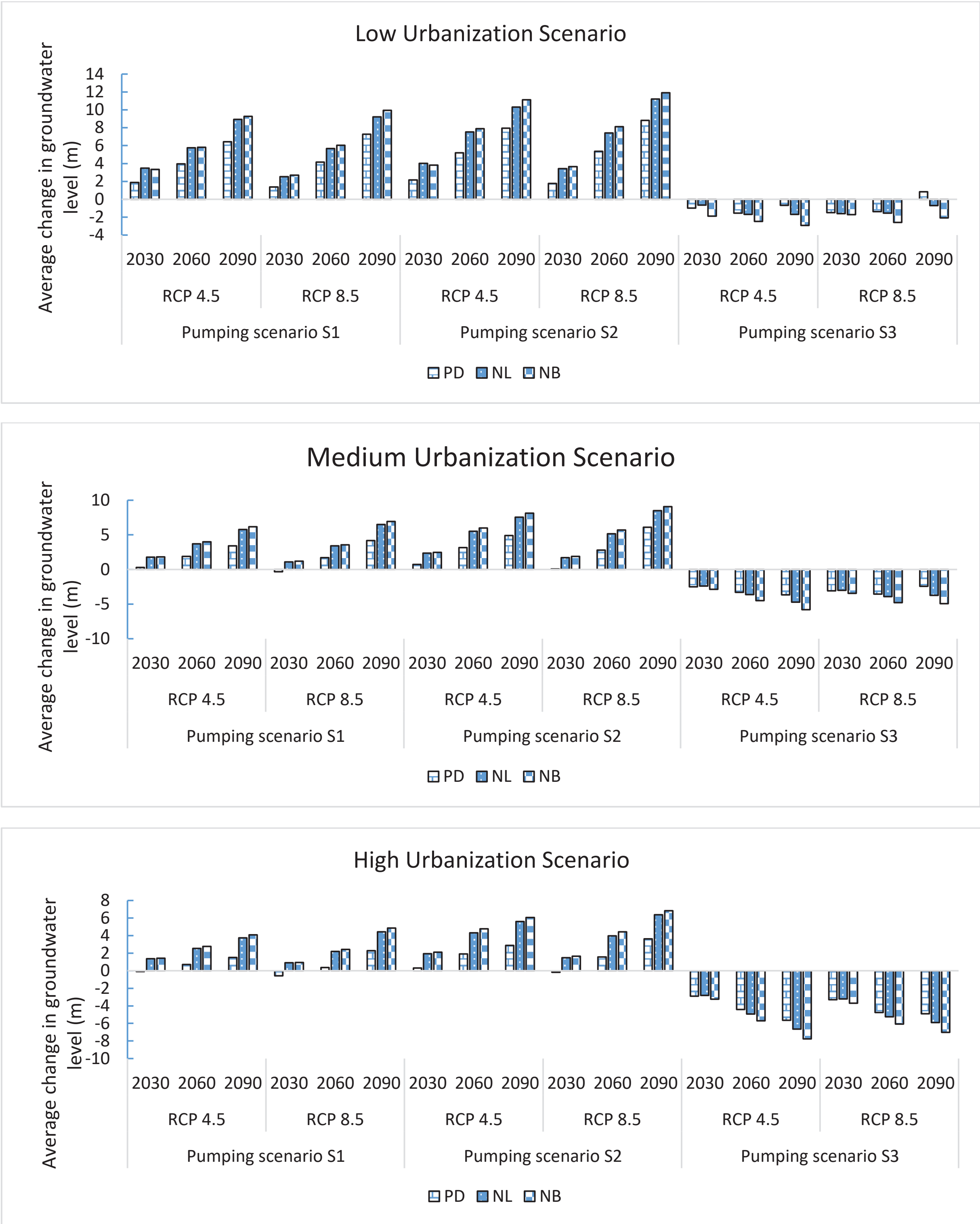
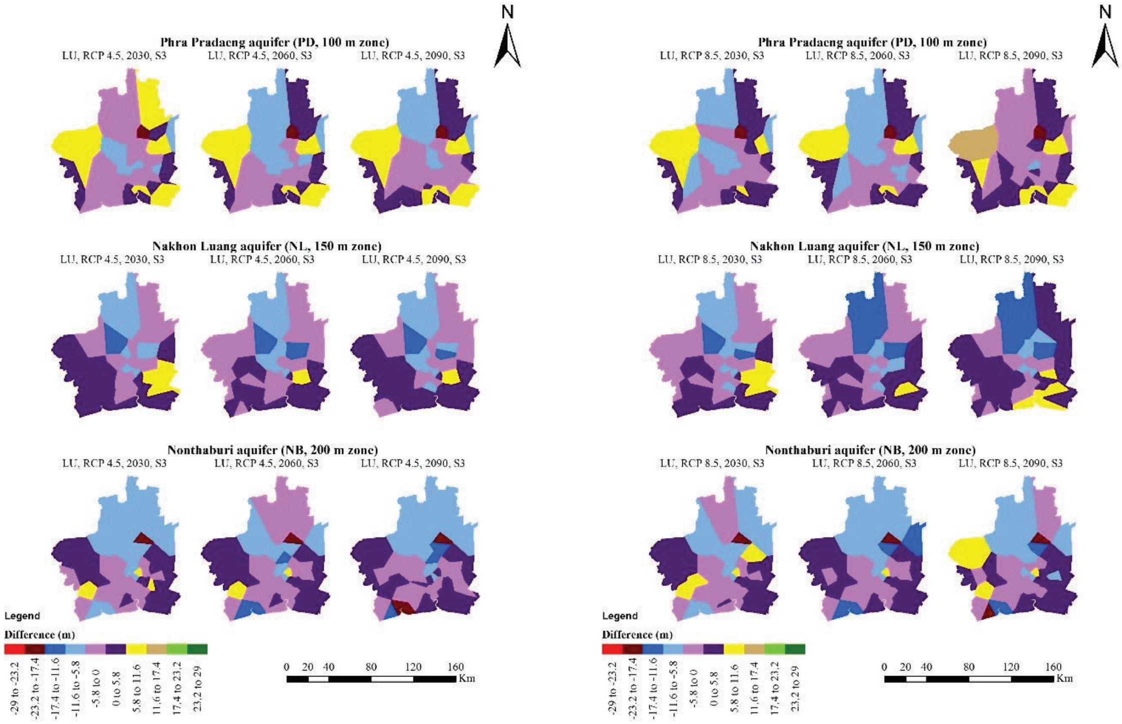
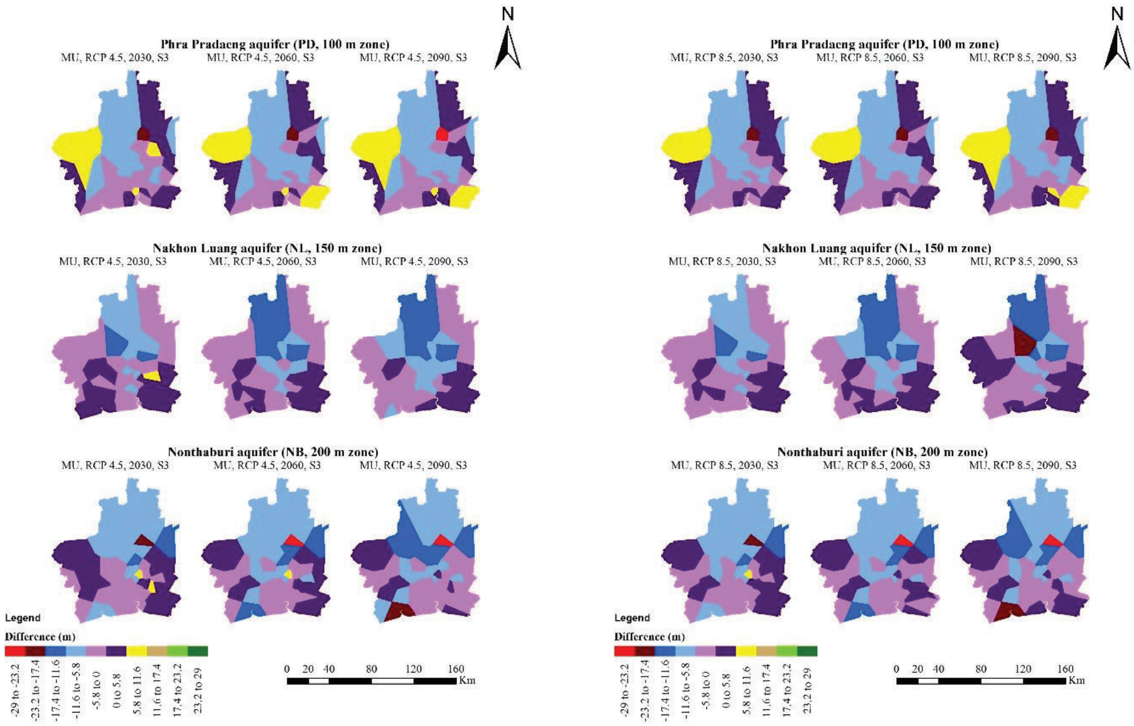


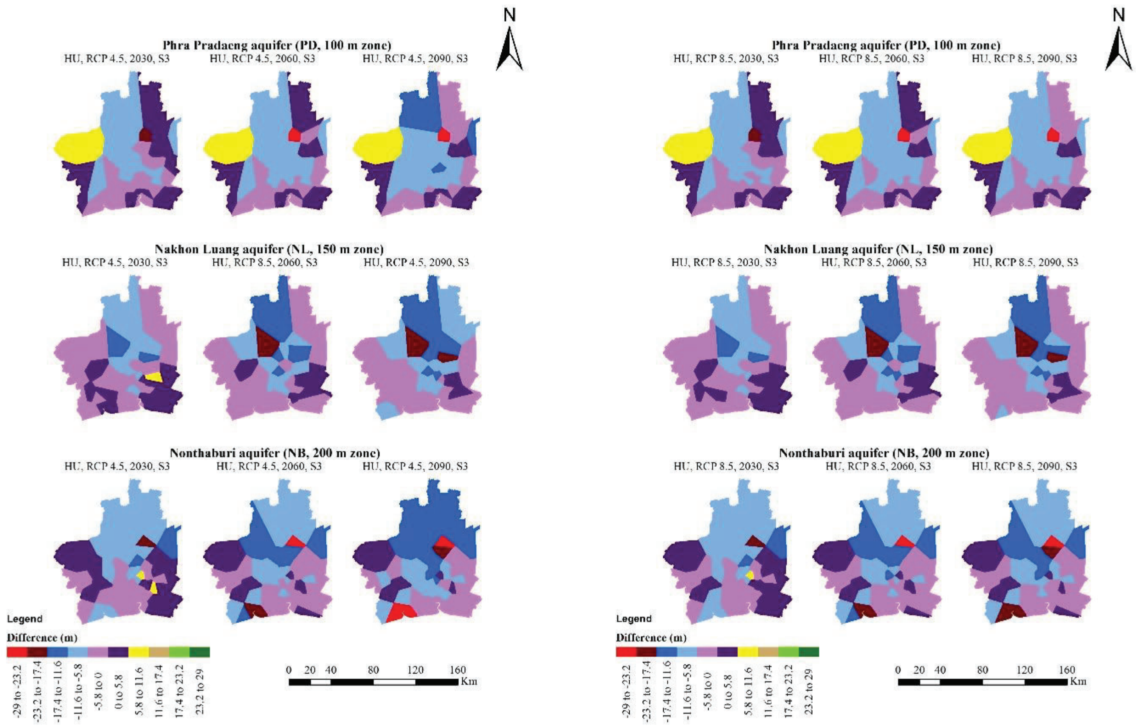
Figure 4: Average change in groundwater level for both RCP scenarios (RCP 4.5, RCP 8.5), three land use change scenario (low, medium and high urbanization) and three pumping scenarios (S1, S2 and S3) for three future periods: 2030, 2060 and 2090 relative to the baseline (2001).


Phra Pradaeng aquifer (PD, 100 m zone)
LU, RCP 4.5, 2030, S3
LU, RCP 4.5, 2060, S3
LU, RCP 4.5, 2090, S3
Nakhon Luang aquifer (NL, 150 m zone)
Nonthaburi aquifer (NB, 200 m zone)
LU, RCP 8.5, 2030, S3
LU, RCP 8.5, 2060, S3
LU, RCP 8.5, 2090, S3
N
Legend
Difference (m)
-29 to -23.2
-23.2 to -17.4
-17.4 to -11.6
-11.6 to -5.8
-5.8 to 0
0 to 5.8
5.8 to 11.6
11.6 to 17.4
17.4 to 23.2
23.2 to 29
0 20 40 80 120 160
Km

A


Phra Pradaeng aquifer (PD, 100 m zone)
MU, RCP 4.5, 2030, S3
MU, RCP 4.5, 2060, S3
MU, RCP 4.5, 2090, S3
Nakhon Luang aquifer (NL, 150 m zone)
Nonthaburi aquifer (NB, 200 m zone)
MU, RCP 8.5, 2030, S3
MU, RCP 8.5, 2060, S3
MU, RCP 8.5, 2090, S3
N
Legend
Difference (m)
-29 to -23.2
-23.2 to -17.4
-17.4 to -11.6
-11.6 to -5.8
-5.8 to 0
0 to 5.8
5.8 to 11.6
11.6 to 17.4
17.4 to 23.2
23.2 to 29
0 20 40 80 120 160
Km

b



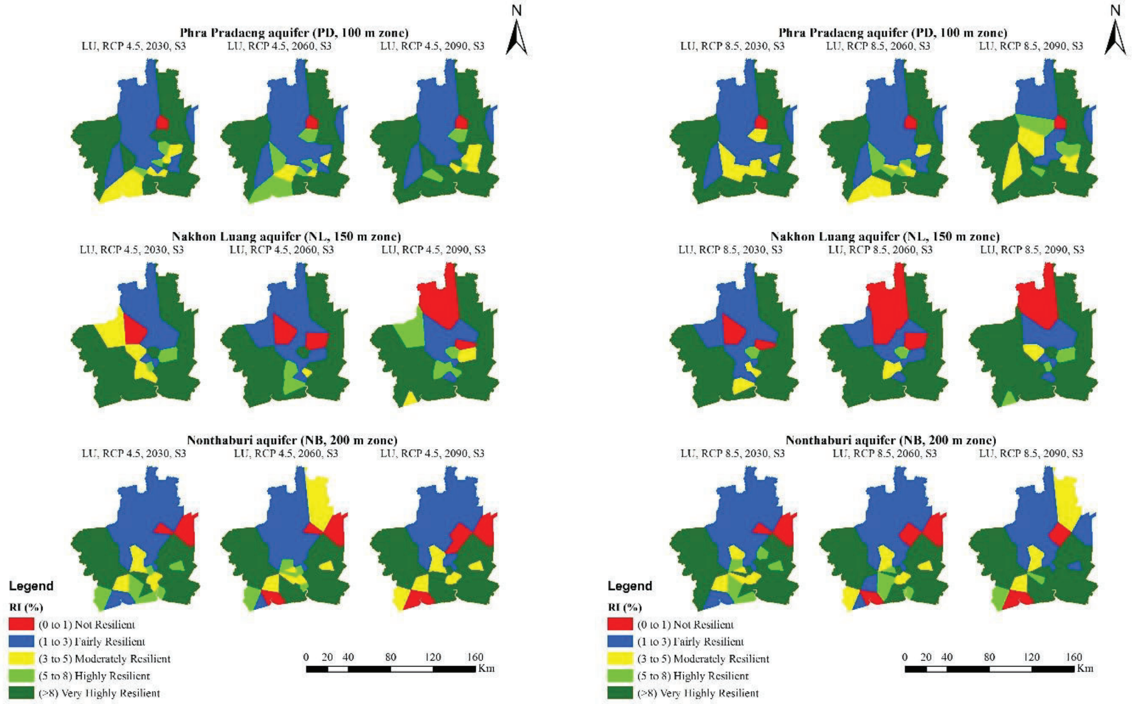
C

Figure 5: Absolute change in future groundwater level with respect to observed groundwater level (2001) in 2030, 2060 and 2090 for PD, NL and NB aquifer layers under low urbanization scenario (LU) (fig. 5a), medium urbanization scenario (MU) (fig. 5b) and high urbanization scenario (HU) (fig. 5c) and RCP 4.5 and 8.5 scenario for pumping scenario S3

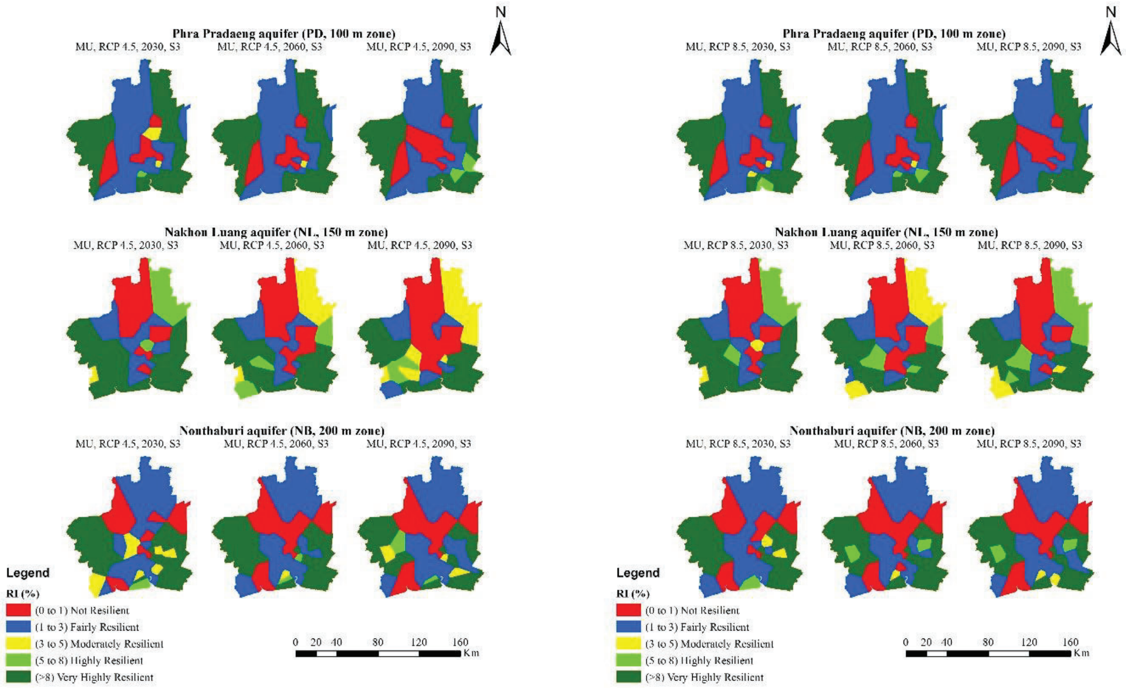
4.3 Spatial distribution of groundwater resiliency

The groundwater resiliency map of the Bangkok and its vicinity was developed based on the indicators described in Section 3.2 for all three pumping scenarios (S1, S2, S3) and three time periods (2031, 2061, 2091) under RCP 4.5 and RCP 8.5 scenario and three land use scenario (low, medium and high urbanization scenario). The results shows projected increase in percentage of area under very highly resilient class, whereas, the area under not resilient class is very low or some time even zero for pumping scenario S1 and S2, and for pumping scenario S3, there is projected decrease in percentage of area under very highly resilience class while the area under not resilient class is increasing and this is valid for all land use scenario, climate change scenario and all three aquifer layer.

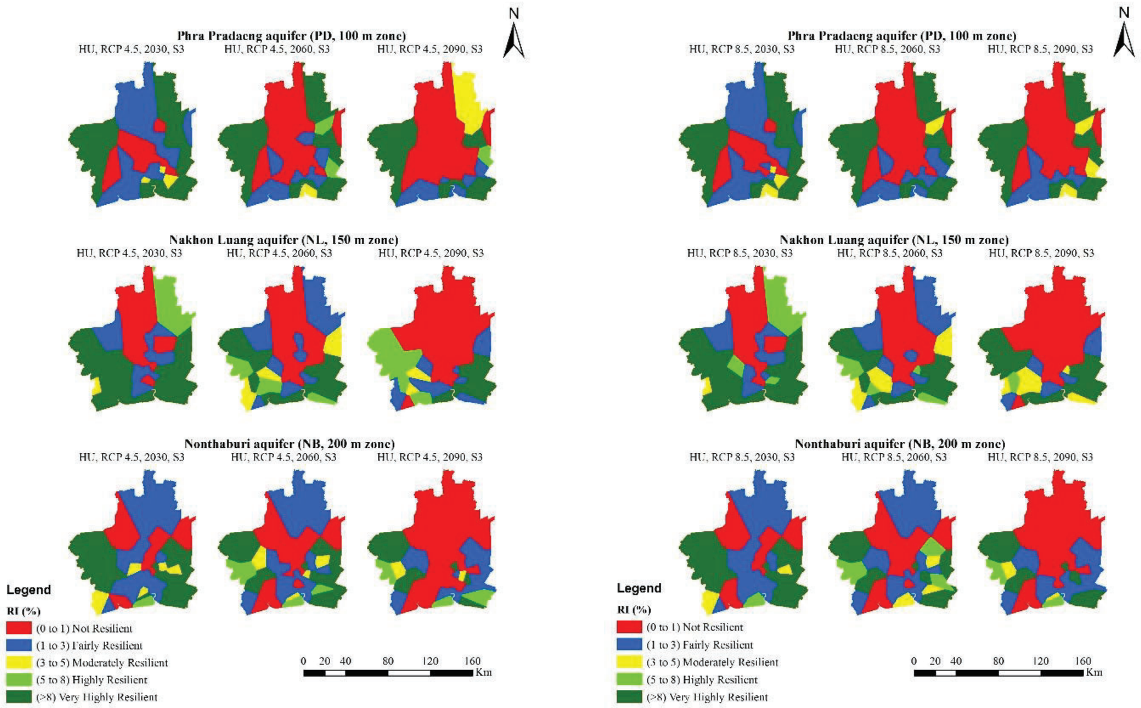
For high urbanization scenario and pumping scenario S3, by 2090 48.8%, 54.2% and 57.9% of area in PD, NL and NB aquifers respectively is under not-resilient class under RCP 4.5 scenario. Whereas, for RCP 8.5 scenario, 43.7%, 53.7% and 53.3& of area in PD, NL and NB aquifers respectively is under not-resilient class. For low urbanization scenario and pumping scenario S2, by 2090 almost 100% of the area is under very highly resilient class and this is valid for all climate scenario and three aquifer layer. The result reveals that the majority of the study area in central part is projected to fall under the not resilient and fairly resilient classes whereas the area in the eastern and western parts of the study area are resilient for all three land use scenarios, pumping scenario and RCP scenarios. Groundwater resilience map of Bangkok and its vicinity, Thailand for three different time period 2030, 2060 and 2090 for Pumping scenario (S3) under low, medium and high urbanization and RCP 4.5 and RCP 8.5 scenario of aquifers PD, NL and NB is shown in figure 6. Whereas the groundwater resiliency map of pumping scenario S1 and S2 is stated in Supplementary figure 3-4 respectively.



a



b



c

Figure 6: Groundwater resiliency map of Bangkok and its vicinity, Thailand for three different time period 2030, 2060 and 2090 for Pumping scenario (S3) under low, medium and high urbanization (fig 6a, 6b, 6c) and RCP 4.5 and RCP 8.5 scenario of aquifers PD, NL and NB

5. Conclusion

The groundwater resiliency map of Bangkok and its vicinity was developed using the results from the hydrological model, groundwater model under RCP scenarios (RCP 4.5 and RCP 8.5), three land use change scenarios (low, medium and high urbanization scenario) and three pumping scenarios (S1, S2 and S3). We expand on Ghimire et al., 2021's findings on climate and land-use change influences on spatiotemporal variability in groundwater recharge: A case study of the Bangkok Area, Thailand to include climate change and land-use change effects on groundwater recharge.

The impact of climate change and land use change on groundwater level was also analyzed. The results show that for pumping scenarios S1 and S2, groundwater levels are expected to rise under all RCP scenarios and land use change scenarios. In the case of pumping scenario S3, it is expected to decline in the future. The maximum increase in average groundwater level by 12m is seen in low urbanization scenario and pumping scenario S2 whereas, the maximum decrease in average groundwater level up to 7m is seen in high urbanization scenario and pumping scenario S3. However, the decrease in groundwater level is uneven across the Bangkok city. The central part of the city faces a higher decrease in groundwater level than the eastern and eastern areas. The results shows projected increase in percentage of area under very highly resilient class, whereas, the area under not resilient class is very low or some time even zero for pumping scenario S1 and S2, and for pumping scenario S3, there is projected decrease in percentage of area under very highly resilience class while the area under not resilient class is increasing and this is valid for all land use scenario, climate change scenario and all three aquifer layer.

Based on the findings and climate change and land use change variability, it can be concluded that Bangkok's groundwater resources are under severe threat from climate change and land use change. As a result, proper groundwater monitoring and the development of a credible strategy to safeguard it from human-induced causes and climate change are critical for the long-term management of groundwater resources in Bangkok and its vicinity, Thailand.

Acknowledgements

This study was conducted under the project "Mapping groundwater resilience to climate change and human development in Asian cities" (CRRP2018-01MY-Shrestha) supported by the Asia-Pacific Network on Global Change Research (APN). The authors would like to express sincere thanks to the Thai Meteorological Department (TMD), Department of Groundwater Resources (DGR) and Land Development Department (LDD) for providing required data for research.

Reference

Vijaya, V. R. S., Sanjairaj, I., & Goic, R. (2012). A review of climate change, mitigation and adaptation. Renewable and Sustainable Energy Reviews 16.1 (2012): 878-897.

Treidel, H., Martin-Bordes, J.J., & Gurdak, J.J. (Eds.) (2012). Climate change effects on groundwater resources: A global synthesis of findings and recommendations. International Association of Hydrogeologists (IAH)-International Contributions to Hydrogeology. New York, Taylor & Francis Group, CRS Press.

Wada, Y. (2016). Modelling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. Geoscientific Model Development, 9, 175–222.

Veldkamp, T.I.E. (2017). Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century. Nat. Commun, 8, 15697.

Wattayakorn, C. (2016). Groundwater Situation in Bangkok and Its Vicinity. (November). https://doi.org/10.13140/2.1.1734.7528

Zhou, Y., & Li, W. (2011). A Review of Regional Groundwater Flow Modelling. Geoscience Frontiers, 2(2), 205-214.

Yang, Y., Wang, G., & Yu, J. (2010). Groundwater depth simulation based on Beijing country level SWAT application tool. Water and Sediment Science, 309-317.

Sharma, U. C., and Sharma, V., 2006. Groundwater sustainability indicators for the Brahmaputra basin in the north eastern region of India, in Sustainability of Groundwater Resources and its Indicators, edited by B. Webb, IAHS Publ. 302, IAHS Press, Foz do Iguacu, Brazil

IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from Geneva, Switzerland:

Boretti, A., Rosa, L. (2019). Reassessing the projections of the World Water Development Report. npj Clean Water 2, 15 (2019). Doi: https://doi.org/10.1038/s41545-019-0039-9

Koundouri, P., Groom, B., 2010. Groundwater Management: An Overview of Hydrogeology, Economic Values and Principles of Management. Groundwater-Vol. III. Encyclopedia of Life Support Systems (EOLSS).

Gupta, A. D., & Babel, M.S. (2006). Challenges for sustainable management of groundwater use in Bangkok, Thailand. International Journal of Water Resource Development, 21(3), 453-464. Doi: https://doi.org/10.1080/07900620500036570

Lorphensri, O., Nettasana, T., & Ladawadee, A. (2016). Groundwater Environment in Bangkok and the Surrounding Vicinity, Thailand. In Groundwater Environment in Asian Cities: Concepts, Methods and Case Studies. https://doi.org/10.1016/B978-0-12-803166-7.00011-8

Cheng, T., Mo, Z., & Shao, J. (2013). Accelerating Groundwater Flow Simulation in MODFLOW Using JASMIN-Based Parallel Computing. Groundwater, 52(2), 194-205. Doi: https://doi.org/10.1111/gwat.12047

Lachaal, F., et al., 2012. Seismic, gravity, and wire line logging characterization of the Zéramdine fault corridor and its influence in the deep Miocene aquifers distribution (east-central Tunisia). Arabian Journal of Geosciences, 8 p. doi: 10.1007/s12517-011-0298-3

Maheswaran, G., Selvarani, A.G., Elanogvan, K. (2016). Groundwater resource exploration in Salem district, Tamil Nadu using GIS and remote sensing. Journal of Earth System Sciences, 125(2):311–328

Ali, R., MCfarlane, D., Verma, S., Dawes, W., Emelyanova, I., Hodgson, G., & Charls, S. (2012). Potential climate change impact on groundwater resources of South-Western Australia. Journal of Hydrology, 475, 456-472.

Gunderson LH. 2000. Ecological resilience - in theory and application. Ecology, Evolution and Systematics, 31: 425–439.

Peters, E., vanLanen, H.A.J., Torfs, P.J.J.F., Bier, G. (2004). Drought in groundwater drought distribution and performance indicators: Journal of Hydrology, v. xx, p. 1-16

Shrestha, S., Neupane, S., Mohanasundaram, S., Pandey, V.P. (2020). Mapping groundwater resiliency under climate change scenarios: A case study of Kathmandu Valley, Nepal. Environmental Research. 183-109149.

IPCC, 2014. Climate change 2014: Synthesis Report. In: Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland (p. 151).

Ghimire, U., Shrestha, S., Neupane, S., Mohanasundaram, S., Lorphensri, O. (2021). Climate and Land-use Change Impacts on Spatiotemporal Variations in Groundwater Recharge: A Case Study of the Bangkok Area, Thailand. Science of the Total Environment. 792, 148370

TC-316S

Roles of multi-stakeholders in sustainable groundwater management towards SDG6. A Case of Khon Kaen, Thailand

Preeyaporn Muenratch[1], Thi Phuoc Lai Nguyen[1*], Joyee S. Chatterjee[1]
[1]*Department of Development and Sustainability, School of Environment, Resources and Development*
Asian Institute of Technology
Pathum Thani, Thailand
E-mail address: phuoclai@ait.ac.th

Sangam Shrestha[2]
[2]*Water Engineering and Management, School of Engineering and Technology*
Asian Institute of Technology
Pathum Thani, Thailand

Salvatore G.P. Virdis[3]
[3]*Remote Sensing and GIS, School of Engineering and Technology*
Asian Institute of Technology
Pathum Thani, Thailand

Abstract

The rapid economic development is driven by The First National Economic and Social Development Plan from 1962 until now. Thus, Khon Kaen's economy is significantly expanded and led to the emergence of new businesses. Meanwhile, groundwater is much withdrawn by the business sector resulting in the downward trend of groundwater level. In addition, there is a lack of capacity assessment among stakeholders to manage invisible resources in their community. Heterogeneous stakeholders' involvement is needed to support groundwater management to achieve sustainable development goals (SDGs). The study aims to investigate the roles of multi-stakeholders at the local level to contribute to sustainable groundwater management in Khon Kaen. We identified stakeholders and the capacity of multi-stakeholders to manage groundwater resources in the community toward the targets of SDG6 (water and sanitation). The stakeholder identification is applied to identify the key stakeholders and online questionnaires. The finding shows many groups of stakeholders have high interest and high power for groundwater management in Thailand (most of them are state actors). Meanwhile, high interest and low power groups include various groundwater users (marginalized and vulnerable groups). Low interest and high power of stakeholder groups are policymakers and donors while low interest and low power of stakeholder groups are civil society and media. The capacity assessment of multi-stakeholders will be shown in the study. The multi-stakeholder roles and capacity assessment could support the capacity building program to strengthen local groundwater governance toward SDG6 targets and contribute to the groundwater policy at the national level as well as transboundary aquifer management.

Keywords- Groundwater management; Stakeholders; SDG6; Khon Kaen

1. Introduction

Groundwater is the key supporter of socio-economic development, livelihood and water insecurity. Since groundwater is also a significant resource for local people, groundwater management should be extended to the local level (Mauroner et al., 2021). Nevertheless, both national and local governance needs to be designed urgently to cope with the multi-level groundwater issues (Faysse et al., 2011; Jerbi et al., 2018). The rapid economic development is driven by The First National Economic and Social Development Plan since 1962. Khon Kaen's economy is significantly expanded and led to the emergence of new businesses. Groundwater is much withdrawn by the business sector while groundwater level is a downward trend. In Thailand, it is found that there is a lack of stakeholder engagement in groundwater management and previous researches only focused on the state actors, official organizations and experts appraised groundwater governance at the national level (see, Cheyasit et al., 2019; Sarami Froushani et al., 2021).

Stakeholder engagement is the key element of good groundwater governance (Closas & Villholt, 2019). The rise of awareness on groundwater use among stakeholders is necessary to alter their behavior related to groundwater resources. This approach will enhance the acceptance among stakeholders to adapt the behavior to uncertain situations of groundwater dynamics (van der Gun, 2021). A stakeholder is a person or entity (e.g., water authorities, non-governmental organizations (NGOs), or community members) with an interest or concern in the issues. Stakeholder participation can add saliency, credibility, and legitimacy to scientific assessments, which may lead to more effective and adaptable water management decisions (Cash et al., 2003; Elshall et al., 2020; Heink et al., 2015). Therefore, if there is a lack of local participation by various stakeholders, any measures related to groundwater management tend to collapse (Mumma, 2011).

Since there is a lack of capacity assessment among stakeholders to manage invisible resources in their community, the stakeholder involvement is needed to support groundwater management by contributing the capacity-building in water-related activities in groundwater governance to respond to sustainable development goals (SDGs). In addition, it may support the participation of local communities in improving water management (UN, 2020). Consequently, we aim to investigate the roles of multi-stakeholders at the local level to contribute to sustainable groundwater management in Khon Kaen. The study may contribute to the multi-stakeholder partnerships which can unlock the potential to adapt new solutions toward SDG6 to ensure more effective progress on sustainable development.

2. Study area

Khon Kaen faces an increase in water demand since the population growth and business expansion including the industries related to agro-based and food processes which required more irrigated water (Artlert & Chaleeraktrakoon,2013). Meanwhile, the UbolRatana Dam also requires a large volume of water to generate electricity (Thilakarathne & Sridhar, 2017). The competition of water use is to be intensified and have several impacts on Khon Kaen metropolitan area in the future. Whereas climate change is occurring, Khon Kaen encounters low effectiveness of urbanization management (Beringer & Kaewsuk, 2018). The absorbed surfaces and natural floodways in the city have declined since the lack of land use planning in the past (Ito et al., 2016). Since the economic development pushed by government policies, Khon Kaen’s economy substantially expanded and led to the emergence of new businesses, such as hired transportation, hotels, restaurants, bars, wholesale and retail services and the garment industry, attracting an influx of migrants from the surrounding rural areas.

3. Methodology

3.1 Stakeholder identification

The secondary data were gathered and analyzed based on the existing studies (i.e. Chanyaluk, 2020; DGR, 2020; Garduño et al., 2010; OECD, 2018; Paenmonkul, 2020, etc.). A stakeholder identification was applied to identify who are the beneficiaries and disadvantages in groundwater issues. The step starts with a stakeholder matrix which is identified from the official reports, researches, media and documentaries to illustrate who is related to groundwater issues in Khon Kaen. The method aims to clarify the influence and interest among key stakeholders. The procedure will provide the basis of groundwater stakeholder information to identify the roles in groundwater issues.

3.2 Stakeholder’s capacity assessment

The primary data is collected from the online questionnaires to assess the stakeholder capacity in groundwater management toward SDG6. Descriptive Statistics are used to analyze the level of stakeholders’ capacity to address the challenges of groundwater management toward SDG6 (i.e. mean and percentage). One-way ANOVA is used to compare the mean score of capacity among stakeholder groups.

4. Results

4.1 Groundwater Stakeholders

Stakeholders refer to institutions, organizations or groups that have some interest in a particular sector in the issues. Groundwater stakeholders are people who have a significant interest in the groundwater resources of a specified aquifer. Meanwhile, they use groundwater resources in their activities that could cause or prevent groundwater pollution, and they are regarded with groundwater resources and environmental management (Garduño et al., 2010). The stakeholders in the groundwater context can be scientists or experts, policymakers, users (farmers, industrial users, service users, etc.) (Mitchell & Mezias., 2012; Zellner, 2008), indigenous people, environmental interests and rural landholders (Knuppe & Pahl-Wostl, 2011). Stakeholder participation can be engaged in several levels (i.e., individual wells, aquifer systems, river basin and national level). If stakeholders can access to plan groundwater management at all levels, it can contribute to effective groundwater management, conservation and protection significantly (Garduño et al., 2010).

Groundwater stakeholders can be considered to private authorities or some organizations which are related indirectly. For instance, drilling contractors, surface irrigation providers, drainage and flood management authorities, sand and gravel mining operators, land use planning authorities, watershed management, educational establishments, professional associations and journalists or mass media (Garduño et al., 2010). Groundwater management cannot be achieved if it is focused only on the technical perspective. Thus, it should include groundwater users and develop a variety of instruments to regulate groundwater use and effective aquifer management (Gupta and Babel, 2005).

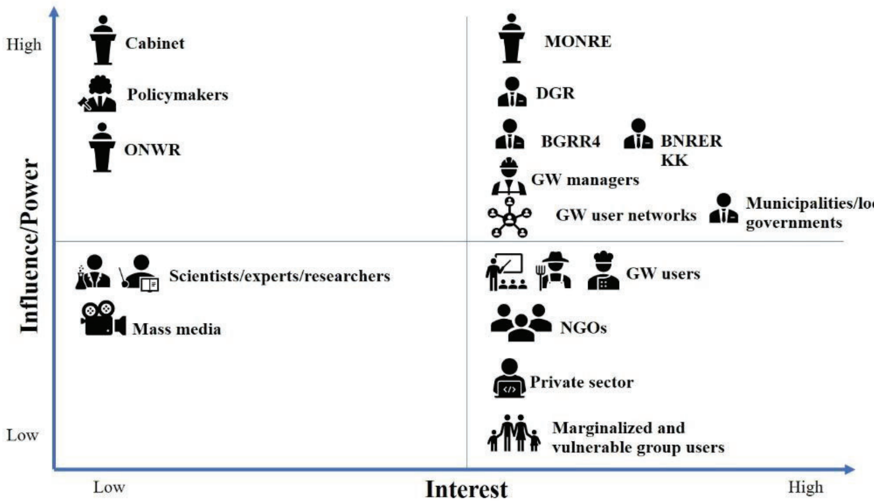


Fig. 1 Stakeholder Matrix

Fig. 1 represents the stakeholder matrix to understand the influence or power, and interest among groups of groundwater stakeholders. The stakeholder identification is classified to the main categories;

4.1.1 High influence and high-interest stakeholders

Groundwater policies, plans and regulations were taken by the sub-institutions that control and manage groundwater resources (i.e., Ministry of Natural Resources and Environment (MONRE), Department of Groundwater Resources (DGR), Bureau of Groundwater Resources Regional 4 (BGRR4) and Bureau of Natural Resources and Environment Regional (BNRER). The actions have been affecting many sub-groups of groundwater stakeholders in both direct and indirect ways according to the hierarchy of authorities. Registered (agricultural, business and domestic users) and non-registered (marginalized and vulnerable users) groundwater users may also be affected by the actions in terms of positive and negative impacts (i.e. poor people cannot access good quality of groundwater since lack of water supply by PWA in the slum community) (Mark, 2019). Moreover, groundwater resources and the environment are also affected by users in terms of groundwater depletion and land subsidence which are the dominant effects of groundwater issues in Thailand (Ngoc et al., 2015).

The MONRE transferred the mandate of groundwater resources management to the DGR. Therefore, DGR has much power to take control and manage groundwater resources directly. Meanwhile, BGRR4 is a bureau of groundwater resources regional 4 (Khon Kaen) which is a department that governs the groundwater resources at the local level. The provinces which BGRR4 cover are Khon Kaen, Kalasin, Maha Sarakam, Leoi and Nong Bua Lam Pu. Khon Kaen is a pilot province that local government authorities and municipalities can implement in some missions to manage and control groundwater at the local level. Thus, local government authorities and municipalities can provide services for the groundwater users in some ways (i.e., people in pilot areas can ask for groundwater license in the provinces which is dominated by local departments transferred by DGR in a case of well's size is smaller than 100 mm. or the quantity of use is less than 10 m^3/day.) (DGR, 2020).

In addition, groundwater managers are the actors who help to solve groundwater in the hydrological aspect. They took some findings or consulted with scientists to manage groundwater in terms of technical aspects. Coelho et al. (2019) indicated that the task of water monitoring has become a key action to provide significant information to water users and to reduce over expenses caused by increases in water uses among different human activities (Coelho et al., 2019).

Groundwater user networks are also one of the actors who has been interested recently since they have more power than individual users in terms of bargaining the power of users to governments. Initially, DGR has started to create networks of groundwater users in 2020. The activity aims to create knowledge and experience about groundwater resources among groundwater users, especially agricultural users (DGR, 2020). In 2021, there are several laws related to water resources announced by ONWR. The recent law is the Water User Associations. The law aims to strengthen the participation among water users to cooperate with water resources in each river basin. WUA can suggest, inform and give opinions that relate to water resources management in the water basin to water basin committees. The law may support the specific groundwater user's associations. Meanwhile, groundwater user networks have also been empowered to comanage groundwater resources at the local level. Moreover, DGR prepared the activities to enhance the awareness of users in terms of groundwater knowledge and development among various sectors through the strengthening of understanding the laws and regulations related to groundwater resources. The activities can empower the community to overcome the challenges at the local level.

4.1.2 High influence and low-interest stakeholders

The Prime minister and cabinet have a role to consider and enforce the policies according to the cabinet's agreement. The National Water Resources Committee (NWRC) has a policymaker of water management, and the Office of National Water Resources (ONWR) adopts policies from NWRC to operate the functions of water management at the national level. ONWR has a role to propose the water policies in Thailand including holistic water management (Phanthaphech and Chittaladakorn, 2021). The organization is under the Prime Minister's office of Thailand (ONWR, 2021). The government has established the main organization that controls water management policy which conforms to the sixth strategy of the national water resources management strategies. The vision of the organization is "To be the main organization that systematically regulates and manages the policies of integrated national water resources management (ONWR, 2021).

4.1.3 Low influence and high-interest stakeholders

Groundwater users play a key role in terms of groundwater abstraction to support their activities (i.e. domestic drinking in their households, agricultural production as well as business purpose.) The main activities are based on the regulations under the Groundwater Act which determined the main three purposes of groundwater use in the license application. Another group of users are the marginalized and vulnerable groups who reside in the slum communities along the railways in Khon Kaen municipality. These groups have been affected since the residence is illegal. There is no public water supply investment and these users did not have the money to pay for water meter installation provided by Provincial Water Authority (PWA). They had to buy water from the company and drill the private well to use water temporarily (Mark, 2019).

In case of conflicts among groundwater users, local NGOs have a role to support equal access for the vulnerable and marginalized group while environmental NGOs are interested in protecting aquifers and groundwater tables in sustainability. Donors or financial supporters need to sustain and conserve groundwater by supporting aquifer recharge. They support budgets to public and private sectors in terms of research funding and financial to NGOs (Garduño et al., 2010).

4.1.4 Low influence and low-interest stakeholders

Mass media has a role to inform the news about groundwater resources. However, there is a lack of power of mass media to raise the awareness of groundwater users and other groups of stakeholders to manage groundwater at the local level. Scientists or researchers have a role to solve problems related to groundwater resources. (i.e. Groundwater institution under Khon Kaen university). The roles of the institution are developing databases and conducting research related to groundwater. Moreover, extending networks with universities, research institutes as well as related authorities to conduct researches and funding. They can influence DGR and BGRR4 by cooperating in terms of research and experiments to find innovations and better ways to improve the situation in such areas. Therefore, DGR and BBRG4 should support and facilitate scientists in both inside and outside organizations.

However, some groups of groundwater stakeholders are still invisible and behind the water sector since the lack of studying groundwater stakeholders at the local level. Therefore, the research aims to explore more groundwater stakeholders to balance the issues of groundwater resources. The findings of stakeholder identification can be the preliminary data to understand the key stakeholders who play the various roles in the groundwater governance in Khon Kaen.

4.2 Stakeholder capacity to address the groundwater challenges toward SDG6

Most stakeholders are private companies (23.1%), municipalities (15.4%), domestic household users (12.8%) and communities (12.8%). The average age of stakeholders is 28 years old, female (76.7%), and the highest level of education is bachelor degree (55.8%). Furthermore, the level of capacity to address the groundwater challenges toward SDG6, the average score of the capacity to address SDG6 and compare the average score of capacity among stakeholder groups are described;

4.2.1 Percentage of stakeholders responded to the capacity to address the groundwater challenges toward SDG6

Overall, Fig.2 shows that the stakeholders assess "probably yes" (score = 4) to all groundwater challenges to contribute to the SDG6 targets: 48.60% of respondents selected the challenge of conflicts among groundwater stakeholders toward SDG 6.B community participation. Furthermore, 27% of them assess "Definitely yes" (score = 5) to the challenge of groundwater depletion while 5.40% of stakeholders selected "Definitely not" (score = 1) are groundwater pollution, groundwater depletion, groundwater policies and marginalized and vulnerable groups inclusive.

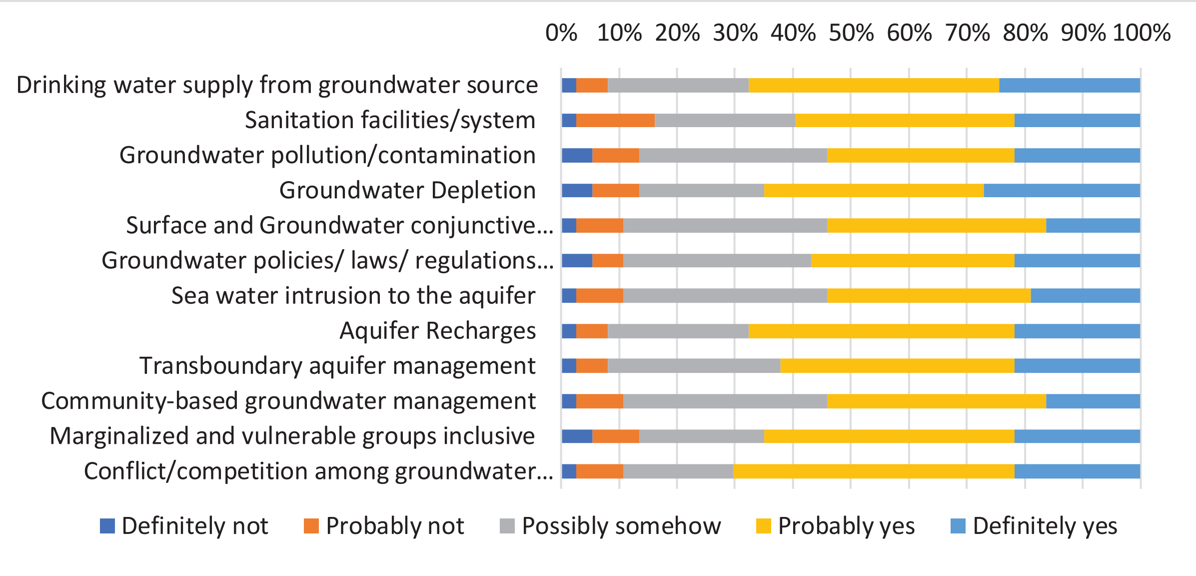


Fig. 2 Percentage of stakeholders responded to the capacity to address the groundwater challenges toward SDG6

4.2.2 The level of stakeholders' capacity to address groundwater challenges toward SDG6

Fig. 3 illustrates that the multi-stakeholders can address the challenge of conflicts among groundwater stakeholders toward SDG 6.B community participation (mean score = 3.82). Furthermore, the stakeholders can address the challenge of drinking water supply from groundwater sources toward SDG 6.1 – water access for all (mean score = 3.79). Groundwater pollution or contamination, Surface and Groundwater conjunctive management, Groundwater policies, laws, regulations improvement and Community-based groundwater management (mean score = 3.56).

4.2.3 Comparison of mean score of stakeholders' capacities

Table 1 shows there is a significant difference of score mean of stakeholder capacity between groups; Aquifer Recharges (F=2.50, p-value = 0.025) and Seawater intrusion to the aquifer (F=2.29, p-value = 0.037). The groundwater challenges related to SDG6 target 6.6 – aquifer protection.

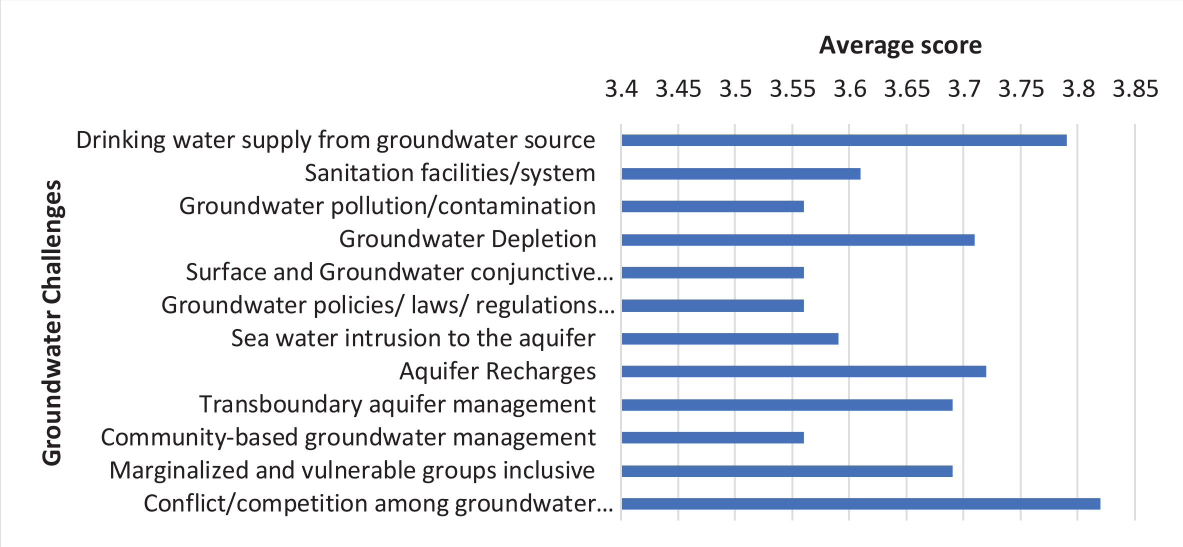


Fig. 3 The level of stakeholders' capacity to address groundwater challenges toward SDG6

Table 1 ANOVA results of stakeholder capacity to address groundwater challenges

SDG6 targets	Groundwater *Challenges*	Sum of Squares	df	Mean Square	F	P-value
6.1 Access to drinking water for all.	Drinking water supply from groundwater source	6.87	12	0.57	0.54	0.87
6.2 Access to sanitation and hygiene for all.	Sanitation facilities/system	11.29	12	0.94	0.82	0.63
6.3 Improve water quality	Groundwater pollution/contamination	14.52	12	1.21	1.08	0.41
6.4 Ensure sustainable withdrawals	Groundwater Depletion	17.16	12	1.43	1.29	0.28
6.5 Implement integrated water resources management (IWRM)	Surface and Groundwater conjunctive management	9.99	12	0.83	0.92	0.54
	Groundwater policies/ laws/ regulations improvement	9.01	12	0.75	0.56	0.85
6.6 Aquifer protection	Seawater intrusion to the aquifer	18.21	12	1.52	2.29*	0.04
	Aquifer Recharges	19.23	12	1.60	2.50*	0.03
6.A International cooperation	Transboundary aquifer management	12.75	12	1.06	1.28	0.29
6.B Participation of local communities	Community-based groundwater management	12.09	12	1.01	1.22	0.32
	Marginalized and vulnerable groups inclusive	17.31	12	1.44	1.39	0.23
	Conflict/competition among groundwater stakeholders	11.69	12	0.97	1.05	0.44

5. Discussion and conclusion

Stakeholder identification illustrates who are the key stakeholders, and the power and interest of each group in groundwater management. Key actors who manage closely (High power – high interest) (i.e., DGR, BGRR4, BNRER and MONRE) should integrate the level of capacity in terms of stakeholder participation in the policymaking process. Also, they should address the challenges which stakeholders can address (i.e., conflicts among groundwater stakeholders and drinking water supply from groundwater sources). The findings may help to boost the capacity up in groundwater management. Karatzas et al. (2021) highlighted that it can increase governance capacity by addressing people's skills in jointly decision-making and engaging stakeholders through participation.

The findings show overall stakeholders assess their capacity in the score level (4) represented to 'possibly'. Multi-stakeholders accepted and preferred to address the groundwater challenges in the community. In addition, the challenge of conflicts among groundwater stakeholders and drinking water supply from groundwater sources are the dominant high average preferences among stakeholders. The findings suggest that there should be supported measures to stakeholders in terms of stakeholder participation or consultation to formulate policies related to conflict resolution and knowledge dissemination or training about clean drinking water supply in communities.

However, groundwater pollution and contamination, surface and groundwater conjunctive management, groundwater policies, laws, regulations improvement and community-based groundwater management are the lowest preferences among stakeholders. The findings suggest that groundwater authorities should implement the policies related to these challenges to respond to the capacity building of the groundwater stakeholders. It may help to overcome the groundwater challenges in which there is a low capacity of the stakeholders.

Aquifer Recharges and seawater intrusion to the aquifer were the difference in mean score among stakeholder groups. The findings may imply that the governments should consider the policy related to raising awareness among stakeholders to understand the impacts on groundwater resources (i.e. seawater intrusion) and knowledge about aquifer recharge to make stakeholders understand the beneficiaries of addressing groundwater challenges.

The stakeholders' capacity to address groundwater challenges toward SDG6 can contribute to the roles of broader stakeholder participation in terms of local groundwater management strategies, and bringing all significant groundwater issues into the decision-making process for the groundwater regulatory or policy cycle (Foster, 2008) to support sustainable groundwater management in multi-level of groundwater governance.

References

Artlert, K., & Chaleeraktrakoon, C. (2013). Modeling and analysis of rainfall processes in the context of climate change for Mekong, Chi, and Mun River Basins (Thailand). *Journal of hydro-environment research*, *7*(1), 2-17.

Beringer, A. L., & Kaewsuk, J. (2018). Emerging livelihood vulnerabilities in an urbanizing and climate uncertain environment for the case of a secondary city in Thailand. *Sustainability*, *10*(5), 1452.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., ... & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the national academy of sciences*, *100*(14), 8086-8091.

Chanyalak, J. (2020). Groundwater Department Restructure. Academic Report. Retrieved from http://www.dgr.go.th/th/download/141 (August, 16th 2020)

Cheyasit, N., Kamkiew, W. & Phetsatit, P. (2019). The Components of Administration in Accordance with Good Governance of the Department of Groundwater Resources. *Journal of Social Development*, 21(2), 196-215.

Closas, A., & Villholth, K. G. (2019). Groundwater governance: Addressing core concepts and challenges. *Wiley Interdisciplinary Reviews: Water*, *7*(1), e1392.

Coelho, M., Fernandes, C. V. S., & Detzel, D. H. M. (2019). Uncertainty analysis in the detection of trends, cycles, and shifts in water resources time series. *Water Resources Management*, *33*(8), 2629-2644.

DGR. (2020). A daily report of groundwater situation in Thailand. Retrieved from http://www.dgr.go.th/th/news-daily/3615 (Aug, 14th 2020)

Elshall, A. S., Arik, A. D., El-Kadi, A. I., Pierce, S., Ye, M., Burnett, K. M., ... & Chun, G. (2020). Groundwater sustainability: A review of the interactions between science and policy. *Environmental Research Letters*, *15*(9), 093004.

Faysse, N., Hartani, T., Frija, A., Tazekrit, I., Zairi, C., & Challouf, A. (2011). Agricultural use of groundwater and management initiatives in the Maghreb: challenges and opportunities for sustainable aquifer exploitation. *AFDB Economic Brief*, 1-24.

Foster, S. (2008). Thailand: strengthening capacity in groundwater resources management. *World Bank Case Profile Collection*, *1*.

Garduño, H., van Steenbergen, F., & Foster, S. (2010). Stakeholder participation in groundwater management. *GW Mate Briefing Note Series*.

Gupta, A. D., & Babel, M. S. (2005). Challenges for sustainable management of groundwater use in Bangkok, Thailand. *International Journal of Water Resources Development*, *21*(3), 453-464.

Heink, U., Marquard, E., Heubach, K., Jax, K., Kugel, C., Neßhöver, C., ... & Vandewalle, M. (2015). Conceptualizing credibility, relevance and legitimacy for evaluating the effectiveness of science–policy interfaces: challenges and opportunities. Science and Public Policy, 42(5), 676-689.

Ito, H., Ko, S., Watanabe, K., Fujii, T., & Hayashit, K. (2016, May). Assessment by land use change using SI models in Khon Kaen, Thailand. In *Proceedings of the 36th Annual Conference of the International Association for Impact Assessment, IAIA16, Resilience and Sustainability, Aichi-Nagoya, Japan* (pp. 11-14).

Jerbi, H., Massuel, S., Leduc, C., & Tarhouni, J. (2018). Assessing groundwater storage in the Kairouan plain aquifer using a 3D lithology model (Central Tunisia). *Arabian Journal of Geosciences*, *11*(10), 1-10.

Karatzas, G., Vozinaki, A., Trichakis, I., Anyfanti, I., Varouchakis, E., Goumas, C., Roggero, P. P., Akrout, H., & Jomaa, S. (2021). Living Labs towards sustainable groundwater management: case study in Malia, Crete, Greece.

Knüppe, K., & Pahl-Wostl, C. (2011). A framework for the analysis of governance structures applying to groundwater resources and the requirements for the sustainable management of associated ecosystem services. *Water Resources Management*, *25*(13), 3387-3411.

Marks, D. (2019). Water access and resilience to climate-induced droughts in the Thai secondary city of Khon Kaen: Unequal and unjust vulnerability. In Urban climate resilience in Southeast Asia (pp. 41-62). Springer, Cham.

Mauroner, A., Timboe, I., Matthews, J., Taganova, J., and Mishra, A. (2021). Planning Water Resilience from the Bottom-Up to Meet Climate and Development Goals. UNESCO and AGWA: Paris, France and Corvallis, USA

Mitchell, E. N., & Mezias, S. J. (2012). The quest for cognitive legitimacy: Organizational identity crafting and internal stakeholder support. *Journal of Change Management*, *12*(2), 189-207.

Mumma, A., Lane, M., Kairu, E., Tuinhof, A., & Hirji, R. (2011). Kenya groundwater governance case study,https://openknowledge.worldbank.org/bitstream/handle/10986/17227/717260WP0Box370C00GWGovernanceKenya.pdf?sequence=1

Ngoc, N. T. M., Lee, E., & Jayakumar, R. (2015). Current Status and Issues of Groundwater in the Mekong River Basin. K. Ha (Ed.). Korea Institute of Geoscience and Mineral

OECD. (2018). Implementing the OECD Principles on Water Governance: Indicator Framework and Evolving Practices, OECD Studies on Water, OECD Publishing, Paris, https://doi.org/10.1787/9789264292659-en.

ONWR. (2021). The National Water Resources Management Strategies. Online report. http://www.onwr.go.th/en/?page_id=4207

Phanthaphech, N., & Chittaladakorn, S. (2021). Sustainable groundwater bank project management model of Yasothon province. *Journal of Social Science and Buddhistic Anthropology*, *6*(3), 92-107.

Sarami Froushani, T., Balal, H., & Movahedi, R. (2021). Evaluation of Groundwater Resources Governance Indicators in Iran's Agriculture Sector: Application of the OECD Governance Framework in the Hamadan-Bahar Plain. *Iranian Journal of Agricultural Economics and Development Research*, *52*(3), 591-615.

Thilakarathne, M., & Sridhar, V. (2017). Characterization of future drought conditions in the Lower Mekong River Basin. *Weather and Climate Extremes*, *17*, 47-58.

UN. (2020). Goal 6: Ensure access to water and sanitation for all. Retrieved from https://www.un.org/sustainabledevelopment/water-and-sanitation/ (June, 11th 2021)

van der Gun, J. (2021). Groundwater resources sustainability. In *Global Groundwater* (pp. 331-345). Elsevier.

Zellner, M. L. (2008). Embracing complexity and uncertainty: the potential of agent-based modeling for environmental planning and policy. *Planning Theory & Practice*, *9*(4), 437-457.

TC-317S

Spatio-temporal distribution of groundwater recharge under climate change in the Namngum++ River Basin

Santosh Dhungana, Sangam Shrestha, Tuan Pham Van, Saurav KC, Ashim Das Gupta
Water Engineering and Management (WEM), Department of Civil and Infrastructure Engineering (CIE), School of Environment and Technology (SET), Asian Institute of Technology (AIT),
P.O. Box 4, Klong Luang, Pathum Thani, 12120, Thailand
santosh.dhung@gmail.com

Key Words: groundwater recharge, SWAT, climate models, HRU

Groundwater contributes to one-third of the global water consumption and is critical for supplying global ecological, economic and societal needs. The burgeoning population has escalated groundwater demand for groundwater abstraction for industrial, domestic and irrigation consumption. In contrast to surface water, climate change, though it does not directly impact groundwater resources, influences groundwater in different ways: infiltrating water through soil, deep percolation, and increasing the evaporative demands of land, altering the groundwater recharge. The main objective of this study is to quantify the current groundwater recharge and assess the impact of climate change on its spatio-temporal distribution in the Namngum ++ river basin of the Lower Mekong Region (LMR). Namngum++ is a transboundary river basin that transcends Laos and Northern parts of Thailand, where groundwater is garnering wider attention in recent days. Thus, it is imperative to understand the impact of climate change on groundwater recharge for sustainable and progressive groundwater planning and management as erratic rainfall and prolonged droughts have made surface water unpredictable in this region. In order to quantify the current groundwater recharge, a physically semi-distributed Soil and Water Assessment Tool (SWAT) model for Namngum++ basin has been used. Hydrological simulation in SWAT is based on water balance, as given in equation 1.

$$\mathrm{SW_t} = \mathrm{SW_0} + \sum_{i=1}^{t} \left(\mathrm{R_{day}} - \mathrm{Q_{surf}} - \mathrm{W_{seep}} - \mathrm{ET_a} - \mathrm{Q_{gw}}\right) \quad (1)$$

where SW_t is soil water (mm), SW_0 is the base soil water (mm), t is time (days), R_{day} is rainfall (mm), Q_{surf} is surface runoff, ET_a is actual evapotranspiration (mm), W_{seep} is seepage of water through soil into deeper layers, Q_{gw} is groundwater runoff (mm).

Recharge on a given day in SWAT is calculated using equation 2,

$$r_{rchrg,i} = \left(1 - \exp[-1/\delta_{gw}]\right) \cdot r_{\mathrm{seep}\,+\exp[-1/\delta_{gw}]} \cdot r_{rchrg,i-1} \quad (2)$$

where $r_{rchrg,i}$ and $r_{rchrg,i-1}$ are the recharges reaching aquifers on day i and i-1 respectively, δ_{gw} is time delay posed by underlying geological section (days), r_{seep} is total water exiting bottom of soil layer on day i (mm H2O).

In this study, the SWAT model is calibrated (1997-2010) and validated (2011-2015) to the observed monthly streamflow (figure 1) prior to recharge estimation for present and future climate stress periods. The model performance was good with the coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), and percentage bias (PBIAS) values of 0.72, 0.70 and 9.2% for the calibration period and 0.80, 0.77 and 4.9 % for the validation period, respectively. The simulated recharge at the hydrologic response unit (HRU) level was processed for spatio-temporal representation.

The study linearly bias-corrected 3 climate variables(precipitation, minimum and maximum temperature) of four global circulation models (GCMs: BCC-CSM2-MR, Canesm5, GFDL-CM4 and MRI-CSM2-0) of the sixth phase of the Coupled Model Intercomparison Project (CMIP6) against the available observed (1985-2015) datasets to project the impact of climate change on groundwater recharge, this study The projections are computed for three future climate stress periods (2016-2045 as near future, 2046-2075 as mid future and 2076-2100 as far future) under two Shared Socioeconomic Pathways scenarios -

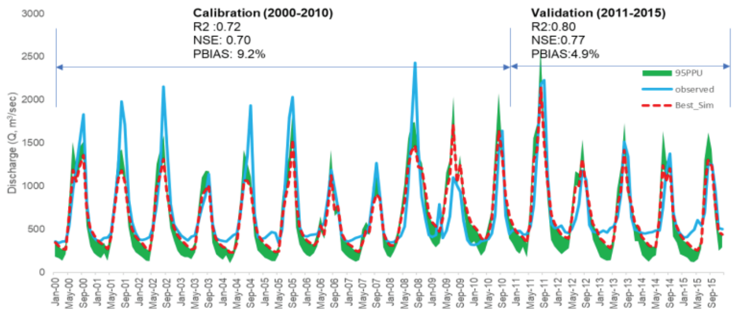


Figure 1: Monthly hydrographs of SWAT model during calibration and validation

(SSP2-4.5 and SSP 5-8.5). The bias-corrected hydrometeorological variables are then used as an input to SWAT. Considering the time scale at which SWAT runs, 8 SWAT models (for 4 GCM models and 2 SSP scenarios) were developed to assess the impact of climate change on groundwater recharge of Namngum++ basin (Lacombe et al., 2017). Groundwater recharge from each model for the future run was later averaged to obtain ensemble mean housing uncertainties of all models. As presented in figure 2, the lower flank of the basin shows the decline in groundwater recharge in ssp585 for all future stress periods while the northern region mostly demonstrated increased recharge for all stress periods.

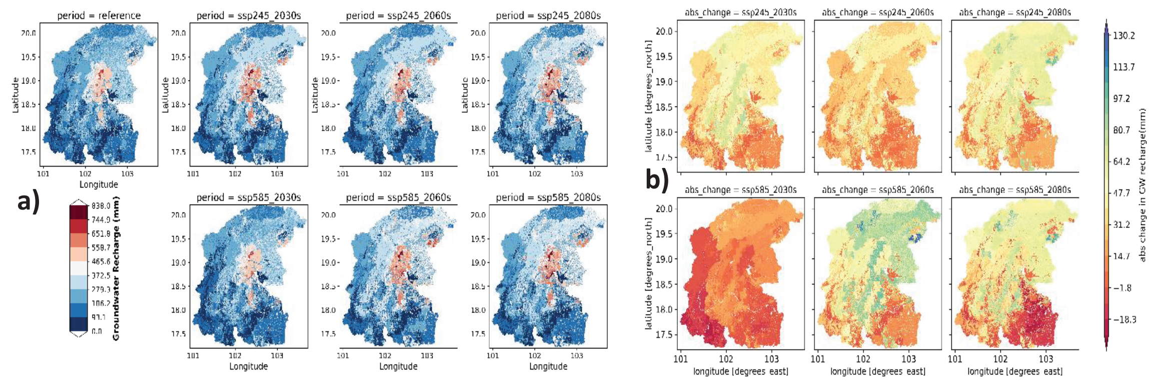


Figure 2: Groundwater recharge in Namngum++ basin a) comparison of different future scenarios with reference period b) absolute change in groundwater recharge for ssp245 and ssp585 scenarios for 2030s, 2060s and 2080s

ACKNOWLEDGEMENT

The authors would like to thank to the "Strengthening Groundwater Governance in Rapidly Urbanising Areas of the Lower Mekong Region (GIRA)" project funded by Stockholm Environment Institute (SEI) under the SUMERNET 4 All Programme which is funded by the Swedish International Development Cooperation Agency (Sida).

REFERENCES

J.G. Arnold, D.N. Moriasi, P.W. Gassman, K.C. Abbaspour, M.J. White, R. Srinivasan, C. Santhi, R.D. Harmel, A. van Griensven, M.W. Van Liew, N. Kannan, M.K. Jha. (2012). SWAT: model use, calibration, and validation Am. Soci. Agric. Biol. Eng., 55 (4) (2012), pp. 1491-1508.

Lacombe, G., Douangsavanh, S., Vongphachanh, S., & Pavelic, P. (2017). Regional Assessment of Groundwater Recharge in the Lower Mekong Basin. Hydrology, 4, 60.

Hughes, A., Mansour, M., Ward, R., Kieboom, N., Allen, S., Seccombe, D., Charlton, M., & Prudhomme, C. (2021). The impact of climate change on groundwater recharge: National-scale assessment for the British mainland. Journal of Hydrology, 598, 126336.

TC-318S

Evaluation of gridded rainfall products in the selected basins of Lower Mekong

Santosh Dhungana, Sangam Shrestha, Tuan Pham Van, Saurav KC, Ashim Das Gupta
Water Engineering and Management (WEM), Department of Civil and Infrastructure Engineering (CIE),
School of Environment and Technology (SET), Asian Institute of Technology (AIT),
P.O. Box 4, Klong Luang, Pathum Thani, 12120, Thailand
santosh.dhung@gmail.com

Key words: Gridded Rainfall Products, Entropy Method, Compromise Programming

ABSTRACT

Rainfall is a primary variable in many hydrological and meteorological studies and majority of these studies rely on direct gauge measurements. However, the reliable long-term gauge data are scarce especially in the developing nations like Laos and Vietnam. To fulfill the gap, gridded rainfall products (GRPs) are being developed and used at local to global scale application. However, these products have inherent uncertainties owing to their gridding algorithms, available gauge density and period of data available suggesting their evaluation prior to their applications. A wide assortment of GRPs evalution techniques ranging from a use of single criteria like correlation coefficient to multi-criteria technique like Cooperative Game Theory, Compromise programming, etc. are available.. Hence this study considers two important sub-basins with unkwown status of GRP evaluation in lower Mekong reion, Nam Ngum River Basin (NRB) in Laos that houses several dams and growing hydropower projects and Vietnam Mekong Delta (VMD) n Vietnam largely dependent on agriculture and aquaculture. Two monthly and six daily GRPs are considered for this study: Asian Rainfall Highly Resolved Observational Data Integration Towards Evaluation (APHRODITE), Climate Hazard Group InfraRed Rainfall with Station (CHIRPS), Climate Prediction Center (CPC) rainfall product, CPC MORPHing (CMORPH) dataset, Southeast Asian OBServed (SAOBS) dataset and Tropical Rainfall Measuring Mission (TRMM). Similarly, two monthly scale datasets are: Climate Research Unit (CRU) dataset and Global Rainfall Climatology Center (GPCC) dataset. Pixel-to-point comparison is carried out for the reference time period of 1998 to 2014 prior to weighing and ranking.

Almost all of the adopted techniques in former studies in Mekong River Basin (MRB) are largely influenced by the skill evaluater in prioritizing the evaluation criteria used and the prior knowledge of the climate of the study area. Hence, the main objective of this study is to utilize the entropy method to automatically assign weights to the criteria without influence of evaluator and rank the dataset using compromise programming. Equations 1 and 2 describes the entropy method for weight calculation and equation 3 represent compromise programming.

$$\mathrm{E}_j = -\frac{1}{\ln(n)}\sum_{a=1}^{n} R_{aj}\ln(R_{aj}) \text{ for } j = 1,2,\ldots\ldots J \quad (1)$$

$$w_j = \frac{1-E_j}{\sum_{j=1}^{J}(1-E_j)} \quad (2)$$

$$CP_p(a) = \left[\sum_{j=1}^{n} w_j\left|R_j^* - R_j(a)\right|^d\right]^{\frac{1}{d}} \quad (3)$$

Where E_j is the entropy, n is the number of GRPs and R_{aj} and R_j^* are the normalized value of jth evaluation criterion for GRP and observed data respectively, and w_j is the weight for the jth criterion. $CP_p(a)$ is the distance of the ath GRP, j is the evaluation criteria, D is the distance parameter(d=1 represents linear approach and d=2 indicate Euclidean distance).Higher E_j represents higher uncertainty and vice versa. Similarly, lower CP_p value indicate higher rank of dataset and vice versa.

The Taylor diagrams in figure 1 represents the ability of the GRPs to represent the mean monthly rainfall for NRB and Mekong Delta through the three statistical criteria: correlation coefficient, standard deviation, and root mean squared deviation. Performance of GRPs is variable across stations and individual criterion suggest different GRP. The entropy method employed finds the tradeoffs among criteria through weight distribution. The weights distribution for different criteria across different stations is presented in figure 2. For both NRB and VMD, bias dominates and largely influences the ranking of the GRPs. For a daily scale dataset, APHRODITE for NRB and TRMM for VMD outweighed other dataset in capturing mean monthly rainfall.

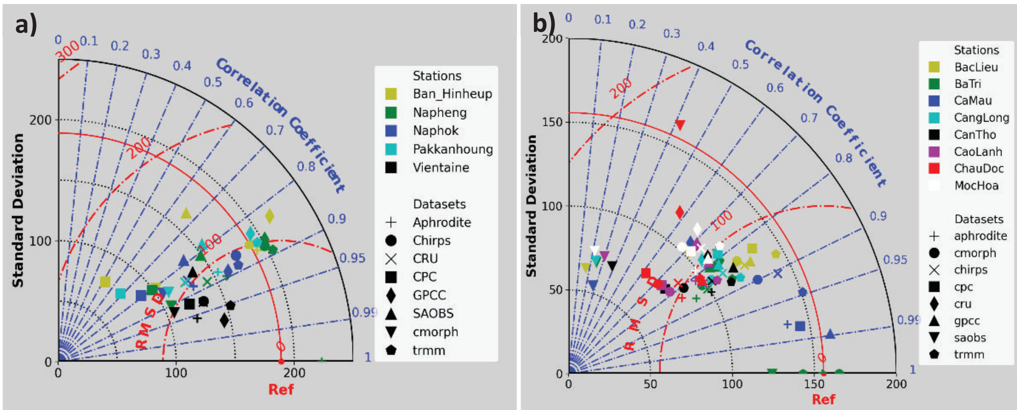


Figure 1:Taylor Diagram representing performance of GRPs across NRB; b) across VMD

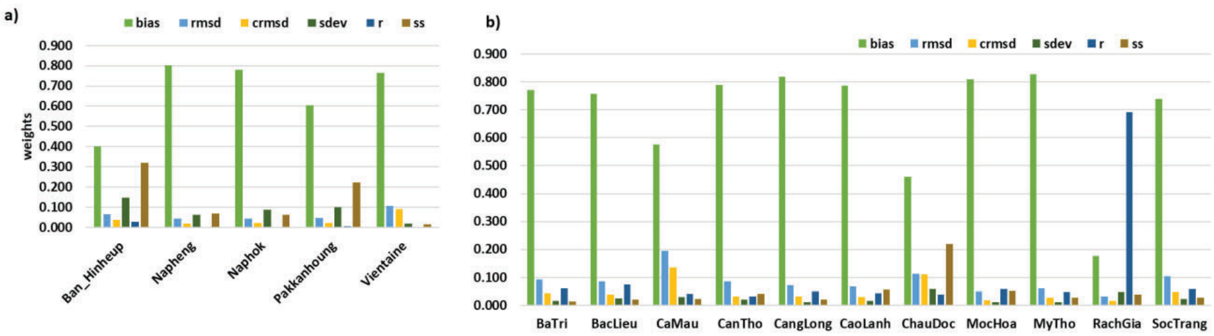


Figure 2: weight distribution among evaluation a) across NRB and b) across VMD

ACKNOWLEDGEMENTS

The authors would like to thank to the “Strengthening Groundwater Governance in Rapidly Urbanising Areas of the Lower Mekong Region (GIRA)” project funded by Stockholm Environment Institute (SEI) under the SUMERNET 4 All Programme which is funded by the Swedish International Development Cooperation Agency (Sida).

References

1. Dandridge, C., Lakshmi, V., Bolten, J., & Srinivasan, R. (2019). Evaluation of Satellite-Based Rainfall Estimates in the Lower Mekong River Basin (Southeast Asia). In Remote Sensing (Vol. 11, Issue 22).
2. Raju, K. S., & Kumar, D. N. (2014). Ranking of global climate models for India using multicriterion analysis. Climate Research, 60, 103–117.

TC-319S

SUSTAINABLE GROUNDWATER DEVELOPMENT IN CAN THO CITY, MEKONG DELTA VIETNAM UNDER CLIMATE CHANGE

Tuan Pham Van*, Santosh Dhungana, Saurav KC, Sangam Shrestha, Ashim Das Gupta

In the Mekong Delta Vietnam (MDV), agriculture, especially rice, and aquaculture are considered staple food and a principal source of income to millions of smallholders (Van Kien et al., 2020). Also, agriculture production has a substantial contribution to the gross domestic product (GDP) of Viet Nam (Huong et al., 2021). For this, farmers are increasingly installing tube wells to support small-scale irrigation and provide supplemental water for agriculture in dry seasons. As a result, depletion in groundwater resources due to over-extraction in the aquifer in recent years is a serious threat to people's livelihood, farming systems, thereby affecting socio-economic growth (Vuong, 2013, Ha et al., 2015, Minderhoud et al., 2017). In addition to anthropogenic pressure, climate change is expected to worsen the impact because floods and droughts have led to water security issues in many parts of the MDV (Smajgl & Ward, 2013, Smajgl et al., 2015, Jin et al., 2018). One of severe areas is the delta aquifer in Can Tho city where is known as the center of the key economic region in the MDV (Moglia et al., 2012, Ngo et al., 2018). Thus, assessing sustainable groundwater development is crucial in the MDV in general and in Can Tho city in particular. In this study, the calibrated groundwater flow model MODFLOW from GMS (Groundwater Modeling System) software is constructed based on geo-hydrogeological data and calibrated by using measured monthly groundwater level series from January 2000 to December 2016 at 21 observation wells in Can Tho city and surrounding area. The impacts of groundwater abstraction to groundwater resources is significant through the following indexes including decrease of groundwater levels, changes of groundwater storage. The long-term extensive exploitation has depleted groundwater resources and caused several problems. In some places with heavy groundwater withdrawal, the water table dropped from 2-5m below the ground surface in 2000 to 15-21m below the surface in the early 2016s. Based on the estimated groundwater budget in 2016, there was 27% of groundwater abstraction comes from groundwater storage. Captured storage has been increasing dramatically since 2008 to catch up with the significant growth of groundwater abstraction. In other words, the over groundwater abstraction reduced the storage of the aquifer system and induced the decline of GWL significantly in the period of 17 years.

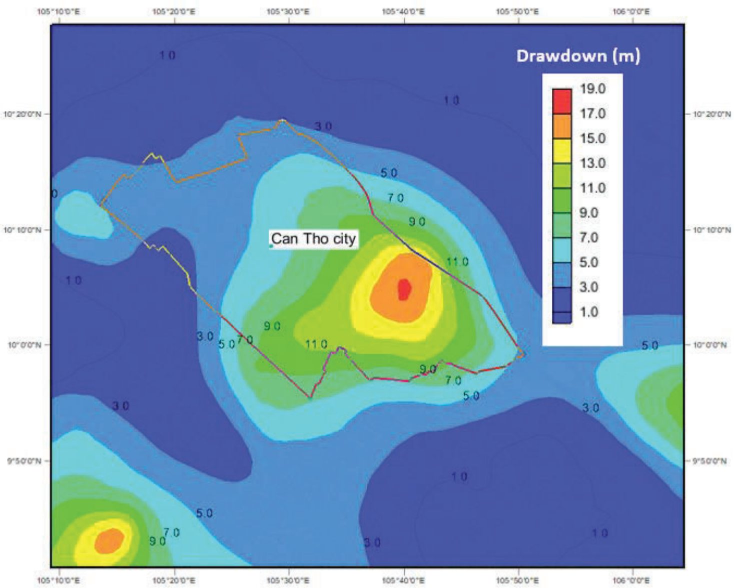
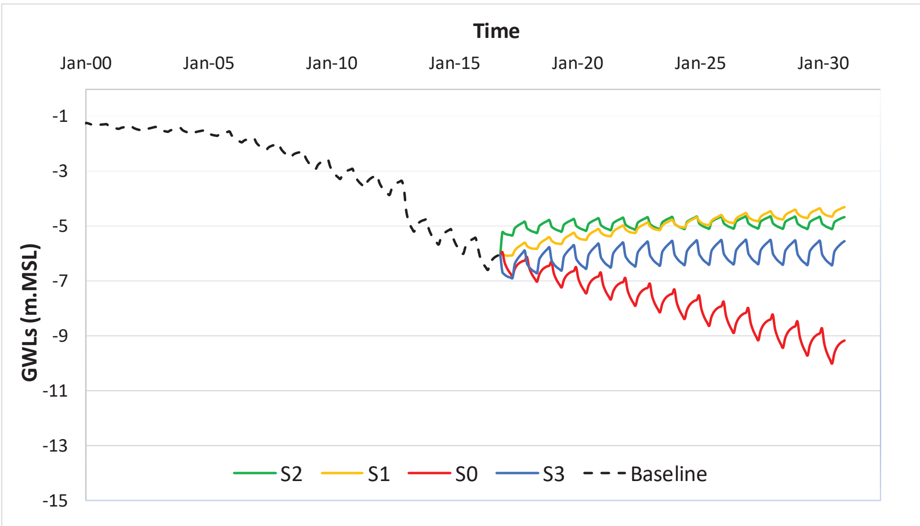
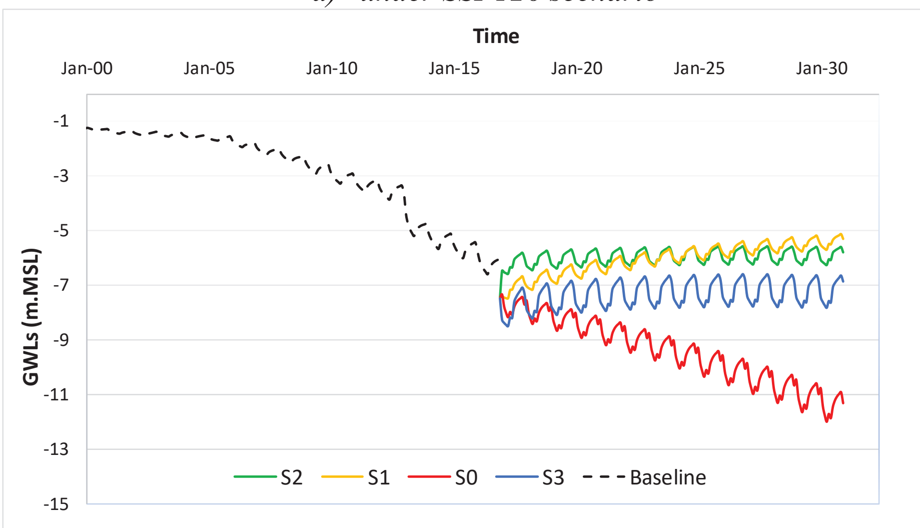


Figure 1 - Drawdown in the Upper-Middle Pleistocene aquifer (qp_{2-3})
from 2000 to 2016

Model results showed that groundwater system in Can Tho city has moved from a pristine system to a developed system then become a depleted system at present and the existing development of groundwater resources is unsustainable. The possible mitigation measures need to be identified for sustainable groundwater development of the Can Tho city in the respective environment and socio-economic contexts. Results of groundwater flow simulation from 2000 to 2016 showed a relatively high rate of groundwater level decline 0.44 m/year and 0.39 m/year in Upper-Middle Pleistocene aquifer (qp_{2-3}) and Upper Pliocene aquifer (n_{2-2}), respectively. With the current increasing demand for water use and projects for securing drinking water supply with installing new pumping wells in rural areas, groundwater abstraction will most likely increased. For better planning and management of groundwater resources in the province, the consequence of groundwater overexploitation must be analyzed along with possible mitigation measures. Therefore, three proposed management scenarios are business as usual (S0), reduction of abstraction (S1 = 40% of current abstraction, S=20% of current abstraction) and increase of groundwater recharge (S3). Future rainfall, minimum and maximum temperature was projected using two shared socioeconomic pathway-representative concentration pathway (SSP-RCP) scenarios namely: SSP126 and SSP585. The projected data together with some input maps such as land-use, topography, soil texture, slope and wind-speed maps were put in a hydrological model called WETSPASS to simulate the future groundwater recharge.



a) under SSP126 scenario



b) under SSP585 scenario

Figure 2 - Comparison the groundwater levels in mitigation and climate change scenarios

The impact of mitigation measures on groundwater resources will be estimated by considering the change in groundwater levels and translating the differences in groundwater levels into storage volume. Groundwater levels in all aquifers will continuously decrease under the business as usual scenario. Both the reduction of abstraction and increase of recharge will stop further decrease of groundwater levels, however, the reduction of abstraction is more effective to reverse the trend of groundwater level decline. In near future, by reducing groundwater abstraction is 145,000 m^3/d under SSP126 scenario and 125,000 m^3/d in SSP585, the decline in groundwater level and storage has been decreasing and stabilizing after 2-3 years. Reduced precipitation and combined with GW over-exploitation are having direct impacts on aquifers recharge, discharge and storage of the aquifer system in Can Tho city. These circumstances call to adaptive strategies from not only groundwater users but also government or stakeholder with the preservation and sustainable management of GW resources. A combined intervention of different mitigation measures will be proposed to achieve sustainable groundwater resources development in Can Tho city in the uncertain context of climate.

Keywords: sustainable groundwater development, groundwater model, mitigation measures.

*Post-doctoral researcher, Asian Institute of Technology (AIT), Thailand.
*email: phamvantuan@ait.asia

References

Ha, K., N. T. M. Ngoc, E. Lee and R. Jayakumar (2015). Current Status and Issues of Groundwater in the Mekong River Basin. *Korea Institute of Geoscience and Mineral Resources (KIGAM): Bangkok, Thailand*, 121.

Huong, N. V., H. V. Hung, M. T. Huyen, N. T. B. Diep, H. M. Duc and N. V. Chuong (2021). Impact of accession to WTO on Agricultural Sector in Vietnam.

Jin, L., P. G. Whitehead, H. Rodda, I. Macadam and S. Sarkar (2018). Simulating climate change and socio-economic change impacts on flows and water quality in the Mahanadi River system, India. *Science of the Total Environment*, *637*, 907-917. https://doi.org/10.1016/j.scitotenv.2018.04.349

Minderhoud, P., G. Erkens, V. Pham, V. T. Bui, L. Erban, H. Kooi and E. Stouthamer (2017). Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam. *Environmental Research Letters*, *12(6)*, 064006. https://doi.org/10.1088/1748-9326/aa7146

Moglia, M., L. E. Neumann, K. S. Alexander, M. N. Nguyen, A. K. Sharma, S. Cook, N. H. Trung and D. D. Tuan (2012). Application of the water needs index: can Tho City, Mekong Delta, Vietnam. *Journal of hydrology*, *468*, 203-212. https://doi.org/10.1016/j.jhydrol.2012.08.036

Ngo, H., A. Pathirana, C. Zevenbergen and R. Ranasinghe (2018). An Effective Modelling Approach to Support Probabilistic Flood Forecasting in Coastal Cities—Case Study: Can Tho, Mekong Delta, Vietnam. *Journal of Marine Science and Engineering*, *6(2)*, 55. https://doi.org/10.3390/jmse6020055

Smajgl, A., T. Q. Toan, D. K. Nhan, J. Ward, N. H. Trung, L. Tri, V. Tri and P. Vu (2015). Responding to rising sea levels in the Mekong Delta. *Nature Climate Change*, *5(2)*, 167-174.

Smajgl, A. and J. Ward (2013). The water-food-energy nexus in the Mekong region. *New York, New York, USA*, Springer

Van Kien, N., N. H. Han and R. Cramb (2020). Trends in rice-based farming systems in the Mekong delta. White Gold: The Commercialisation of Rice Farming in the Lower Mekong Basin, Palgrave Macmillan, Singapore: 347-373.

Vuong, B. T. (2013). Assessment of impacts of groundwater abstraction and climate change on groundwater resources in Mekong Delta, Viet Nam*. MONRE*.

TC-322S

Assessment of Water Quality of Inle Lake and Four Main Streams Flowing into Inle Lake,in Myanmar

Ei Wai Phyo[1*], Cho Cho Thin Kyi[1], Win Win Zin[1]

[1*,1] Department of Civil Engineering, Yangon Technological University,
Gyogone, Insein Road Yangon 11011, Myanmar
Author Email: eiwaiphyo38@gmail.comTel: +9595342343

Robbert De Lange[2*],Thom Bogaard[2]

[2*,2] Department of Civil Engineering Water Management, Delft University of Technology,The Netherlands

Kristin Peters[3*], Nicola Fohrer[3]

[3*,3] Department of Hydrology and Water Resources Management, Kiel University, Germany

1 INTRODUCTION

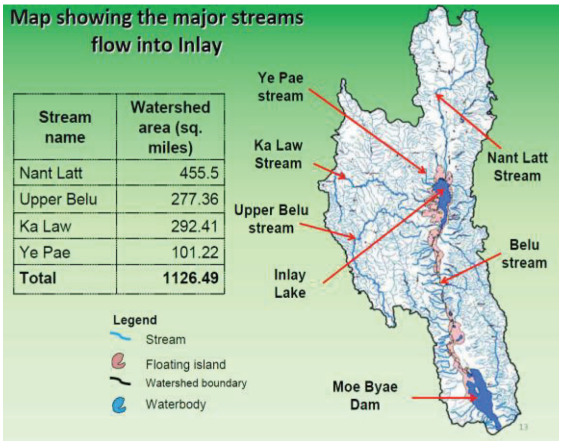
Freshwater resources provide a large number of ecosystem services constituting a valuable natural resource for humans and biodiversity (Dudgeon et al., 2006; Oki & Kanae, 2006). Yet rivers and lakes are threatened by multiple anthropogenic stressors, such as climate change, salinization, hydro morphological changes, and pollution from various sources (Reid et al., 2019). Worldwide nearly 80% of the population are threatened by reduced access to freshwater (Vörösmarty et al., 2010), which especially applies to the country of Myanmar. Since the economy and people's income largely depend on agriculture with more than 65% living in rural areas, the access to water resources is crucial (Taft & Evers, 2016). However, the country has faced major political and economic changes in the past and it is assumed that current and future socio-economic developments will further pressure the water resources (Kattelus et al., 2014). Furthermore, Myanmar is the second most affected country by climate change over the past two decades (Eckstein et al., 2021) and extreme events such as floods and droughts are predicted to mainly influence the coastal areas and the central dry zone (Taft & Evers, 2016).
The Inle Lake is reported to have faced a serious decline in open water surface area and water quality reduction in the recent years (Furuichi & Wasson, 2011; Michalon et al., 2019; Sidle et al., 2007). The lake is well known for its floating gardens; and the traditional stilt housing and one leg rowing technique of the *Intha* used to attract large numbers of domestic and international tourists (Michalon et al., 2019). Another economic sector at the lake is textile production in a traditional small scale for tourists, but also industrialized factories for export of fabric are present. The direct input of fertilizers and pesticides on the floating gardens, as well as wastewater and solid waste from households, hotels and restaurants and the input of other industrial wastewater is assumed to have degraded the water quality of the Inle Lake (Aung et al., 2019; May, 2007; Re et al., 2018; Swe, 2013; Thin et al., 2020). Nevertheless, there is a lack of sufficient monitoring and data about the current status of the lake's water quality and the main sources of the pollution. This study therefore aims to assess the water quality in the lake and its four main streams considering the spatial variation and socio-economic conditions. The analysis can help to identify the main sources of pollution and serve as a basis for measures against the contamination of the freshwater resources to preserve biodiversity and secure access to clean water for the population at the Inle Lake.

2 MATERIALS AND METHODS

2.1 Study Area

It is located within 96°46 - 97°.09´ E longitude and 20°05´- 21°17´N latitude in WGS 84 coordinate system. Inle Lake area is surrounded by hilly region of elevation (about 900 to 1800 masl). It is a part of Shan Plateau which has main limestone formation and is situated between Sagaing Active Fault and faults along the Shan scarp. This area has a humid subtropical climate with subtropical highland climate. and is located in the Balu Chaung Valley (884 masl) between the Sindaung (east) and

Letmaunggwe, Thandaung and Udaung mountain ranges. The lake surface is 116km2, however, varying between 150km2 in the rainy season and 100km2 in the dry season. It is a shallow lake, where maximum depth varies between approximately 4m in the dry season and 5-6m in the rainy season. The average depth is approximately 1.5m in the dry season. In 2014-2015 a maximum depth of 3.7m was recorded. The volume of the lake is 790x106m3, with a total water inflow of 1,132x106m3 per year, the retention time can be estimated to be 0.3 years (NIWR2017, referring to IID 2012).



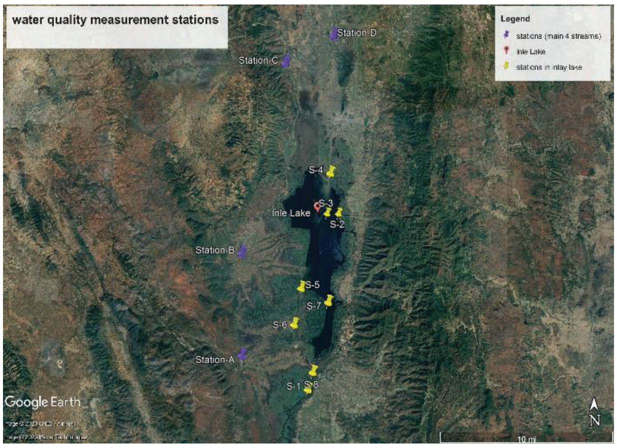


Figure.1. Location of study area, Shan State, Myanmar (MOECAF2014): Figure.2. Location of water quality measurement stations

There are 35 villages within Nyaung Shwe township: 17 of these lie within the lake and 5 lie partly in the lake and partly on land. The remaining 13 villages are situated on land around the lake surroundings. The population was about 160000 and increased about 60 percent within 25 years (source: Department of Rural Development, Shan State Development Committee,2019). In total four major streams drain into the lake: *Nan Lat* from the North, *Ye Pae* from the North-West, *Kalaw* from the West and *Belu* from the South-West. The outflow (*Belu* stream) connects to the downstream *Saga* lake, Moe Byaedam and serves the hydroelectric power plant of *Lawpita* which is a prominent water resource for huge amount of hydropower in country.

2.2 Materials and Methods

Based on environmental survey, there are eight stations in the lake and four main streams stations. To consider the comprehensive measures, a total of three water quality measurements in the lake were undertaken in 3-4 December 2019(the first) ,11-13 February 2020 (the second) and 15-16 March (the third). At second and third time, water samples were collected at four main streams stations to compare with lake water quality status. The water samples were collected for three time and all samples transported to Alarm Ecological Laboratory (Yangon) during 24 hours for analysis. There are 18 water quality parameters measured (Physical characteristic: temperature, turbidity, TDS, TSS, TS, conductivity, color, Chemical characteristics: pH, total hardness, DO, COD, BOD, nitrate-nitrogen, total alkalinity, manganese, arsenic, phosphorous, Biological Characteristic: total coliform). During the field survey, some physicochemical parameters (pH, temperature, TDS, conductivity and DO) were measured in situ by using Hawkeye Sonar, CDT diver and cup, GMH3400 meter [69], the multimeter instrument (Senso Direct150), etc. At second time, spatial water quality measurement was made around 8 stations by Rt4 bait boat equipped with measuring devices (source: Robbert De Lange 2020).[In this study, the lab water sample results are compared with WHO standard for drinking water(2011),US EPA drinking water standard 2018,proposed national drinking water standards, Ministry of Health ,(sep,2014)and National Environmental Quality (Emission)Guidelines, order No(61/2015)(MOECAF,29dec2015) and Malaysia water quality standard for surface water (Class IIA, Class IV).]

Table 1. Location of Stations in Inle Lake and Four Main Streams

No.	Locations	Latitude (N)	Longitude (E)	Reasons
S-1	Maing-Pyo Village	20.4327	96.8996	near outflow
S-2	b/w Sky lake &Paradise Hotel	20.5773	96.9272	b/w two floating hotels
S-3	Rest House	20.57738	96.9271	center of lake
S-4	Nyaung Shwe's Canal	20.6092	96.9196	Inflow
S-5	Nga- Phe -Chaung	20.5162	96.8936	chemical free zone
S-6	Ywar Ma Village	20.4857	96.8873	gold /silver smith
S-7	Kay La Village	20.5040	96.9177	floating garden
S-8	Inn Paw Khone Village	20.4467	96.9039	weaving village
S-A	Indein Weir	20.4601	96.8403	inflow of Inle lake
S-B	Kalaw stream	20.5438	96.8402	inflow of Inle lake
S-C	Yay Pel Stream	20.6985	96.8402	inflow of Inle lake
S-D	Nant latt Stream	20.712	96.9222	inflow of Inle lake

3 RESULTS AND DISCUSSION

Water Depth and Colour

The average water depth at 8 stations of the first, second and third survey was 1.2m,1.6m,2.3m,1.5m,1.13m,1.2,1.6m and1.3m respectively (dry season). Water colour of the lake is noticeable different because of water depth and sedimentation. Colour ranges from 5to 1160 HU in lake and from 0 to 73HU at streams.

Water Temperature

The study area has a humid subtropical highland climate and lake water temperature ranges 19-33 °*C*.

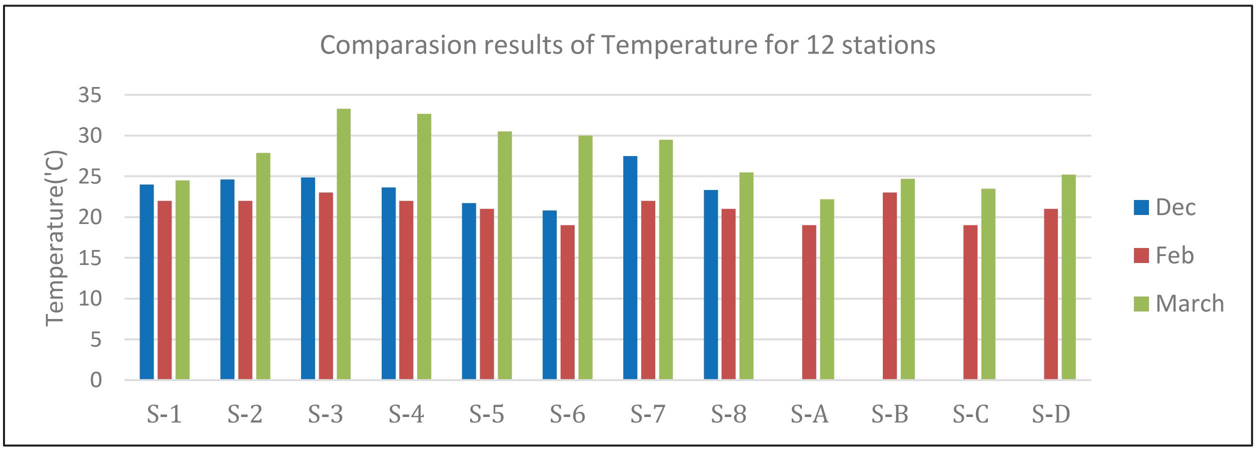


Figure.3. Comparison results of temperature for 12 stations

pH

pH is an important parameter which determine the stability of water for various purpose. The value of pH in water samples of all station is over 7. The results are acceptable by comparing with the permissible limit.

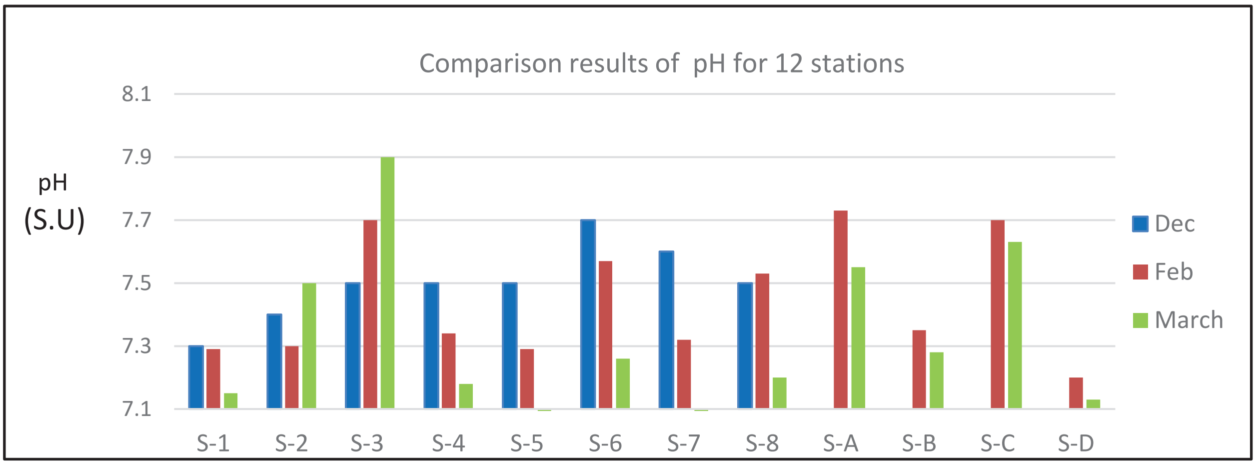


Figure.4. Comparison results of pH for 12 stations

Turbidity

The result of Turbidity values ranges from 5 to 241FAU. Thus, most of the result are higher than the permissible limit expect station 2,3,7 and A.

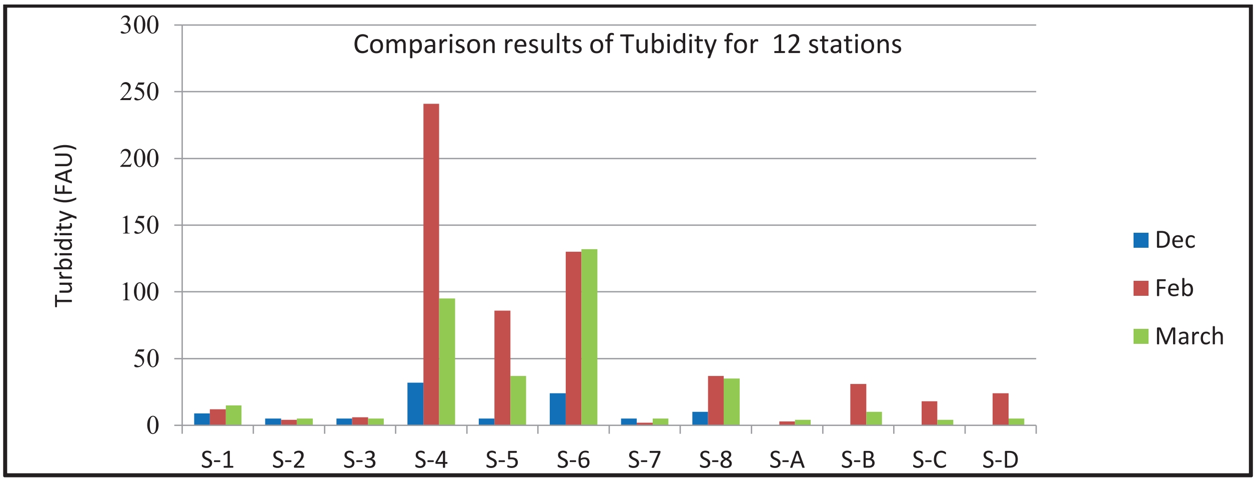


Figure.5. Comparison results of Turbidity for 12 stations

Hardness and Alkalinity

Hardness of Inle lake is high because it is a part of Shan Plateau which has main limestone formation. It ranges from 140 ton363 mg/l. Alkalinity ranges from 185 to 840mg/l.

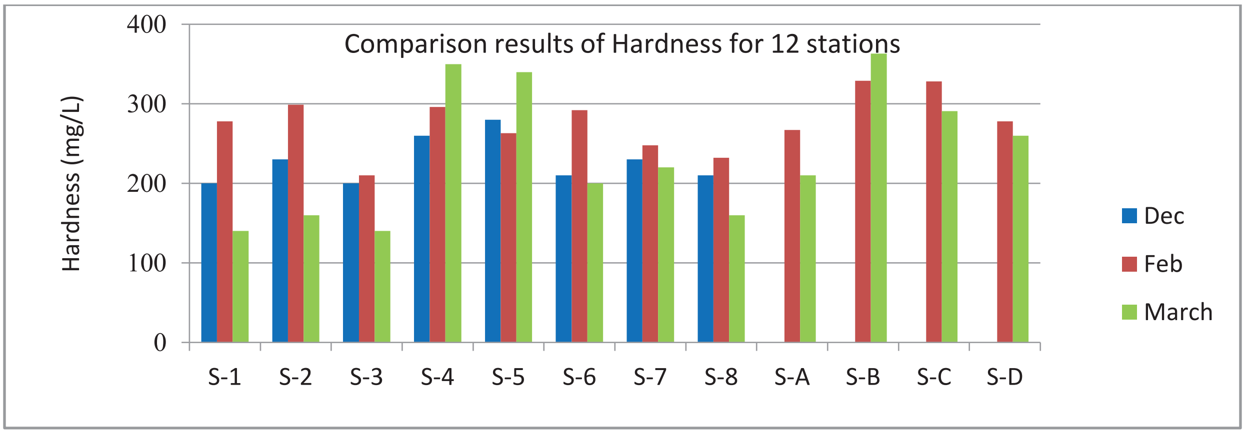


Figure.6. Comparison results of Hardness for 12 stations

Total Dissolved Solid, Total Suspended Solid, Total Solid

TDS represents the total concentration of dissolved substances in water. Result of total dissolved solid in all stations are lower than the standard limit. TSS ranges from 0 to 129 m/l and TS ranges from 172 to 409 mg/l.

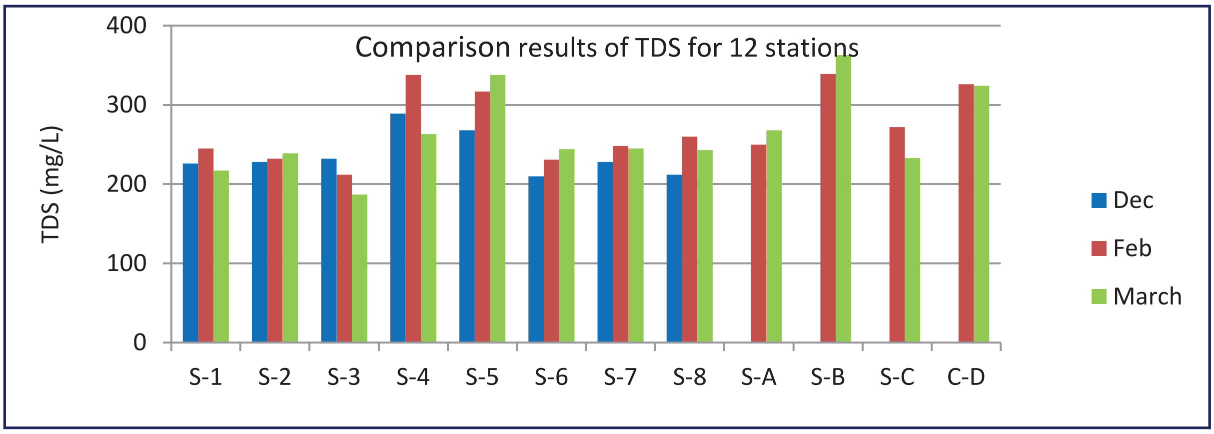


Figure.7. Comparison results of TDS for 12 stations

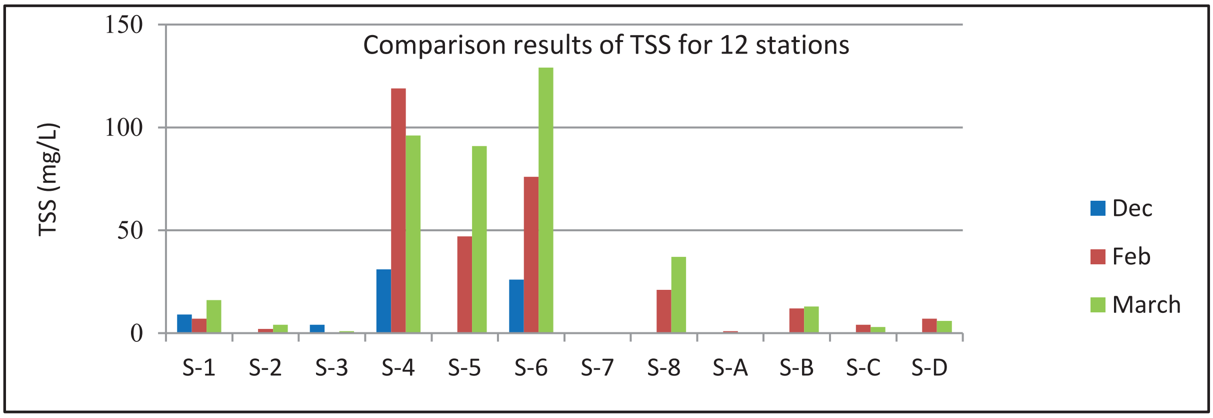


Figure.8. Comparison results of TSS for 12 stations

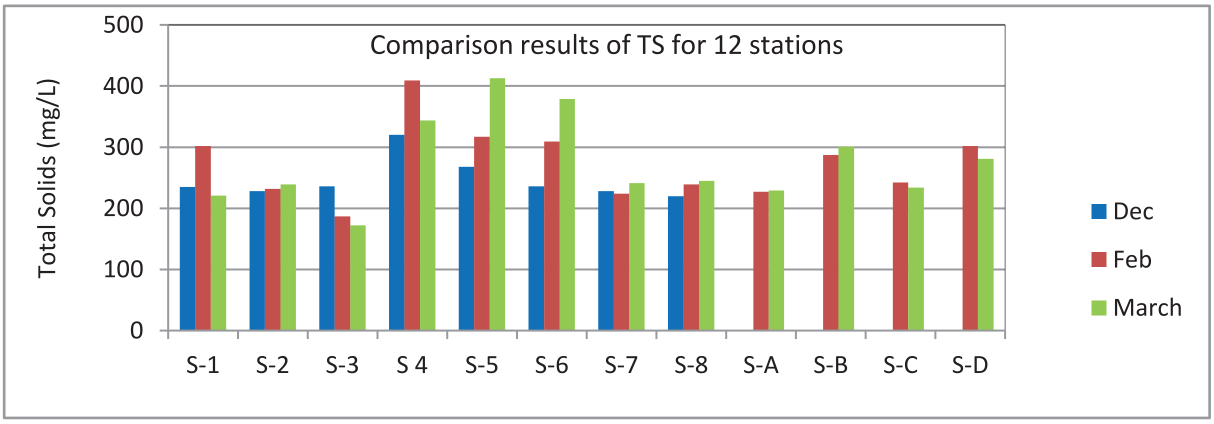
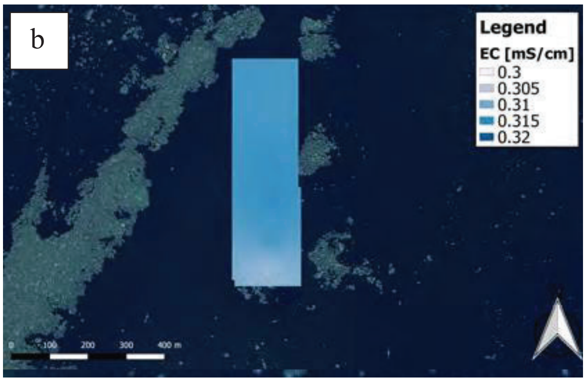


Figure.9. Comparison results of TS for 12 stations

Electrical Conductivity

Electrical Conductivity (EC) measures the water's ability to conduct electricity, which provides a measure of what is dissolved in water and a higher conductivity value indicates that there are more chemicals dissolved in the water. It ranges from 0.3 to 0.5 mS/cm at 12 stations.

(a) Station-1 WQM around Maing Pyo Village ,

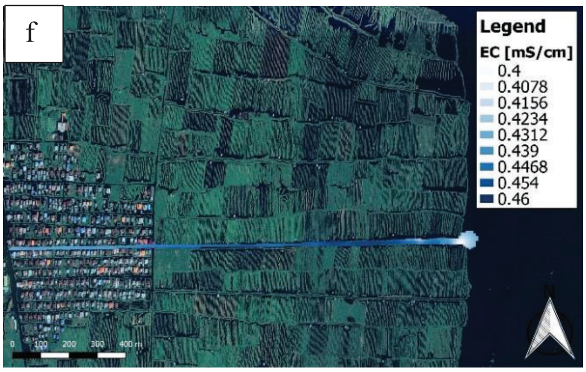


(b)Station-3 around the middle of lake

(c) Station-4 around Nyaung Shwe Canal,

(d) Station-5 Near Nga Pha Chaung

(e) Station-6 Near Yoma Village,



(f) Station-7 along Kela Village

Figure.10. Water Quality Measurement (Source: Robbert De Lange report)

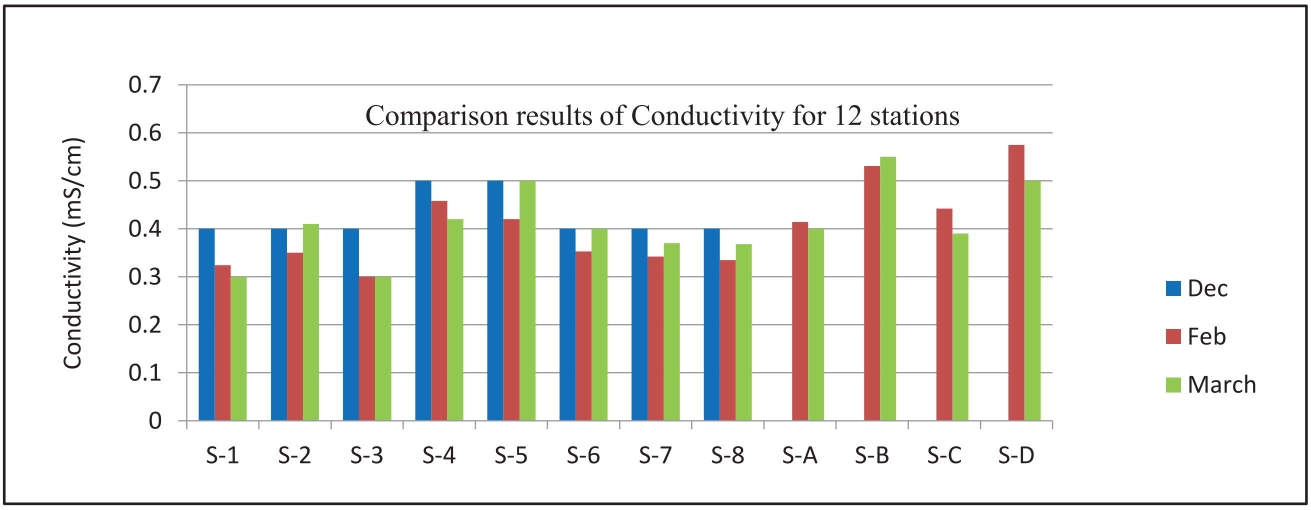
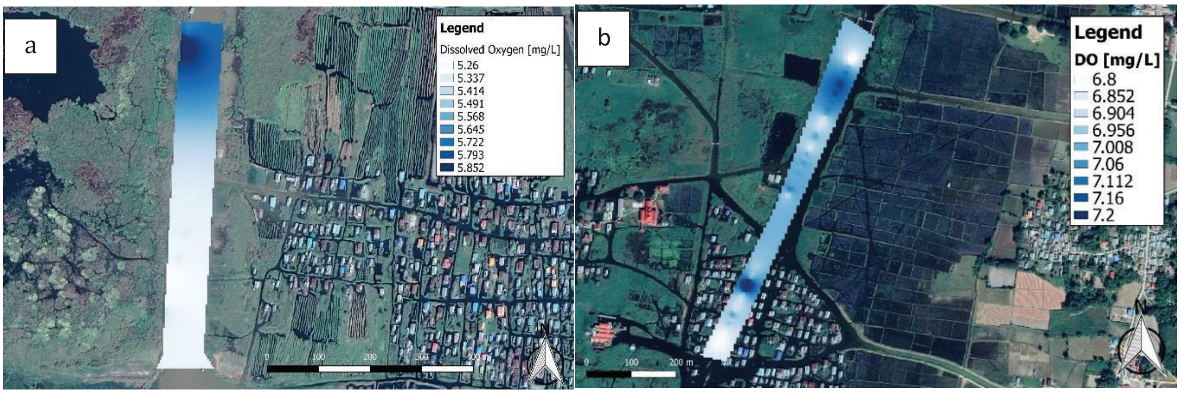


Figure.11. Comparison results of Electrical Conductivity for 12 stations

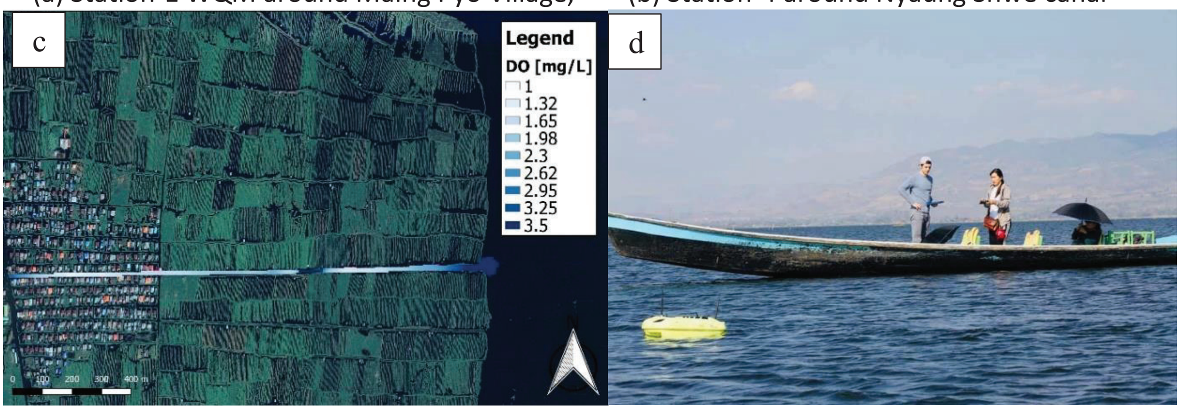
Dissolved Oxygen (mg/l),Electrical Conductivity(µs/cm) ,Chlorophll-A(µg/L) and Cyanobatetria (µg/L) were measured with Rt4.From Rt4 boat survey result, EC ranges from 2.9 to 3.15 µs/cm around Maing Pyo village (Station 1), from 0.3 to 0.32 µs/cm around the middle of the lake(station 3),from 0.5 to 0.52 µs/cm along Naung shwe canal (station 4),from 0.47 to 0.49 µs/cm near Nge Phae Chaung(Station 5),from 0.365 to 0.37 µs/cm near Yoma Village(Station 6) and from 0.4to0.45 between Kela village and floating garden (Station 7).(Source: Robbert De Lange report)

Dissolved Oxygen

The presence of dissolved oxygen is essential to maintain the higher forms of biological life and to keep proper balance of various pollutions thus making the water bodies healthy.DO ranges 5 to 21.2 mg/l. From Rt4 boat survey result, DO ranges from 6.8to 7.2 µs/cm around Maing Pyo village (Station 1), from 7.5 to 9 µs/cm around the middle of the lake(station 3),from 5.26 to 5.852µs/cm along Naung shwe canal (station 4),from 4.2to 4.65 µs/cm near Nge Phae Chaung(Station 5),from 5.9 to 6.65 µs/cm near Yoma Village(Station 6) and from 1to3.5 µs/cm between Kela village and floating garden and from 2.9 to 3.2 µs/cm within floating garden (Station 7).(Source: Robbert De Lange report)



(a) Station-1 WQM around Maing Pyo Village, (b) Station-4 around Nyaung Shwe canal



(c) Station-7 along Kela Village (d) water quality measurement by RT4at Inle Lake

Figure.12. Water Quality Measurement (Source: Robbert De Lange report)

COD

COD is the total concentration of chemical determination in water bodies and the result of most stations less than 30mg/l but station 4 is 39mg/l at second time; station 5 is 31 mg/l and station 6 is 32 at third time.

BOD

Most of BOD results (from 3 to 7.5mg/L) are higher than the standard limit of Class II. The higher the BOD, the higher the amount of organic matter or 'food' available for oxygen consuming bacteria.

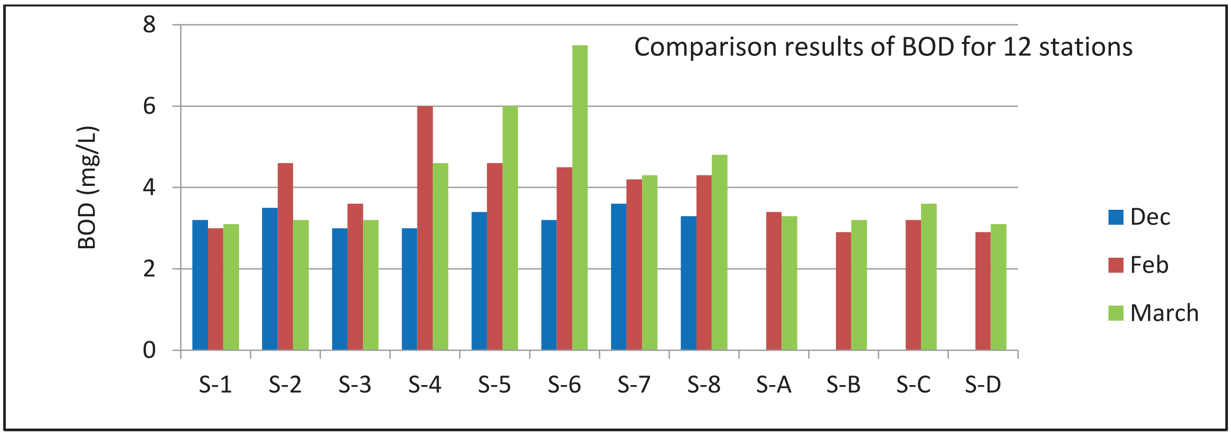


Figure.13. Comparison results of BOD for 12 stations

Phosphorus, Arsenic and Manganese, Nitrate-Nitrogen, Total Coliform

Phosphorus has a direct effect on plant and algae growth in lakes. The more phosphorus is available, the more plants and algae are in the lake.The results of Phosphors ranges 3.3 to 6.8 mg/l at 8 stations .But second and third time results are less than 0.2 mg/l First time result of Arsenic at station 3 and 8 are 0.05mg/l over the standard limit and second and third results of all station is below the limit. Second time and third result of Manganese at station 4 and 8 are 0.46 and 0.42mg/l and first and third results of station 6 are 0.5 mg/l over the standard limit. Other stations are below the limit.In this study, the results of nitrate nitrogen are between 0.02mg/L and 11 mg/l in lake and less than 2.6 mg/L at the main stream stations . Total Coliform is primary indicator of suitability for consumption of drinking water. The result of most of station in lake are greater than 1100 MPL/100ML expect station2.

4 CONCLUSIONS

The study area is one of the most valuable existences in Myanmar and it is therefore important to monitor and manage the water quality. From field surveys and water quality results, the levels of arsenic, manganese and phosphorus were above the permissible limit at some stations. According to the water level measuring records, the water depths of the lake are lowering over time and it increases the turbidity of the water. This raises the main point to consider the question on how to control sedimentation in the lake. Another observation is that most villages had sanitary waste water systems (bio-tech), but some villages had poor sanitary waste water systems. At the most stations in lake, total coliform count was found more than 1100 MPN/100 mL. The immediate attention should also be paid on the problems of the construction and management of floating gardens if the open lake area and water quality are to be preserved . Due to many factors the water quality of Inle Lake is changing and it should be checked seasonally and spatially. Concluding, the continuous monitoring of the Inle Lake is required in the district to protect the water quality in the future from any possible contamination due to population growth, increasing industrialization and agricultural practices, etc. Water quality of Inle lake are one of the primary issues to be considered in the long-term integrated water management system for the Inle basin.

References

Aung, P. P., Mao, Y., Hu, T., Qi, S., Tian, Q., Chen, Z., & Xing, X. (2019). Metal concentrations and pollution assessment in bottom sediments from Inle Lake, Myanmar. *Journal of Geochemical Exploration*, *207*(October 2018), 106357. https://doi.org/10.1016/j.gexplo.2019.106357

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z.-I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A.-H., Soto, D., Stiassny, M. L. J., & Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, *81*(02), 163. https://doi.org/10.1017/S1464793105006950

Eckstein, D., Künzel, V., & Schäfer, L. (2021). *GLOBAL CLIMATE RISK INDEX 2021*. www.germanwatch.org

Furuichi, T., & Wasson, R. J. (2011). Placing sediment budgets in the socio-economic context for management of sedimentation in Lake Inle, Myanmar. *IAHS-AISH Publication*, *349*(June 2016), 103–113.

Kattelus, M., Rahaman, M. M., & Varis, O. (2014). Myanmar under reform: Emerging pressures on water, energy and food security. *Natural Resources Forum*, *38*(2), 85–98. https://doi.org/10.1111/1477-8947.12032

May, S. Y. (2007). *Changes of water quality and water surface area in Inle Lake Myanmar*.

Michalon, M., Gunnell, Y., Lejot, J., Mialhe, F., & Aung, T. (2019). Accelerated degradation of Lake Inle (Myanmar): A baseline study for environmentalists and developers. *Land Degradation and Development*, *30*(8), 928–941. https://doi.org/10.1002/ldr.3279

Oki, T., & Kanae, S. (2006). Global hydrological cycles and world water resources. *Science*, *313*(5790), 1068–1072. https://doi.org/10.1126/science.1128845

Re, V., Thin, M. M., Setti, M., Comizzoli, S., & Sacchi, E. (2018). Present status and future criticalities evidenced by an integrated assessment of water resources quality at catchment scale: The case of Inle Lake (Southern Shan state, Myanmar). *Applied Geochemistry*, *92*(August 2017), 82–93. https://doi.org/10.1016/j.apgeochem.2018.03.005

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D., & Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, *94*(3), 849–873. https://doi.org/10.1111/brv.12480

Sidle, R. C., Ziegler, A. D., & Vogler, J. B. (2007). Contemporary changes in open water surface area of Lake Inle, Myanmar. *Sustainability Science*, *2*(1), 55–65. https://doi.org/10.1007/s11625-006-0020-7

Swe, T. (2013). *Assessment of Water Quality of Inlay Lake*.

Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. *Hydrology and Earth System Sciences*, *20*(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016

Thin, M. M., Setti, M., Sacchi, E., Re, V., Riccardi, M. P., & Allais, E. (2020). Mineralogical and geochemical characterisation of alkaline lake sediments to trace origin, depositional processes, and anthropogenic impacts: Inle Lake (Southern Shan State, Myanmar). *Environmental Earth Sciences*, *79*(8), 1–18. https://doi.org/10.1007/s12665-020-08909-4

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, *467*(7315), 555–561. https://doi.org/10.1038/nature09440

TC-325L

AN AGENT-BASED APPROACH FOR MANAGING FOOD-ENERGY-WATER SYSTEMS UNDER FUTURE CLIMATE SCENARIOS USING FEWCALC AND DSSAT: OPPORTUNITIES AND CHALLENGES FOR LOCAL DECISION-MAKERS IN THAILAND

Jirapat Phetheet[1*] and Mary C. Hill[2]

Thailand is one of the world's leading agricultural suppliers and has been known as the Kitchen of the World. About half of the country's total area is used for agriculture. In 2020, the agricultural sector contributed about 1.3 trillion baht to GDP, accounting for 8.64 % of GDP (Office of Agricultural Economics, 2021). The global population is expected to reach 9.1 billion by 2050. Feeding this growing population would require a substantial increase in food production to meet the global dietary demand. Increasing food production would require land, water, and energy. Even though water resources are generally thought of as renewable resources, it is dependent on parts of the water cycle and sometimes limited in daily life. Over 30% of the world's total freshwater is capped in the ground; however, surface freshwater accounts for 1.2%, which is obviously essential to all life. Nowadays, usable surface freshwater is relatively scarce due to overexploitation and pollution caused by nutrients, pathogens, and chemicals. In Thailand, groundwater becomes an important source of water in many agricultural areas. As the Thai population grows 3.3% in the last decade (National Statistical Office, 2021), food, energy, and water (FEW) demands certainly increase, causing a lack of energy supplies for food production and groundwater withdrawal, groundwater overdraft, and eventually a decline of groundwater level in many areas.

Rising global temperatures, shifting precipitation patterns, and experiencing extreme weather events are happening and currently affect all life on earth. Climate change poses intractable problems for water and food insecurity. These impacts could cause Thailand not to be on track to achieve the United Nations Sustainable Development Goals (SDGs) related to food, energy, and water: "Zero Hunger" (Goal 2), "Affordable and Clean Energy" (Goal 7), and "Clean Water and Sanitation" (Goal 6).

FEWCalc (Food-Energy-Water Calculator) is an innovative and accessible tool for farmers and decision makers (Phetheet et al., 2021a, 2021b). Here, FEWCalc's agent-based model constructed using NetLogo was designed to integrate complex systems of FEW systems. This new freeware model was developed to close critical knowledge gaps among the FEW components and relates present FEW decisions to long-term dynamics under alternative climate and production decisions. FEWCalc provides an adjustable range of options, including simulation year, crop type, crop production area, renewable energy investment, tax incentive, groundwater availability, and future climate scenarios. The first and current version of FEWCalc was tested and validated using data from Garden City, Finney County, Kansas, USA.

FEWCalc integrates crop production and irrigation water demand using outputs from a novel cropping system model called Decision Support System for Agrotechnology Transfer (DSSAT). DSSAT requires daily weather data (e.g., minimum and maximum air temperature, precipitation, and solar radiation), physical and chemical properties of soil, and crop management practices (e.g., crop cultivars, planting date, method, plant population, fertilizer application, simulation date, crop module, and irrigation and water management).

Crop simulation was based on two sets of weather data. One is 10-year historical daily data from 2008 to 2017 (base period), and the other is 81-year projected data from 2018 to 2098. Long-term climate projections were obtained from 20 downscaled General Circulation Models (GCMs), which were statistically downscaled using the Multivariate Adaptive Constructed Analogs (MACA) method. These climate projections are driven by concentration or emission scenarios of greenhouse gasses and aerosol, chemically active gases, and land use/land cover, being consistent with Representative Concentration Pathways (RCPs). In this work, RCPs 4.5 and 8.5 were chosen to represent an intermediate emission scenario with an increase of 1.1-2.6°C of global temperature by 2100 and the most warming scenario with an increase of 2.6-4.8°C, respectively.

Results show how climate change affects crop production and farm income in the Midwest USA, without effective technological advances. Income and crop productivity vary depending on the RCP scenario applied. The RCP 4.5 scenario causes a difficult financial situation for farmers, while the RCP 8.5 is considerably worse. Under this extreme climate condition, FEWCalc results illustrate that crop yield continuously losses with an increase of water use, resulting in agricultural income being worse throughout the simulation years. Due to the limited groundwater supply, the system can maintain irrigation for some years, causing crop production to drop significantly. In such circumstances, it would affect the global food and water demands in the future.

The simulation under climate variability produces negative impacts on SDG 2 (Zero Hunger) and SDG 6 (Clean Water and Sanitation). However, the outcomes also present that renewable energy development would reduce farmers' reliance on agricultural production. This leads to achieving SDG 7 (Affordable and Clean Energy). Consequently, farmers tend to use less water for crop production when they achieve financial security, with positive impacts on SDG 6 (Clean Water and Sanitation). In addition, some farmers prefer to continue agricultural activities with supports from clean energy. This would ultimately lead to reducing adverse impacts on SDG 2 (Zero Hunger).

Climate change will have a global impact affecting many countries including Thailand. FEWCalc agent-based model can be modified using data in Thailand to better enable its abilities to help tackle climate issues locally. As stated earlier, Thailand is one of the world's leading food exporters, which causes its economy to be vulnerable to climate change. Hence, policymakers are responsible for being aware of upcoming issues and implementing suitable policy decisions.

Keywords: Climate projection; Agent-based model; Decision making

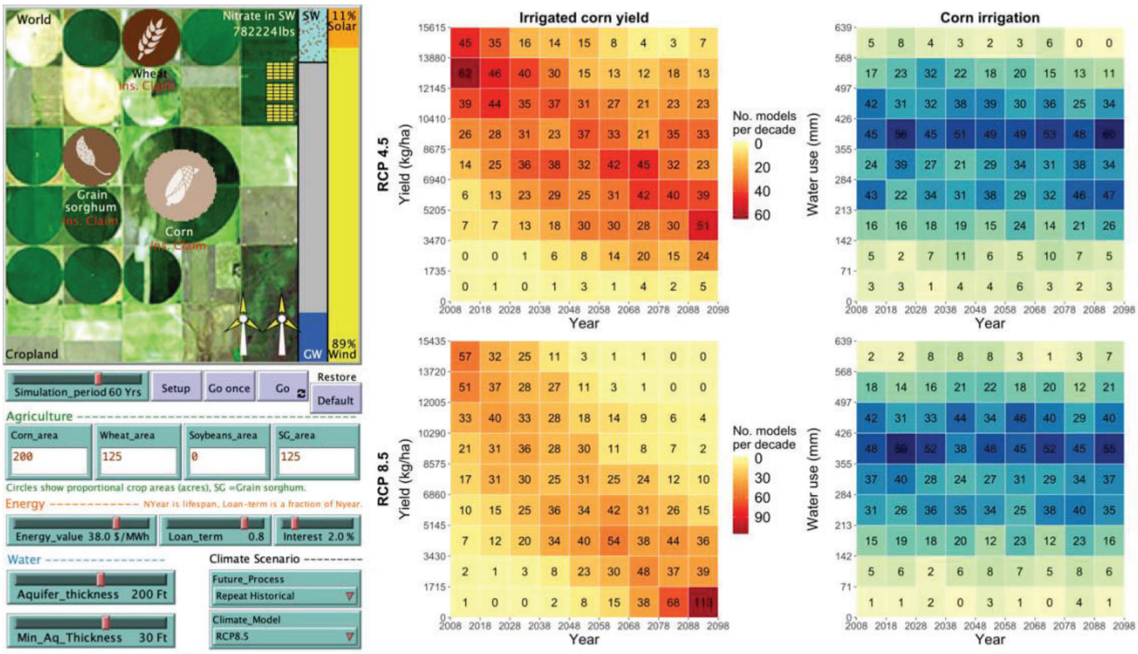


Fig. 1. (Left) An interface of FEWCalc NetLogo with some user-defined parameters. (Right) Heatmaps of DSSAT irrigated corn yield (in kg/ha) and irrigation water demand (in mm), showing the decreasing trend of crop yield and changes in water use over time. The calculation is based on the 20 individual GCMs under the RCPs 4.5 (upper) and 8.5 (lower) from 2008 to 2098.

[1] Department of Groundwater Resources, Chatuchak, Bangkok, 10900, Thailand
[2] Department of Geology, University of Kansas, Lawrence, KS, 66045, USA
* Corresponding author e-mail: jirapat.p@dgr.mail.go.th

TC-326L

OPINIONS AND PERSPECTIVES IN CHAO PHRAYA DELTA'S 2040 DEVELOPMENT

Suttisak Soralump and Thapthai Chaithong*

The Chao Phraya delta is in the central plain of Thailand, which is the most important region of the country. Bangkok, the capital of Thailand, is located in the Chao Phraya delta and is the centre of Thailand's government, economy, culture, education, and transportation. In the Chao Phraya delta, the people have established communities and developed the land from the prehistoric era to the present day (Hutangkura, 2014). Currently, there are more than 18 million people, approximately one-third of the total population of Thailand, living in the 19 provinces located in the Chao Phraya delta. Moreover, the total gross domestic product (GDP) of the 19 provinces is approximately 60 percent of the total GDP of Thailand. The historical irrigation development projects in the Chao Phraya delta are the canal system in the east bank area of the Chao Phraya River, from the King Chulalongkorn era, and the Greater Chao Phraya water control project of the 1950s. Nowadays, there are several challenges and problems, such as climate change, natural and man-made disasters, and technological disruptions, that hinder the development of the Chao Phraya delta. Thus, it is currently very important to establish long-term visions and development plans for the Chao Phraya delta. Therefore, the objective of the study was to find and summarise the challenges, development perspectives, and case studies of the delta and city development activities in the Chao Phraya delta for the next 20 years. This study conducted in-depth interviews with 11 people who are in the academic field, industrial sector, and government sector; in addition, four sessions of group discussions were held. According to the interviews and group discussions, the five main points for development can be summarised as follows.

First, floods are one of the significant natural hazards in the Chao Phraya delta where flows from the north region, tidal intrusions, and urban flooding are the most notable challenges for water disaster management during the rainy season. Every year, the Chao Phraya delta area experiences flooding, which results in economic damages and the loss of human life, in the case of the great flood of 2011, for example. One of the challenges of flood management is collaboration across the ministries and administrative districts. Currently, the Royal Thai Government has enforced the Water Resources Act 2018 and the strategic Plan on Thailand's Water Resources Management, which may increase the collaboration and coherence among the related agencies concerning flood management. Regarding issues across the administrative districts, experts have mentioned that the concept of *average happiness and suffering* in all areas may be the better solution to reduce conflict among people in the different administrative districts. At present, people only consider their own districts and try to protect them against floods by using flood walls or dikes. The consequence is that the floods spread to the neighbouring districts, leading to conflicts. For example, some people pressure the government officers to open the gate to decrease the flood levels in their village, but others also urge the officers to close the same gate to protect their village; this leads to conflicts between people in different villages.

Second, the flood walls in the Chao Phraya delta have been constructed by several agencies, such as the Bangkok Metropolitan Administration or Subdistrict Administrative Organisation. In some areas, the flood walls have not been designed by professional engineers or followed the standard code. Moreover, the flood walls are designed and constructed according to different assumptions regarding the return period of the floods. Notably, in the rural areas, the flood walls have been designed using a 25-year flood return period; in contrast, the flood walls in the urban areas have been designed using higher flood return periods. Thus, the dikes or flood walls in rural areas, which have not been professionally engineered, may be the weak points for flood defence in the Chao Phraya delta. If the dikes collapse, the main system of the central government may not be able to assist the local people in that area. Hence, the flood wall system, the maintenance of which is the most important aspect, should be inspected by a specialised agency.

Third, the multi-hazard model is, at present, the significant factor that is lacking in the infrastructure development in the country. The multi-hazard model is a powerful and effective tool in understanding possible scenarios and will lead to pre-disaster management actions that are acceptable solutions to disaster management. Several forms of data, such as topographical information and data on populations, land use, or historical disaster cases, can be input in the multi-hazard model to simulate the affected areas and the efficiency of the disaster management plans, including their integration with other plans, such as economic and land use plans and plans regarding the settlement of people in future. The government or development planner can incorporate the results of the multi-hazard model to develop countermeasures for future disasters. In addition, the model can be made available to everyone in society to develop and take advantage of it. The current major obstacle in developing the multi-hazard model involves the data. Currently, the data are collected by several departments, even though the data are the same, because of the criteria associated with each department's mission. Notably, the collection and measurement methods are different for the same data. To achieve the goal of establishing the multi-hazard model, a single data platform should be built; this platform would collect and integrate the data from all departments and form a single standard of data. The data platform should be open access for everyone in the country.

Fourth, the issue of trust between people and the government is a main topic of concern in Thailand. Based on the group discussions, the people stated that the past development projects of the government sector have left the people of the area with a distrust of the government. People feel that the government sector does not act sincerely in public hearings. In addition, people feel that the government has a preconceived goal in mind before listening to their opinions – this leads to development based on a top-down approach, which may not consider the local culture and be contrary to the way of life of the local people. The representative of the group discussions stated that "We do not hinder development, but the government should be provide comprehensive information and sincerely listens to the people and finds solutions together in development".

Finally, the coherence of plans and policies should be considered in the present situation. Currently, the Royal Thai Government has enforced the National Strategy (2018–2037), which is the country's first national long-term strategy, and its vision is to have "a developed country with security, prosperity and sustainability in accordance with the Sufficiency Economy Philosophy". To achieve this vision, all the ministries have developed long-term strategic plans to serve the National Strategy (2018–2037), but these still lack connections and coherence within the same focus area.

In conclusion, this study presents an overview of opinions and perspectives on development in the Chao Phraya delta. Many points should be addressed, such as the coherence between agencies and departments, the infrastructure for flood defence in the delta, and the issue regarding the trust between the government and the people. The development of the areas of the Chao Phraya delta is a significant step in the country's development. The researchers hope that the final goal of the development is directed towards the local people, to ensure their prosperous future and make them resilient in the face of multiple disasters, and based on social equity.

Keywords: Chao Phraya delta, development, opinions, perspectives

References

Hutangkura T. 2014. A New Interpretation of the Boundary of Dvdravati Shoreline on the Lower Central Plain, Damrong Journal, Vol. 13, No.1, 2014

Kasetsart University.
thapthai.c@gmail.com

TC-327L

A ROBUST APPLICATION OF GOOGLE EARTH ENGINE FOR ESTIMATING SURFACE SUSPENDED SEDIMENT CONCENTRATION (SSSC) DYNAMICS IN MEKONG DELTA

Punwath Prum
Department of Geology and Environmental Science
University of Pittsburgh
Pittsburgh, USA
Punwath.prum@pitt.edu

Monysocheata Chea
Department of Information and Communication Technologies
Asian Institute of Technology
Bangkok, Thailand
cheatamony@gmail.com

Keywords— Suspended Sediment Concentration; Mekong Delta; Google Earth Engine

ABSTRACT
Water from the upstream rivers, streams, and lakes within the Greater Mekong basin transport suspended sediment to the delta. This sediment does not only play an important role to the ecological and agricultural livelihood of millions of people in the delta, but also contributes to the geomorphologic change and water quality of lower Mekong River. Over the last decade, the rapid economic development, changes in land use pattern, and dam constructions in the basin have significantly influenced the amount of suspended sediment depositing on the delta. However, there is a limited amount of research having focused on suspended sediment dynamics at the Mekong delta scale. Therefore, this research develops the “Mekong Data SSSC Explorer” application that automates the process to quantify the information of SSSC in Mekong delta. The application will fill in the gaps of scientific information about SSSC dynamics in the Mekong delta, and help inform the related stakeholders including policy makers and water managers, and foster data driven policy for water management in order to achieve the sustainable development goal 6 on "Ensure availability and sustainable management of water and sanitation for all" in the Mekong delta as well as the Greater Mekong Basin.

The Mekong Data SSSC Explorer is an open-source-code web app with a main functionality to estimate the SSSC in every 14 days from 2013 to the present, and at a high accurate level (in average around 2 mg/L). The app allows public users to intuitively geo visualize the SSSC of the river, analyze the SSSC time series in terms of graphics and export the estimated SSSC data to CSV for further analysis. The source code is stored on GitHub repository and can be accessed publicly without any restriction.

Mekong Delta SSSC Explore is built on Google Earth Engine, a cloud computing platform for planetary research, and uses the remote sensing principle to estimate the SSSC based on the interaction between the suspended sediment and electromagnetic energy. The app adopted Markert' et al. s algorithm (2018), which is an empirical model, using the reflectance value of surface water from Landsat 8 Collection 1 as the primary input for the estimation of the SSSC. In addition to the model, the app implements the Function of Mask (CFMask) algorithm to remove clouds from Landsat8 Level-1 image collection, and applies the Dynamic Surface Water Extent (DSWE) which is an algorithm for automated extraction of surface water at high confidence level, in order to effectively estimate the SSSC.

Mekong Delta SSSC Explore demonstrates that the recent innovation in such Google Earth Engine, and the empirical relationship between suspended sediment concentration and remote sensing observation is a reliable and effective method for delivering the SSCC data in Mekong level.

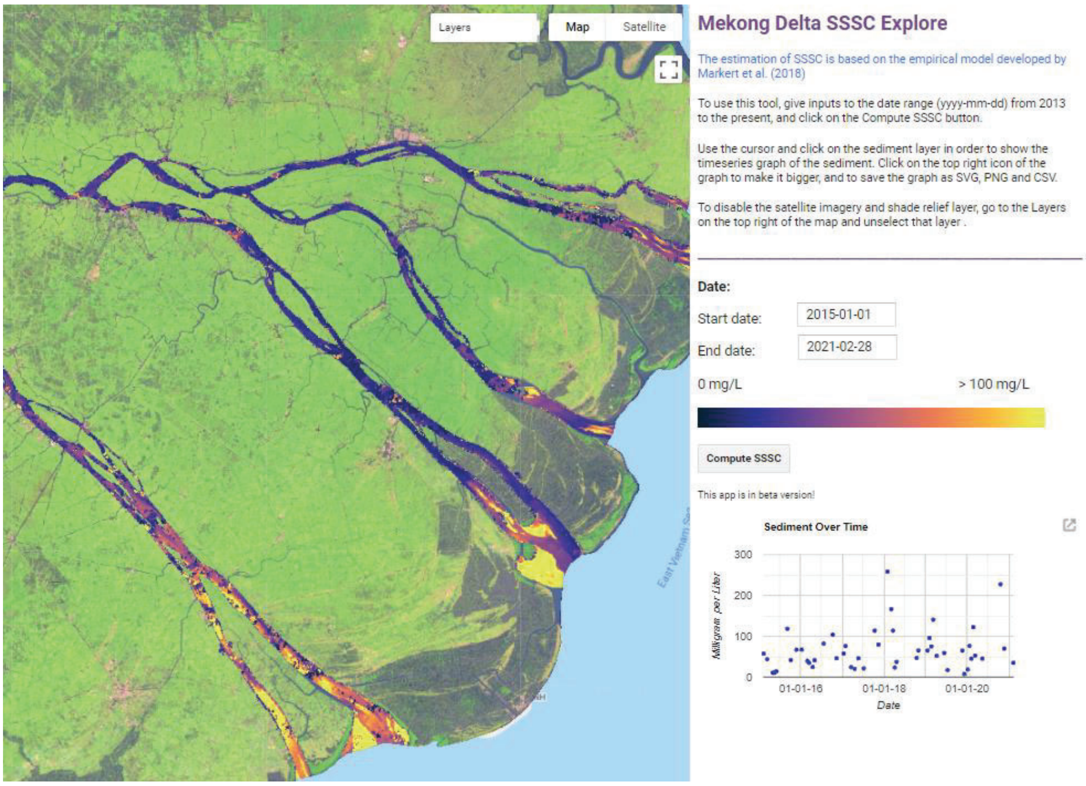


Fig. 1. The interface of Mekong Delta SSSC Explore

$$SSSC = 10^{1.90353307\times 2.718281828459045\times e^{1.44788939\times \log\frac{\mathrm{Band}_{Green}}{Band_{Red}}+0.62996462}}$$

Equation. 1. The expression used in this study to estimate the SSSC based on green and red band of Landsat8.

REFERENCES

(1) Markert, K.N., Schmidt, C.M., Griffin, R.E., Flores, A.I., Poortinga, A., Saah, D.S., Muench, R.E., Clinton, N.E., Chishtie, F., Kityuttachai, K., Someth, P., Anderson, E.R., Aekakkararungroj, A., and Ganz, D.J. (2018), Historical and Operational Monitoring of Suspended Sediment in the Lower Mekong Basin using Landsat and Google Earth Engine Cloud Computing. Remote Sens., 10(6), 909, https://doi.org/10.3390/rs10060909

TC-328L

GIS ANALYSIS FOR GROUNDWATER EXPLORATION IN HARD ROCK TERRAINS: HUAI KRACHAO, KANCHANABURI, THAILAND

Jurarud Yanawongsa*, Vanachawan Hunyek, Jirapat Phetheet, Ocpasorn Occarach, and Kriangsak Pirarai

Nowadays, climate change leads to many natural disasters, for example, thunderstorms, flooding, and drought around the world. Thailand also faces the same issues, especially in Huai Krachao Subdistrict, Kanchanaburi Province, western Thailand. Over the last 5 years, climate change has led to little precipitation in this region, with an annual average of less than 800 mm. Due to prolonged hot and dry conditions, this area is currently facing droughts. Under the circumstances, about 4,800 people are likely to be affected by climate change, causing water shortages for both domestic and agricultural uses. The water level in the Nong Na Talay reservoir – the only surface water storage in this area – continuously declines, resulting in an inadequate surface water supply during the dry season. Since the issues are getting worse than expected, the Department of Groundwater Resources has sent geologists who are responsible for exploring groundwater resources for detailed investigation. Managing surface water with supports from underlying groundwater resources might be one possible solution to prevent water shortages and reduce water stress in this area. Consequently, it would lead to achieving the United Nations' Sustainable Development Goal 6 (Clean Water and Sanitation) whenever people have access to clean and safe water. The recent study aims to delineate groundwater potential zones in the Huai Krachao area using the GIS-based analytical technique. The method provided the basic information and helpful guidelines for field surveys and were used as a tool to make decisions for site selection.

This area extends between latitudes 99°32'21"-99°41'21"N and longitudes 14°15'48"-14°26'36"E, covering an area of about 150 km^2. The study area is underlain by the Silurian-Devonian metamorphic rocks, including phyllite, slate, and quartzite in the west. On the opposite side, the Triassic granite is overlain by colluvial sediments with a thickness of approximately 2-5 m. In addition, large, long, and shallow fractures are predominantly presented in metamorphic rocks, while small, narrow, and deep ones are found in granite. Due to the challenges of groundwater drilling and development in hard rock terrains, more than 4,800 people are experiencing water scarcity and still need water for consumption, agriculture, and livestock. For this study, the geographic information system (GIS) was applied for groundwater resources investigation in hard rock terrains. The Analytic Hierarchy Process (AHP) was used as the decision-making tool for delineating groundwater potential zones based on weights derived from different parameters. There were nine significant parameters involved, consisting of geology, geomorphology, land use and land cover (LULC), slope angle, soil type, drainage density, rainfall, lineament density, and depth to groundwater. These input parameters were integrated using the Weighted Index Overlay Analysis (WIOA) to classify potential groundwater recharge zones, possibly define the groundwater extension, and consequently produce the groundwater potential index (GWPI) map.

Groundwater potential areas can be classified into three zones in accordance with GWPI values: high potential (GWPI > 6), moderate potential (GWPI = 6), and low potential (GWPI < 6) zones. The high potential zone covers an area of 31.2 km^2, accounting for roughly 20% of the study area. It is mostly occupied in the Silurian-Devonian metamorphic rocks and dominated by slopes and hills with an elevation of 82-116 m above MSL. This zone has a high rainfall rate (average 993-1,065 mm/year), high lineament density (>4 km/km^2), gentle slope (<10 degrees), and is mostly used for agriculture. The moderate potential zone covers an area of 62.5 km^2 or about 44% of the total area. It primarily lies within flat and low-lying areas (plains), covered by the Quaternary sediments with an elevation of 40-82 m above MSL. This zone is located in areas with a medium rainfall rate (average 1,012-1,017 mm/year) and a moderate to high density of lineament (>3 km/km^2), where the slope is less than 10 degrees, and most of the areas are currently in use for cultivation.

After obtaining the GWPI map, the accuracy of the map was verified by drilling 10 wells in total, including 5 wells located in two high potential zones, another 3 wells tested in the northwest, and the other drilled in the south. All wells are in the Silurian-Devonian metamorphic aquifer, with a depth ranging from 150 to 300 m. Groundwater aquifers were found in fracture zones at 66, 103-104, 111-117, 150-165, and 281-283 m deep, with an average well yield of 35-40 m^3/hr. In summary, groundwater development in hard rocks with complex geological structures is costly and time-consuming. Thus, the determination of groundwater drilling points must be accurate and precise. GIS was employed in this study as a tool to analyze all related parameters and then displayed a clear and easy-to-use map with high, moderate, and low groundwater potential zones. However, this integrated approach is based on reasonably valid input data. Variation occurs when input parameters are uncertain. In this case, for example, lineament density was not well determined because of the complexity and disconnectivity of the geological media. As lineaments were interpreted from surface features using remotely sensed data like the digital elevation model, they were difficult to determine precisely. Therefore, the procedure had to be followed by detailed geological and geophysical surveys to provide more information before selecting the drilling location. After the GWPI map has been proved and cross-checked by drilling data, the map is effective and capable of delineating the potential zones for groundwater development in the Huai Krachao area.

Keywords: AHP, Groundwater potential index (GWPI) map, Groundwater exploration in hard rock terrains

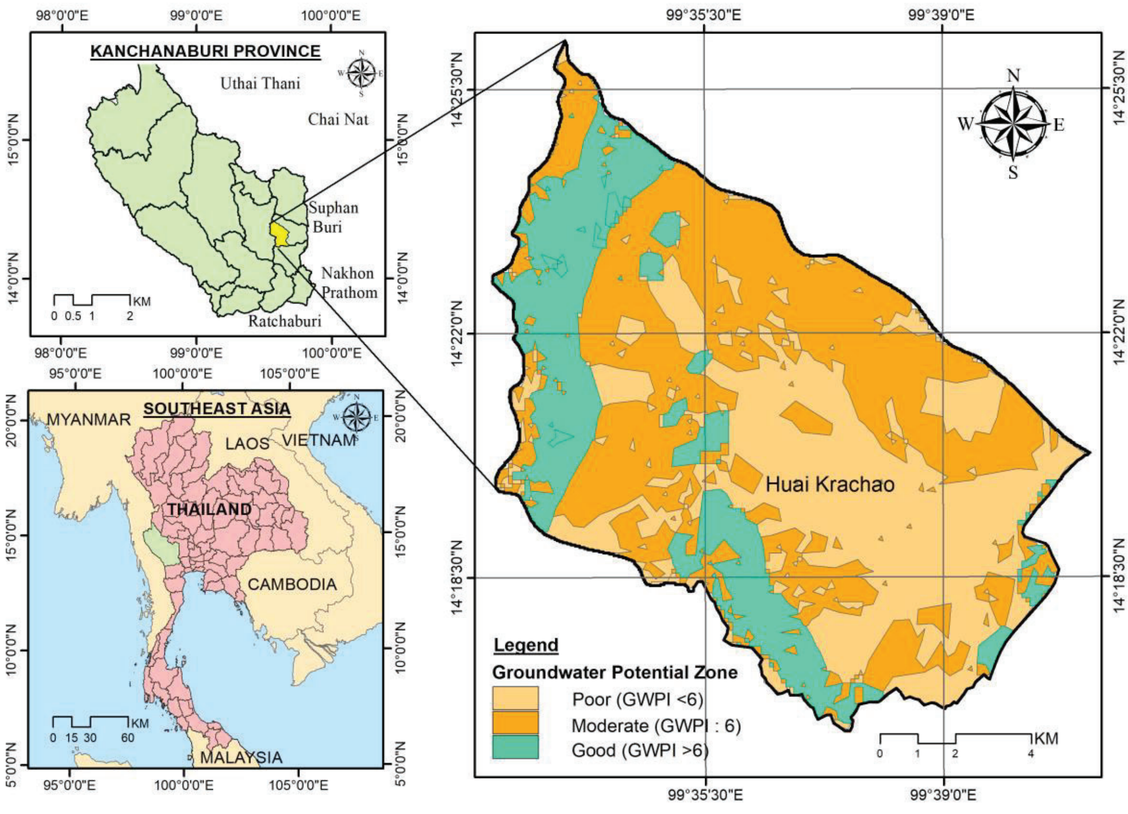


Fig. Groundwater potential zones showing the spatial distribution of groundwater potential index (GWPI)

Department of Groundwater Resources, Ministry of Natural Resources and Environment, Bangkok, Thailand
*Corresponding author email: rainnyjura@gmail.com

TC-330L

Groundwater Resources Planning and Development in Eastern Economic Corridor (EEC) with an Integrated Spatial Plan and Public Participation

Arnon Phongkula[1], Vijitsri Sanguanwongse[2], Mana Luksamee-Arunothai[2], Non Vorlapanit[2], Kanokon Seemanon[2], Krit Won-in[3], and Wandee Thaisiam[4]

The Thai government places importance on Eastern Economic Corridor (EEC) Project in Chachoengsao, Chonburi, and Rayong provinces, where manufacturing industry has been rapidly expanding, resulting in the shortage of surface water and sometimes the water quality is non-consumable. Therefore, the Department of Groundwater Resources, the Ministry of Natural Resources and Environment, in cooperation with Kasetsart University, has launched the Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in the EEC. The objectives of this study are to 1) explore groundwater resources and get information on groundwater potential in the EEC, in both quantity and quality 2) conduct an economic viability and analyse the real cost analysis of groundwater utilisation and 3) construct an area integrated groundwater resources planning and development in the EEC.

The methodology consists of surface-geophysical survey in 4,517 points where soil and rock data are not available using resistivity survey method, Vertical Electrical Sounding (VES), selection of at least 150 existing groundwater wells for jetting, following by constant-rate pumping test of 250 groundwater wells to determine groundwater yield and hydraulic properties of aquifers. The data gathered from the tests were analysed, interpreted, and processed in order to update the hydrologic map at 1:50,000 scale and generate maps of suitable areas for groundwater development of each purpose (consumption, agriculture, industry, and tourism).

Moreover, the research team analysed water uses and water demands in the EEC, and evaluated water scarcity (current and estimated) of 3 EEC Provinces during 2019-2039. Willingness to pay for groundwater were collected from 382 sampling persons. In addition, discussion meetings with 35 relevant organizations, public hearings with 1,217 participants, 3 focus group meetings, and the project launch seminar and the findings dissemination seminar were organized to collect comments and suggestions from all stakeholders.

[1] Department of Ground Water Resources, Ministry of Natural Resources and Environment, No. 26/83 Soi Than Satit Tula (Soi Ngamwongwan 54) Ngamwongwan Road Ladyao, Chatuchak, Bangkok 10900 Thailand.
[2] Faculty of Economics, Kasetsart University (Bangkhen Campus), 50 Ngamwongwan Rd, Chatuchak Bangkok 10900 Thailand.
[3] Department of Earth Sciences, Faculty of Science, Kasetsart University (Bangkhen Campus).
[4] Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University (Bangkhen Campus).

The results of the study indicate that the groundwater resources planning and development in the EEC should achieve the Sustainable Development Goals (SDGs) by creating water resource security and effectively utilizing groundwater with maximum benefits, under control of economic measures. The short term (5-year) groundwater resources planning and development in EEC should comprise of 1) Amendment of related laws and regulations by indicating the EEC area in 3 Provinces as groundwater critical area and imposition of groundwater use fees and groundwater conservation fees for effective groundwater utilisation; 2) Large-scale groundwater development in the EEC area in 2.1) Ban Khai District District, Rayong Province with NPV of 10.44 million baht/well and IRR of 26.69%, 2.2) Sattahip District, Chonburi Province with NPV of 21.42 million baht/well and IRR of 40.59%, and 2.3) Bang Nam Priao and Phanom Sarakham Districts, Chachoengsao Province with NPV of 15.14 and 9.31 million baht/well, and IRR of 32.68% and 25.23%, respectively; and 3) Supporting public participation of citizen and relevant sectors and organizations, and public relation through various types of media.

The medium term (10-year) and long term (20-year) groundwater resources planning and development in EEC should comprise of 1) Effective and sustainable allocation and utilisation (for agriculture, consumption, tourism, and industries) of large-scale groundwater development in 3 EEC Provinces (from year 6 onwards); 2) Groundwater conservation for sustainable and effective groundwater utilisation, which includes increasing effectiveness of management, conserving upstream areas or groundwater recharge areas, controlling amount of groundwater usage, and identifying EEC area in 3 Provinces as groundwater critical area and imposition of groundwater use fees and groundwater conservation fees (operate throughout 20 years); and 3) Monitoring quantity and quality of groundwater, consisting of level and quantity of groundwater data, and dispersion and concentration of contaminants in groundwater data (operate throughout 20 years).

In conclusions, groundwater resources planning and development in the EEC should consist of public participation of citizen and relevant sectors and organizations; large-scale groundwater development, and effective and sustainable allocation and utilisation of large-scale groundwater development; groundwater conservation for sustainable and effective groundwater utilisation; legislative amendments related to collection of groundwater use fees and groundwater conservation fees; and groundwater monitoring (in both quantity and quality).

Keywords: Groundwater Resources Planning and Development; Eastern Economic Corridor (EEC); Public Participation

TC-331L

MANAGED AQUIFER RECHARGE : THE EXPLORATION OF POTENTIAL AREAS, NAM KAM RIVER BASIN, SAKON NAKHON AND NAKHON PHANOM PROVINCES, THAILAND

Natchanok Ounping*, Jirateep Yotmaw, Jirapat Phetheet,
Ocpasorn Occarach, and Kriangsak Pirarai

Climate change has a direct impact on weather and season globally. In Thailand, the rainy season usually starts from mid-May to mid-October every year, but recently this season either comes early or late that would affect human beings and ecosystems, including agriculture and livestock. Moreover, an increase in rainfall intensity, caused by longer and heavier rains, results in floods in many areas. To prevent such a situation, the exceeded water has to be managed in collaboration with local people and all levels of the organization to protect the ecology and environment. In this area, the construction of an infiltration pond is recommended since it is capable to hold stormwater during the wet season and allow water to percolate down to the groundwater system for future beneficial uses. As a result, the groundwater level increases in accordance with the amount of surface water recharge, and eventually leads to sustainable groundwater supply. This solution could lead Thailand to be on track to achieve the United Nations' Sustainable Development Goal 6 (Clean Water and Sanitation).

Nam Kam River Basin is one of the Mekong tributaries situated in the northeastern part of Thailand. The basin partially covers two provinces with an area of approximately 2,500 square kilometers, which is a part of the vast flat area known as The Korat Plateau. This area is rich in rainfall with an annual rate ranging from 1,300 to 2,400 millimeters (Thai Meteorological Department, 2021), and is sometimes affected by tropical cyclones in some years. For example, in 2017, most people who lived near the Nong Han Lake and Nam Kam River — the main lake and river in this river basin — were hit by the tropical depression named Sonca, causing heavy rainfall and considerable flash flooding in Sakon Nakhon municipality. The tropical storm largely affected residential properties, agricultural areas, and businesses, which were eventually compensated by the government. Therefore, the Department of Groundwater Resources is trying to find ways to prevent flood-related disasters as well as manage the volume of stormwater. Based on previous studies (Department of Groundwater Resources, 2020), performing managed aquifer recharge might be one of the appropriate solutions for dealing with this issue. The more exceeding water from the rain is wisely managed, the fewer flood-related problems will occur.

The methodology of the study can be described in four parts. The first part is to review the previous works or relevant secondary data. This would help not only to understand the whole area but also to plan for fieldwork. Next step, the detailed study is principally carried out in the field. This part mainly focuses on the studies of geology and hydrogeology, including groundwater well inventory, resistivity survey, drilling small-diameter wells, and determination of hydraulic properties using a slug test. The study process is then followed by the social study. The questionnaire is used to recognize the flood situation in the area, raise concerns about the lack of water consumption, and broaden an understanding of managed aquifer recharge. The final step is to delineate the potential areas. Weighting methods and geographic information systems (GIS) are the crucial tools used to analyze and identify the suitable zones for performing the managed aquifer recharge. Geology, geomorphology, permeability and slope gradient are the major factors for weighting methods.

This finding presents a map illustrating the different degrees of suitability for managed aquifer recharge with four different colors (Fig. 1). Most of the area is considered as the moderate potential area (pale yellow color) which is around 1,000 square kilometers (44%), following by the low potential area (old rose color), covering an area of 800 square kilometers (33%). Both moderate and low potential areas are found in the upper part of the river basin. The high potential area (green color) comes in the third in size with 350 square kilometers, accounting for 14% of the basin area, and predominantly covers the lower part of the study area. The smallest area is the non-potential area (red color) which is mainly found in the high mountain area of the lower part of the river basin. The size of this area is 200 square kilometers or only 9% of the total area.

The results suggested that high and moderate potential areas must be the first two priority zones if managed aquifer recharge is brought for decreasing the overflow of water during the rainy season. Besides the suitability of the area, the selection of the techniques of managed aquifer recharge is also important. The next step would focus on the study of the appropriate methods and testing the selected technique in the actual sites.

Keywords: exploration, managed aquifer recharge, Geographic Information System

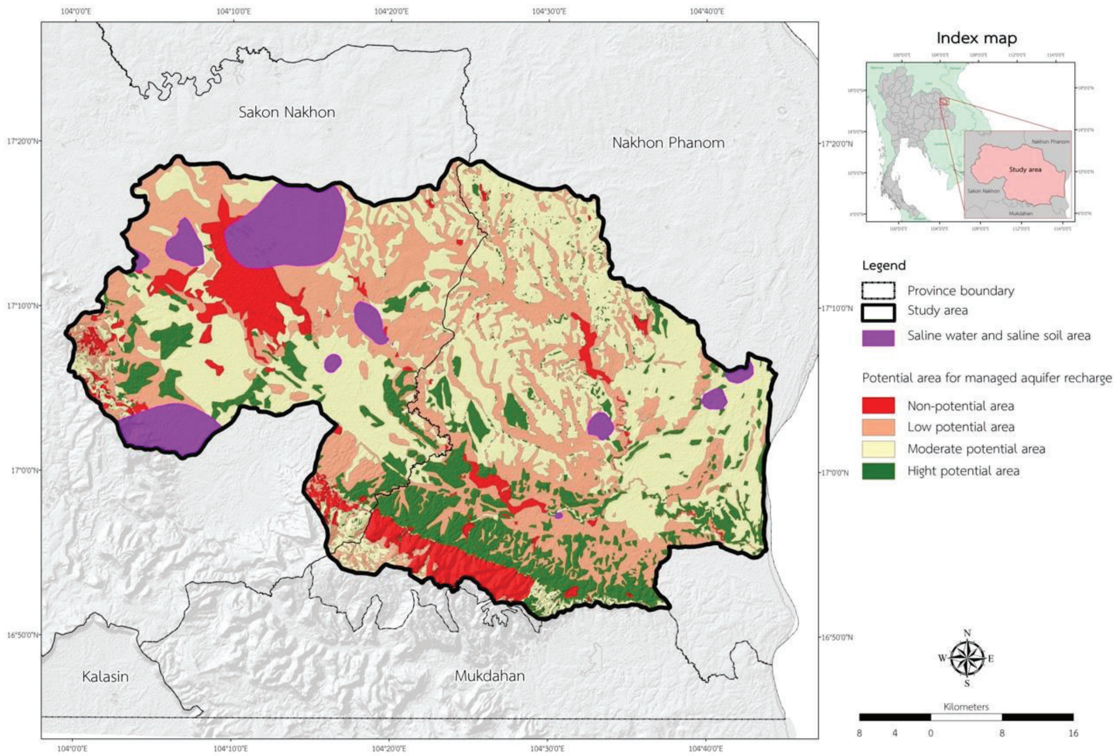


Fig. 1. Potential area for managed aquifer recharge in the Nam Kam River Basin.

Department of Groundwater Resources, Ministry of Natural Resources and Environment, Bangkok, Thailand
Coresponding auther email: natchanokoun@gmail.com

TC-332L

APPLICATION OF NANOFILTRATION MEMBRANE FOR REMOVAL OF VOCS AND HEAVY METALS IN GROUNDWATER, RATCHABURI, THAILAND

Chadaporn Busarakum*[1], Tussanee Nettasana[1], Manussawee Hengsuwan[1], Phanumat Kullaboot[1], Jinhee Park[2] and Kyoung-Woong Kim[2]

The presence of toxic contamination in groundwater has become a concerning issue. Since groundwater is the main source of fresh water that is used for domestic, agricultural, and industrial activities, contamination can result in health issues for humans and animals. Sources of groundwater contamination are from both geogenic origins caused by dissolution of minerals in aquifer, and anthropogenic origin due to high expansion of urbanization, agricultural production, and industrialization. One of the areas affected by groundwater contamination is located in Namphu and Rangbua subdistict, Ratchaburi province, western Thailand. According to the site investigation results performed by the Department of Groundwater Resources, Pollution Control Department, and other environmental government agencies in 2014, the groundwater in the area is contaminated with volatile organic compounds (VOCs) and heavy metals. The pollutant source was identified as leakage from landfill and industrial waste recycling activities which are located upstream. The villagers living downstream were not able to use this contaminated groundwater. However, the methods for improving groundwater quality have not been determined.

The objective of this study was to define the hydrochemistry of contaminated groundwater and examine the efficiency of nanofiltration membrane for removal of pollutants in groundwater as well as the potential implementation of the membrane. Hydrogeological characteristics of the study area is comprised confined aquifer which consist of massive limestone, meta-sandstone, mudstone, and quartzite which is 20-80 meters below surface and unconfined aquifer consists of clay, sandy clay, silty sand, and weathered rock 3-8 meters thick. Depth to water is approximately 1-6 meters. The chemical property of groundwater at the site was Ca-HCO_3 type with high total hardness. The distance of groundwater contamination extended from the landfill area to 1 kilometer downstream from the source. The analytical results of groundwater samples reported that the highest vinyl chloride concentration (2,170 μg/L) was detected in the monitoring well at the landfill in July 2020. The contamination of vinyl chloride and benzene was also detected in shallow wells located in the southeast of the landfill area. Moreover, the heavy metals concentration including nickel was 0.36 mg/L and manganese was 10 mg/l which are higher than groundwater standards. The concentration of the pollutants fluctuated depending on seasonal variables that control water table in aquifer and biodegradation of organic compounds occurring in subsurface environment. Although the industrial waste recycling activities have been suspended since 2018, the contaminants are leaking from the source and flow to the discharge area. Several technologies for groundwater remediation such as the implementation of permeable reactive barriers, pump and treat, or bioremediation could be applied to the site. The processes to clean up subsurface environments includes many steps and can be quite costly to improve water quality for desired standards. Instead of remediating aquifer conditions as a long-term solution, household filtration solutions are cheaper and simpler to achieve. The alternative method to treating groundwater in situ is the implementation of membrane filtration technology to produce safe drinking water for household use.

The pressure-driven membrane processes including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) have been widely used in municipal wastewater treatment as well as household scale. Nanofiltration (NF) is a relatively recent development in membrane technology with characteristics that fall between ultrafiltration and reverse osmosis (RO). In this study, we investigated the potential for removal of chlorinated volatile organic compounds and heavy metals from groundwater. The chemicals of concern were cis-1,2-dichloroethylene, vinyl chloride, benzene, nickel, and manganese. A hand operated filtration system developed by the International Environmental Research Institute (IERI), Gwangju Institute of Science and Technology (GIST), Republic of Korea, pumps water at low pressure through microfiltration and nanofiltration membranes to remove contaminants. The membrane module is composed of spiral-wound type with polyamide thin-film composite Nanofiltration membrane. The module is cylindrical shape of 101.6 cm long and 6.4 cm diameter, and the membrane surface charge is negative with monovalent rejection (NaCl) of 85-95%. The filtration experiments were conducted at a pressure of 0.4-0.6 MPa, which yielded flow rates of approximately 2 L/min. To examine the nanofiltration membrane efficiency, groundwater samples were extracted from four monitoring wells by using a submersible pump with low flow rate, and were used as feed water. The samples were measured for pH, temperature, and electrical conductivity at the site and were collected in bottles for laboratory analysis. Permeate samples were collected for laboratory analysis, and the field parameters were measured. In addition to nanofiltration, an activated carbon filter was used in this experiment to compare the removal rates of pollutants.

According to laboratory results, the maximum concentration of pre-treatment samples were as follows; cis-1,2-dichloroethylene 6 µg/L, vinyl chloride 25 µg/L, benzene 6.9 µg/L, nickel 0.026 mg/L, and manganese 0.53 mg/L. The removal efficiency of the filters was calculated for each parameter of interest. The results indicated that the nanofiltration membrane performs better with contaminant removal than the activated carbon filter. The nanofiltration maximum removal efficiencies for 1,2-dichloroethylene, vinyl chloride, benzene, nickel, and manganese were 97, 99, 98, 99, and 99%, respectively. The activated carbon filter removal efficiencies for 1,2-dichloroethylene, vinyl chloride, benzene, nickel, and manganese were 97, 75, 96, 62, and 2%, respectively. Based on the findings, nanofiltration membrane could be recommended for VOCs and heavy metals removal in the study area. However, the treatment efficiency is dependent on several factors, including pretreatment requirements, influent water quality and the lifespan of the membrane, which needs to be investigated more in details. The Nanofiltration membrane (NM) is generally used for two to three years, but it depends on the input water quality. Therefore, it is recommended to increase the replacement cycle of NM by frequently replacing the relatively cheap pre-filter. The water filtration with the NM is entirely operated by manpower so that the users can save the cost for fuel or electricity. It also reduces the burden of hiring skilled experts and using expensive chemicals required by other treatment processes such as oxidation, precipitation, and adsorption. However, it is necessary to discuss how to control the effluent concentrated with pollutants after filtration. Further research to determine the maximum concentration of VOCs and heavy metals in the feed water should be performed before applying this treatment method to large scale.

Widespread implementation of these nano filtration systems provides the opportunity for Thailand to achieve the Sustainable Development Goals (SDGs) related to “Clean Water and Sanitation” (Goal 6). The presence and regular maintenance of these filtration systems in households and villages would provide local communities ample access to clean water. This clean water can be used for drinking and improved sanitary conditions for people who would otherwise have difficulty obtaining it.

Keywords: Nanofiltration membrane, VOCs, Heavy metals

[1] Department of Groundwater Resources, Bangkok, Thailand
*chadaporn.b@dgr.mail.go.th.
[2] International Environmental Research Institute, Gwangju Institute of Science and Technology (GIST), Gwangju, Korea

TC-334L

HYDROLOGICAL FORENSIC INVESTIGATION COMBINING HIERARCHICAL CLUSTER ANALYSIS: A CASE STUDY OF 16TH LUM NAM JONE RESERVOIR, CHACHOENGSAO, THAILAND

Manussawee Hengsuwan*, Chadaporn Busarakum, Phanumat Kullaboot, Tussanee Nettasana

The 16th Lum Nam Jone is a 1.97 million cubic meters freshwater reservoir, located 500 meters north of 304 Industrial Park in Chachoengsao province, Thailand. For over 30 years, water from this reservoir has been vital for locals' domestic uses, agriculture, and fishery. Various complaints regarding the water's habitability since 2019 led to complete water quality analyses, which showed that the water was highly acidic with pH 2.5-3.5 and contaminated by heavy metals such as iron, manganese, copper, zinc, and lead. In other words, the water from this reservoir is not suitable for aquatic organism and water supply. The main objective of this study is to identify the source of contamination and contamination transport pathway, using a hydrogeological forensic approach, which is necessary for the relevant legal process, including the remediation plan.

Delineating the source(s) of contamination which affect the 16th Lum Nam Jone reservoir is an essential step in reducing the exposure of local communities to hazardous chemicals in the water supply. The implementation of preventative measures and remediation of ground and surface water conditions is imperative to achieve Sustainable Development Goal 6.3.

Identification of contamination sources is considered challenging in environmental studies. Many factors such as multiple contamination events, mixing of many contamination sources, adsorption on clay mineral, co-precipitation of minerals and heterogeneous lithological distribution can complicate interpretation of the findings. Hence, it is important for hydrological forensic investigation to have a thorough understanding of hydraulic connectivity between surface water and groundwater, hydrogeological characteristics, site history and potential sources of contamination.

For this case, geological and geophysical survey were opted for the preliminary site characterization. Geophysical method was helpful in screening areas of contaminated soil and groundwater. Geophysical survey, using electrical resistivity was carried out under the hypothesis that low pH contaminated water should have high electrical conductivity (low resistivity). The preliminary site investigation showed low resistivity anomalies nearby a molybdenum ore processing plant, suggesting that this factory might be a potential source of the contamination. However, this method cannot identify chemical parameters, and thus cannot be used as a stand-alone method.

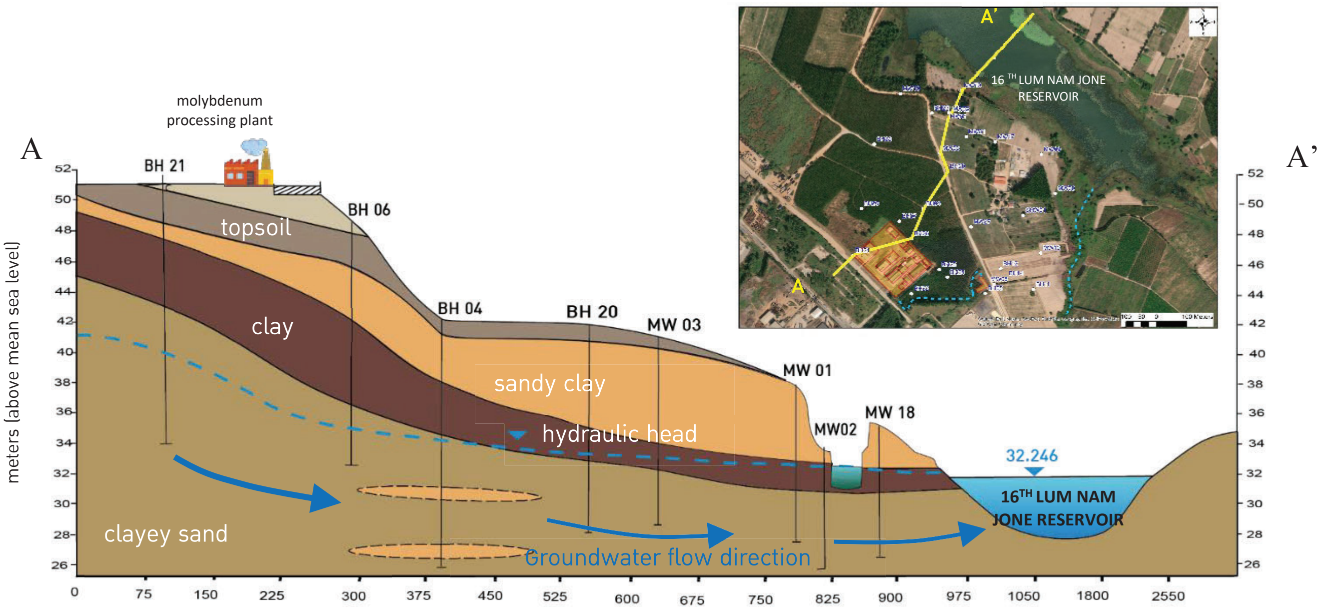


Figure 1 Hydrogeological conceptual model of the study site

The next step, hydrogeological investigation was employed to construct hydrogeological conceptual model, which showed that the groundwater in the study area flows to the 16th Lum Nam Jone reservoir (Figure 1). The hydrogeology of the area consists of unconsolidated sediment units; sandy clay, clay, and clayey sand. The water table was at 2-14 meters below the ground. Based on direct push drilling data using a Hydraulic Profiling Tool (HPT), the estimated hydraulic conductivity of the aquifer layer was 15-21 m/day. To further explore the water- chemistry relationship, cluster analysis of 33 cases data set (groundwater and surface water samples) was performed on major distinguish ion subset (Fe, Mn, Cu and Zn) using Ward's method and Euclidean distance measure. These methods are particularly suited to identify commonalities as well as differences between large data sets. The results of hierarchical clustering procedures are expressed graphically in the form of a dendrogram. In figure 2, the nodes of the dendrogram represent the grouped classes or clusters, while the length of the branches indicates the distance between the groups. Samples are arranged according to similarity. In this study, regarding to dendrogram and total dissolved solids (TDS), water samples can be classified into three main groups. The first group can be subdivided into 2 subgroups: 1.1 uncontaminated or less contaminated water samples (TDS 114 - 696 mg/L) and 1.2 slightly contaminated water samples (TDS 214 – 2,631 mg/L). The second group can be classified as contaminated water samples with high TDS (3,929 – 13,615 mg/L). The third group consists of contaminated water samples with very high TDS (11,841 – 23,217 mg/L). Moreover, the pattern or chemical signature discriminations obtained using both hydrochemistry plotting and hierarchical cluster analysis approach are in good agreement.

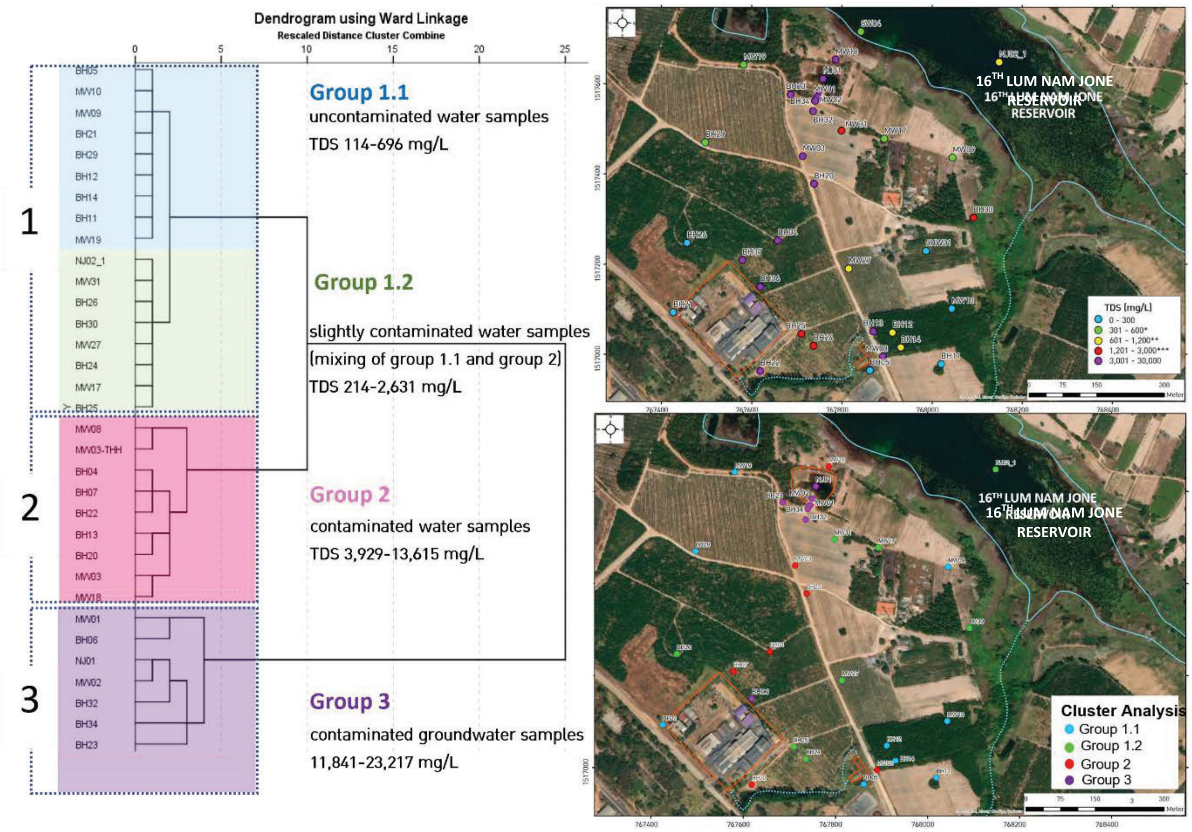


Figure 2 Dendrograms using Ward's method showing three main cluster solutions

A major finding from the combined statistical, hydrogeological, and geochemical assessments confirmed that contaminated water in the 16th Lum Nam Jone reservoir is significantly related to the molybdenum ore processing plant located upgradient. The industrial wastewater from this plant might be illegal discharge into underground and flows due to hydraulic gradient to the 16th Lum Nam Jone reservoir.

Keywords: groundwater, contamination, environmental forensic investigation

Department of Groundwater Resources, Bangkok, Thailand
manussawee.h@dgr.mail.go.th.

TC-335L

COST AND BENEFIT ANALYSIS FROM USING AUTOMATIC METERING READING FOR GROUNDWATER REVENUE MANAGEMENT : CASE STUDY FROM THAILAND GROUNWATER CRISIS AREA

Vijitsri Sanguanwongse[1],Supanee Harnphattananusorn[2]*, Wasin Siwasarit[3],
Mana Luksamee-Arunothai[4], Kanokorn Simanon,[5] and Pimchanok Phupradab[6]

According to The Groundwater Act, B.E. 2520 and its amendments, licensed groundwater users (hereafter licensees) are required to pay groundwater usage and groundwater preservation fees at the rates set forth in the Ministerial Regulations. Groundwater laws require licensees to keep a record of their groundwater usage and submit it to the local groundwater staff for the specific groundwater area. However, some licensee reports contradict the actual usage recorded by the water meters, and some users have failed to submit their groundwater usage reports and have refused to pay the groundwater usage fees.

Even though there is a default fee and punishment for late payments, there is still a significant revenue loss due to law enforcement due to a lack of government personnel and a low penalty rate. Furthermore, uneconomical groundwater use in excess of the permitted amount may cause damage and the risk of land subsidence, as well as a drop in groundwater levels, resulting in future water shortages. Aside from that, payments are made on a quarterly basis due to the metering groundwater usage collection and bill operating process with a limited number of government officers. Revenue collection efficiency, managerial efficacy, and cost effectiveness are all essential considerations.

At the moment, a number of countries, both developed countries such as the United States and developing countries such as Indonesia, India, and Bangladesh are hiring private agents to collect certain types of public revenue, for instance tax revenue and revenue from water consumption fees/groundwater usage fees. Additionally, the automatic metering reading (AMR) installation is an alternative for increasing the efficiency and efficacy of revenue collection from groundwater usage fees. The benefits of AMR, such as automated leak detection, water measurement and verification, water theft prevention, and so on, will provide efficiency/effectiveness/sustainability, and will be economically cost-effective.

Aside from that, the acquired groundwater usage data is available in real time. It can assist in reducing the volume of lost and wasted water by notifying both the utility and the licensee of water leaks and unusual use patterns. The collected data can be made available to licensees via mobile applications, and billing systems will allow licensees to access specific information about their groundwater use, generating equity in billing.

This study attempts to examine the cost and value of shifting the collecting process of groundwater revenue and groundwater preservation fees from a manual system to an automatic metered reading system utilizing marginal cost and marginal benefit. The methodology is based on a benefit-cost analysis that takes into account the time value of money. There are two types of AMR benefits: tangible benefits and intangible benefits. For tangible benefits, we classified AMR benefits as follows: (i) switching to AMR allows the possibility of shifting payment frequency from quarterly to monthly basis, creating reinvesting opportunity from revenue or interest on interest, and (ii) the AMR system and the IOT system helping to reduce the workload of the Department of Groundwater Resources staff. (iii) the marginal benefit derived from an efficient collection process. For intangible benefits, we evaluate (i) reducing the Department of Groundwater Resources personnel budget, and (ii) providing economic value by reducing the chance of an accidental rate arising attributable to licensee monitoring travel. AMR installation expenses can be broken down into four categories: (i) network security devices (Firewalls), (ii) core network devices (Core Switches), (iii) server computers for system development, and (iv) backup devices for ready maintenance backup programs.

The data in this study are gathered from groundwater crisis areas in seven provinces: Bangkok, Samut Prakan Province, Nonthaburi Province, Pathum Thani Province, Samut Sakhon Province, Nakhon Pathom Province, and Phra Nakhon Si Ayutthaya Province. Surveys and questionnaires would be collected from stakeholders and connected sectors, which are sample groups/representatives in the

1,2,4, and 5 from Kasetsart University,Bangkok,Thailand , 3 from Thammasat University, Bangkok,Thailand, and
6 from Department of Groundwater Resources,Thailand
Corresponding author Email addresses: supanee.h@ku.th

commercial and industrial sectors, agricultural sector, and household sector, as well as related government organizations.

Due to the large number of groundwater licensees, the groundwater crisis area of four provinces, namely Pathum Thani, Samut Sakhon, Nakhon Pathom, and Phra Nakhon Si Ayutthaya, is chosen from billing of groundwater charge and preservation costs of at least one million baht every quarter. For the remaining groundwater crisis areas in three provinces: Bangkok, Samut Prakan, and Nonthaburi, the majority of licensees bill less than one million baht per quarter; thus, the selection criteria for these three provinces are the number of groundwater wells with the highest groundwater usage and groundwater conservation costs.

The following are the specific results: (1) Changing to an AMR meter can provide additional benefits in terms of time-savings for current personnel, as administrative work related to revenue collection from groundwater usage fees and groundwater preservation fees can be reduced by 70 percent. In this study, based on 2 personnel per province, using the rate of 26,397.46 baht per person per month to calculate, 70 percent will equate to an opportunity cost of 18,000 baht per person per month. (2) It will help reduce the accident rate from personnel having to travel to perform examinations of groundwater usage by licensees. This study utilizes the Traffic Accident on National Highways in 2019 reported by the Bureau of Highway Safety, Department of Highways, and the Ministry of Transport.

The report revealed that, in 2019, one instance of accident is valued at 3.25592 million baht. In 2019, the accident rate was equal to 149.46 accidents per 100,000 population. This study calculates the benefits from reducing accidents equal to 98,652.57 baht per person per month. In the case that the assumption of the marginal benefits in revenue collection through the AMR meter system fails to increase by 2 percent as assumed, the implementation of the project could still be carried out as long as the increase in collection efficiency is at or above 1.613 percent, which is the project's breakeven point.

However, because the AMR system is complicated and customizable, transitioning from manual to AMR systems is not a one-size-fits-all proposition. We propose that, in order for the AMR installation project to be implemented properly, a pilot project be carried out, and licensees to join the project be selected based on the following criteria: 1. Choose licensees from four groundwater crisis provinces: Pathum Thani Province, Samut Sakhon Province, Nakhon Pathom Province, and Phra Nakhon Si Ayutthaya Province, with a minimum of 1 million baht per quarter in groundwater usage and groundwater preservation fees. 2. For the groundwater crisis areas in Bangkok, Samut Prakan Province, and Nonthaburi Province, a criterion should be utilized to pick 10 to 15 wells among the enterprises with the highest groundwater usage fees and groundwater preservation fees to participate in the AMR meter installation project.

Keywords: AMR, Cost-Benefit ,Groundwater Revenue Management

TC-336L

GROUNDWATER MONITORING NETWORK IN THAILAND

Thayarat Srikamma, Wasana Sartthaporn*

The excessive groundwater extraction can deteriorate groundwater quantity and quality in Thailand such as groundwater level decrease continuously in central area, land subsidence in metropolitan areas, saline water intrusion in Northeastern and Southern Thailand. In addition, contamination in groundwater can be problematic as a result of human activities such as improper waste management, industrial activities, mining and chemical uses in agriculture. Department of Groundwater Resources (DGR) has been monitoring the changes in groundwater level and quality from to control the impacts of groundwater abstraction and contamination, and monitoring aquifer response and quality trends provide key inputs for Sustainable Development Goals 6 (clean water and sanitation: implement integrated water resources management at all levels).

Currently, there are 1,944 groundwater monitoring wells which monitor groundwater levels and quality. The groundwater monitoring networks are divided into 2 patterns. First, the monitoring networks for observing groundwater levels and groundwater quality in large scale covering 27 groundwater basins. In the study, these networks should add 4,558 monitoring wells by 6 criteria, (1) number of monitoring wells in the present, (2) land use (industrial, agriculture, tourist attraction, and service business), (3) number of groundwater development and groundwater consumption of each area, (4) risk of groundwater contamination (saltwater intrusion, occurs naturally (iron, arsenic, manganese), and industrial waste), (5) risk of earthquake or geohazard affected groundwater resources, and (6) transboundary aquifer of ASEAN Community. Second, the monitoring networks are designed for the risk areas of contamination or losing the water balance such as landfills, industrial waste disposal areas, mining areas, and the areas with high demand of groundwater use.

Nowadays, groundwater levels measurement can be categorized by necessary areas into 3 methods. First of all, 93 observation wells in the specific areas, groundwater levels continue to drop steadily, saltwater intrusion, and land subsidence, are measured by online automatic recorders. That provides continuous data and deliver the data as automatic real-time to database system of Thailand Groundwater Monitoring System (TGMS). Second of all, 332 observation wells in areas of declining trend of groundwater levels and risk of groundwater contamination, are measured by recorders and retrieving stored data from recorder with a laptop. Eventually, 1,519 observation wells in areas of groundwater levels and groundwater quality slightly changed, are measured by using electric tape and data is collected twice a year.

The groundwater levels and groundwater quality are stored in the TGMS and disseminate information for groundwater levels and groundwater quality to the public and governmental agencies through the website www.tgms.dgr.go.th. Groundwater monitoring data can be implemented in drilling permit. The annual report of groundwater monitoring has been applied for creating regulations by groundwater committee. TGMS is an important data to increase the performance of groundwater measures in terms of groundwater conservation. The focus areas include: 1) contaminated areas, e.g., municipal and industrial waste; 2) saltwater intrusion areas, e.g., Northeastern Thailand and coastal areas; 3) the areas with highly use of groundwater, e.g., Central Thailand and big cities or industrial estates.

Keywords: monitoring wells, groundwater level, groundwater quality

TC-337L

Characterization of Contaminated Groundwater and Remediation Plans in Namphu and Rangbua Subdistricts, Ratchaburi, Thailand

Tussanee Nettasana[1], Manussawee Hengsuwan[1], Chadaporn Busarakum[1], Phanumat Kullaboot[1], Jirapat Phetheet[1]

[1]Department of Groundwater Resources, Bangkok, Thailand E-mail: tussanee.n@dgr.mail.go.th, chadaporn.b@dgr.mail.go.th

Abstract

Volatile organic compounds (VOCs) and nickel concentration were detected higher than standards in groundwater monitoring wells and domestic wells located nearby the landfill area of an industrial waste recycling company in 2014. The groundwater quality monitoring results from 2015-2019 also indicated that there has been the presence of cis-1,2-dichloroethylene, trichloroethylene, benzene, vinyl chloride, manganese, and nickel in the area. The project aims to identify the presence and characteristics of contaminants in the sub-surface, propose the potential remediation plans, and provide guidance for the community and environmental agencies in terms of groundwater management in contaminated areas.

The hydrogeology of the area includes unconfined and confined aquifers. The unconfined aquifer consists of clay, sandy clay, silty sand, and weathered rock with 3-8 meters thick. Depth to groundwater is approximately 1-6 meters. The confined aquifer is occupied in bedrock consisting of massive limestone, meta-sandstone, mudstone, and quartzite which is 20-80 meters below the surface. Groundwater flow appears to follow the topography from the high plain in the northwestern side of the area to the river plain in the southeast. The field investigation comprised the geophysical survey using a resistivity method, a direct push drilling technology which is the Membrane Interface Probe and Hydraulic Profiling Tool (MiHPT),

Results of the MiHPT investigation indicated that significant VOCs contamination exists in the landfill area and the private property which is located within 1 kilometer from the landfill. The analytical results of groundwater reported that vinyl chloride and benzene were detected in shallow wells located in the southeast of the landfill area. A mathematical model performed using the Visual MODFLOW Flex program is then used to confirm the flow direction, define the distribution of the contaminate plume, and identify the possible hotspot of pollutants where the contaminants were leaked from surface to groundwater system.The potential remediation methods from the analytical data are to construct the permeable reactive barrier with zero- valent iron or activated carbon. Further investigation and continued monitoring are required in order to design remediation measures.

Keyword: Contaminated groundwater, Membrane Interface Probe, Mathematical Model

TC-338L

HYDRAULIC TOMOGRAPHY USING FIBER BRAGG GRATING MULTILEVEL WELL

Jui-Pin Tsai* YenTe Ho

Understanding the spatiotemporal distributions of groundwater pressure and temperature is essential to evaluating groundwater resources, flow, shallow geothermal resources, etc. A conventional groundwater monitoring well measures aquifer status (i.e., groundwater pressure, temperature, pH, electrical conductivity, etc.) by opening a screening interval on the casing at a specific depth in a single borehole. The sensors (e.g., piezometer and thermometer) can measure the aquifer status at a depth of the well screen. The measurements of aquifer status from these conventional wells represent an average value within the screen interval. The method of constructing this type of monitoring well is well-developed and broadly used in subsurface environmental investigations, such as groundwater resource monitoring, contaminated site remediation, seawater intrusion, etc. Developing a well monitoring system for some complicated groundwater systems to observe the depth-discrete aquifer status and collect water samples is essential. Moreover, a depth-discrete monitoring system allows monitoring the fracture flow in bedrock for single or multiple fracture systems at the depths of interest, including sampling, level measurements, and hydraulic tests. Accordingly, a depth-discrete monitoring system provides a more complete and detailed groundwater delineation than the traditional full-screened well system. There are two conventional approaches to monitoring the depth-discrete aquifer status: (1) a monitoring well cluster, which consists of several traditional monitoring wells spaced alongside; the screens of these wells must be placed at the depth interval corresponding to their target aquifers; (2) a nested well, which assembles multiple well casings in a single borehole; the screen of each well casing is placed at its target aquifer. Also, the vertical hydraulic connection between any of the two well casings is interrupted by a grout seal. These two types of well groups can successfully observe the depth-discrete aquifer status of the multi-aquifer system. However, constructing a well cluster is costly and time-consuming. Developing a nested well risks failure in interrupting the vertical hydraulic connection as the number of monitoring zones increases. Accordingly, a more economical and efficient monitoring method, the multilevel monitoring system (MLMS), has been developed to satisfy the requirement of monitoring the multi-depth discrete aquifer status for complicated aquifer systems. Currently, optical fiber sensing technology is mature and has been used to develop a variety of environmental sensors. Compared to the electronic sensors, optical fiber sensors have several attractive advantages, such as small size, a lower weight, the possibility of spectral measurements, high acid and alkali resistance, a waterproof nature, immunity to electromagnetic interference, a common voltage requirement, no explosion risk, a serial multiplexing capability, and minimal signal loss over a long distance. So far, three types of optical fiber technologies have been used for environmental sensor development. The first type is the optical fiber sensors developed based on Fabry-Pérot Interferometry (FP). Several studies employed FP sensors to establish a piezometer. However, the FP piezometer's primary drawback is that the measurement accuracy is sensitive to the temperature and stability of the light source. Accordingly, a good temperature compensation method and a stable light source for FP sensors are necessary for stable and long-term measurement. The second optical fiber technique is Bragg grating (FBG) technology. FBG sensors have been used in various fields, such as landslide monitoring, ground settlement monitoring, instant pollutant detection, etc. Moreover, several studies have employed FBG piezometers to measure groundwater pressure under various environments, such as marine sediment, soil slope, alluvial fan areas with subsidence, etc. For accurate field pressure measurement, the FBG pressure sensors are usually developed by packaging method (e.g., packaging and FBG in polymer or by elastic elements method or metal diaphragms. Moreover, these FBG pressure sensors require temperature compensation to improve measurement accuracy since they are sensitive to temperature and strain. In this study, we employed the metal diaphragms method to develop our FBG pressure sensor. The third technique is optical fiber-based technology such as distributed temperature sensing (DTS) and distributed acoustic sensing (DAS). The DTS interrogator is at least four times more expensive than the FBG unit, while the DAS interrogator is even more expensive than the DTS unit. Accordingly, an FBG MLMS developed by our team is used for hydraulic tomography. Conducting hydraulic tomography (HT) needs to collect the groundwater levels during the sequential pumping tests. Afterward, K and Ss fields are estimated by geostatistic inverse technique, successfully linear estimator (SLE, Yeh et al., 1996), through assimilating the observed groundwater levels. These hydraulic parameters describe the characteristics of aquifer heterogeneity. This study employed the new FBG MLMS to conduct HT at a contaminated site during several sequential remediation injection events. Since the water injection for conducting HT is replaced by the remediation agent injection, distributing plume in the aquifer is no longer an issue for conducting HT in a contaminated site. We also compare the images from the time-lapse cross-hole electrical resistivity tomography (time-lapse CHERT) to the derived K field to examine the capability of the new FBG MLMS. The results show that the newly designed multi-function and multi-depth fiber Bragg grating (FBG) sensing system is a viable tool to monitor depth-discrete groundwater pressure and temperature at different wells simultaneously and benefit HT. The groundwater pressures and temperature in response to the four injections are successfully monitored from the FBG system at discrete depths in the 2-inches wells. Afterward, these multi-depth aquifer responses are utilized to delineate the K and Ss fields through SLE. The ratio of electrical resistivity change from CHERT before and after the injections validates the reliability of estimated hydraulic parameter fields. The temperature measurements also support the derived K field. These analysis results support that the multi-depths FBG sensing system is a particle for conducting HT. Besides, this new system collects much more data than the traditional well with a single screen interval. In other words, these results demonstrate that the integration of HT and MLMS to delineate the hydraulic heterogeneity in the remediation site is a particle method, thus reducing the well construction cost and enhancing the data collection efficiency, and providing a more economical approach conduct HT.

Keywords: Mulitilevel well, fiber Bragg grating, hydraulic tomography

Department of Bioenvironmental Systems Engineering, National Taiwan University, Taiwan. jptsai@ntu.edu.tw

TC-340L

Water use efficiency improvement at local level via training process -Case study in the Thor Tong Daeng (TTD) Irrigation Project area, Kamphaengphet Province Thailand-

Chitsanuwat Maneesrikum
Creative Intelligence Co Ltd.
tanate091@hotmail.com

Teetitorn Chullapram
Chula Unisearch, Chulalongkorn University
teetitorn@gmail.com

Introduction

Thailand has long been developing large water reservoirs and irrigation systems consisting of a lot of medium and small. But when analyzing the utilization from the development and use of existing resources, it is found that operations are clearly segregated in terms of water management including local level, land use, farming, production, and marketing resulting in inefficiency in view of integrated management. In rainfed areas, it is based on individual management. Agricultural productivity is also relatively low in contrast to the higher demand for water in cultivation. Land use patterns have also changed. All these factors tend to lead to the problem of poverty and inequality of farmers.

In recent years, both problems of water shortage in the dry season and floods in the rainy season have been experiencing more frequent and more severe due to increasing climate vulnerability.

Thus, the sustainability transitions (Derk Loorbach, et al.,2017) are crucial for agriculture communities adaptation that includes the hard-side factor, soft-side factor, and people-side factor (UNRISD, 2016). There were studies on good practices (J.B. Foundation, 2010: Water Aids in Nepal (2011)), guidelines (Institution of Civil Engineers (2011), and research works (Ellie Chowns (2017): Henry Bikwibili Tantoh, et. al (2019)) to strengthen community water management for more water security and water management improvement at local level.

Research objectives

The research, under the TSRI-NRCT Spearhead Research Program (Sucharit K., 2020), aims to improve water management efficiency at local level; to reduce the disparity in access to water resources of people in the community within the Thor Tong Daeng (TTD) Irrigation Project area, Kamphaengphet Province, Thailand, that the local agriculture communities have long been traditionally adopted the conjunctive use of water for their crop production (Thailand Climate Change Adaptation Information Platform (T-PLAT)); and to summarize key characteristics of good water management practices at local level achieving through the process of participatory and training approach (PAR/CBR) for future applications of capacity assessment of water community organisation (Chitsanuwat M., 2020).

Research methodology

Community-based action research (CBR) is a core method of research operation by organizing a small group meeting, an in-depth interview, collecting community data using online tools. The key focuses are to encourage community leaders (Water Community Organization) on the participatory and integration and to find ways to increase the efficiency of water management at local level in the area among water users, farmers, and government staffs.

The emphasis is placed on the study in 3 key steps as follows: (1) to study of content patterns and training processes/co-operation mechanisms among the leaders of the irrigation water management group; basic water users groups, farmers, irrigation officials ,local government officials and related agencies in the area through the research process for localities, (2) to study the results, outputs and impacts of water management in the project in order to optimize water management at local level in the area of the Thor Tong Daeng (TTD) and leads to (3) to synthesise process patterns/mechanisms/methods used to summarize key characteristics that enhanced and expanded the learned knowledge and practices and improved water management efficiency at the local level through the local participatory research process in the area of the Thor Tong Daeng (TTD) Irrigation Project with follow up capacity assessment of water community organization (see Figure 1).

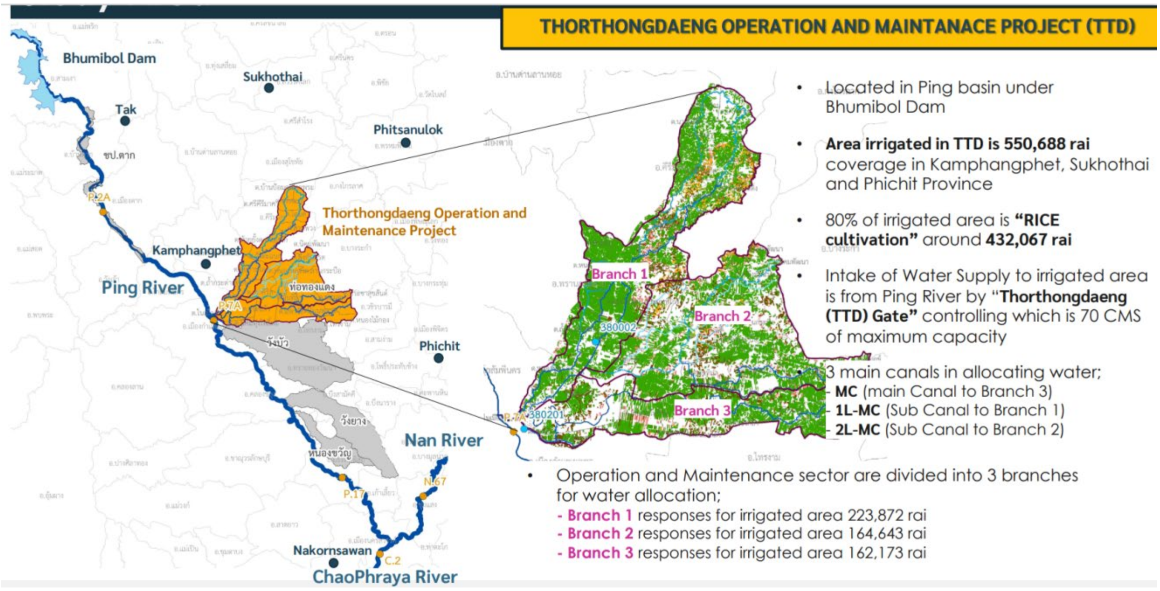


Fig.1 Study area and location

Method used

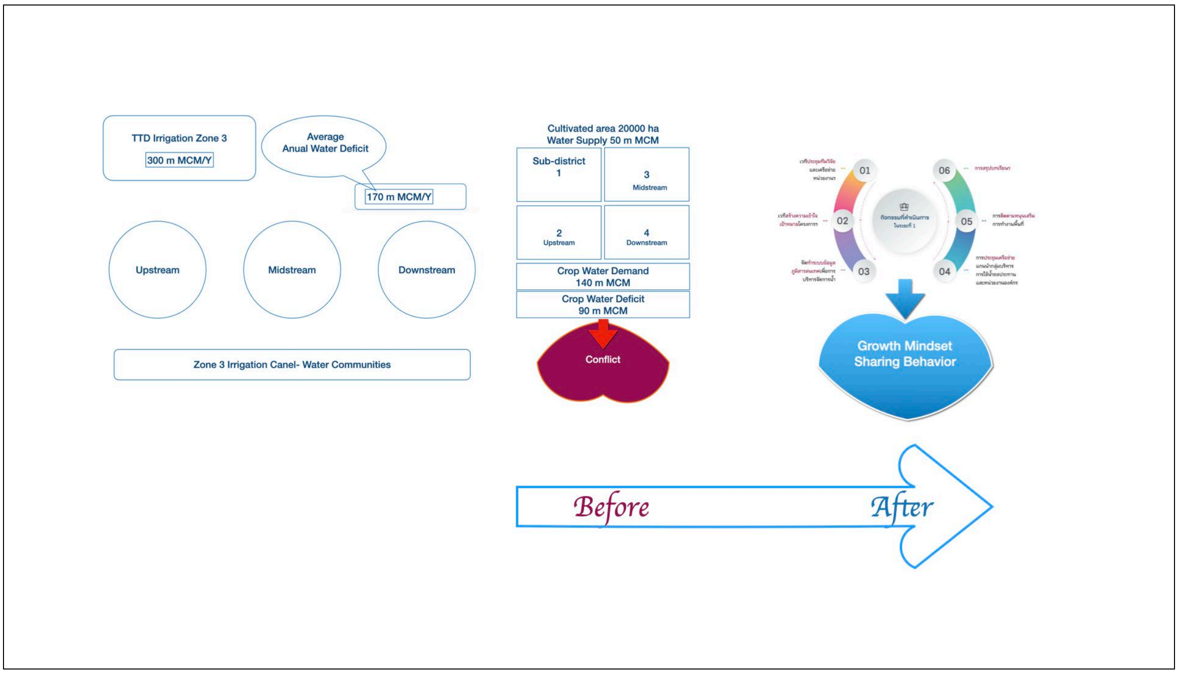
Aiming at the local level that includes leaders of water user groups, irrigation officials, and communities, the implementation process focuses on building engagement through local level action research; building a good relationship; collecting data (such as community funds, waterway maps, crop calendar and crop cultivation timeline, etc.); developing the training process to create (1) group power, and joint vision, (2) local coach on water community organization management process and practices and (3) powerful data analysis and synthesis for the preparation of water community organization plans; and creating processes, formats /mechanisms for promoting the cooperation among the expanded local level covering leaders of the irrigation water management group, water users, basic groups, farmers, irrigation officials, local government officials, and related agencies in the study area.

Research results

From the implementation in the pilot sub-district in 3 zones, it was found that the total water demand was 299,511,096 cubic meters/year, but the irrigation water supply in the area was only 129,677,342 cubic meters/year, resulting in the water deficits up to 169,833,754 cubic meters/year. This had caused the necessity for representatives of the water users in each sub-district to communicate with each other. Thus, the problem situation has induced an opportunity to create a neutral and safe arena for each sub-district in the same irrigation canal to exchange information on problem situations including constraining factors and conditions affecting the water management of the area until they all are becoming a network of irrigation water users who reach mutual understanding and become aware of the importance of irrigation water sharing among upstream, midstream and downstream with joint benefits. Particularly in the area of zone 3 (Sorbor. 3) of 4 sub-districts, consisting of NikhomThung Pho Thale Subdistrict, Sa Kaeo Subdistrict, Nong Mai Kong Subdistrict, and Mahachai Subdistrict with a total cultivation area of 126,290 rai (about 20200 ha.) covered upstream to the downstream area, the total irrigation water supply is 50,506,964 cubic meters/year but the water demand is as high as 140,801,874 cubic meters/year, resulting in deficits as high as 90,294,907 cubic meters/year and in Mahachai Subdistrict and Nong Mai Kong Subdistrict which both are in the downstream area with a total cultivation area of more than 57,902 rai (about 9200 ha).
This required a good collaboration on the planning in the water management at local level and led to a common water management action plan in 3 important elements:

1) Developing a group of people or communities (people-side factor) that focused on group management both in the water users in the sub-district and the canal network group. All 4 sub-districts had a water users group meeting once a month to exchange information on the water situation of the area and every 2 months there was a water users network forum that allowed each sub-district to explain the water situation of the area as well as problems encountered from irrigation water management. This participatory process enabled sympathy in each canal network management
2) Defining processes, rules, regulations (soft-side factor) that created the working atmosphere with a good degree of acceptance for having a joint implementation together. This was not only at the sub-district level, but linking to create a network of the integration of water users in each zone (Sor Bor.) having joint activities throughout the upstream, midstream to the downstream end of the canal.
3) Infrastructure development (hard-side factor) including development of water resources especially small water reservoirs in the area to support drought-flood situations under climate vulnerability, including the underground water artificial recharge, constructing water trap wells to increase in water seepage, digging a pool, constructing regulating reservoirs (small-sized monkey cheek), making troughs, installing rain gauges and installing solar panels to reduce the cost of using groundwater pumping. All of these activities increased career opportunities for people in the community throughout the year from the agriculture and land utilization planning in accordance with the situation of water supply deficits and climate vulnerability. The realization and a good understanding of the cause and effect factors had caused an altering into the cultivation of plants that required less water and a farming model that reduced water use in the lead farmers who participated in the activity

The common water management action plan of all 4 sub-districts in zone 3 (Sorbor. 3) helped reduce the conflicts among irrigation water users within the area and in different areas (different sub-districts). And it raised a better understanding of the problem situation and the mutual awareness arising from communication to exchange the information. The team of staff and officials from the Thor Tong Daeng (TTD) Kamphaengphet Province had gone down to discuss the irrigation plan and explain the situation periodically for the agricultural water users to gain sufficient knowledge in doing crop planning and crop cultivation. In addition, under the circumstances of the irrigation water deficits, this had caused people in the sub-district to adjust the crop planning of the agricultural production, for example, in NikhomThung Pho Thale Sub-district in which there had been a reduction in the area of lemon cultivation for the people in the sub-district. They shifted to focus on the production of the crop that produced more value. While Nong Mai Kong Subdistrict, Sa Kaeo Subdistrict, and Mahachai Subdistrict, there had been a change in plant species in cultivation, not focusing on farming alone as in the past. They also made a change to grow crops that used less water, such as lemongrass, pumpkin, squash-fang, as well as medicinal plants. That helped generate more income for the people in the community and led to the water users grouping to raise the level of occupation that is consistent and related to irrigation water management at the local level in the area.



Capacity Assessment of the Water Community Organisation

The research synthesized and developed good water management practices at local level and found that there are 10 characteristics in three aspects for strong engagement from stakeholders and better water management at local level, i.e.,

Social, economic and environmental aspect

1) Opening areas for participation of all sectors
2) Taking the “community” as the basis for managing the problem
3) Community costs and community structure systems that are conducive to operations
4) Creating a “joint ownership” in water management throughout the ecosystem
5) “Authorities and Local Administrative Organizations”

Engineering and technology aspect

6) Combining knowledge in applying modern technology to match the way of the local community
7) The use of information systems to help for analyzing and presenting information until it leads to planning and decision making.

Management aspect

8) The presence of staff in the agency to support water users closely and continuously in the role of "coach“
9) There is a three-tiered information system at community level, agency level and research results level
10) There is a course to develop the capacity of community leaders and staff in water management

Based on these characteristics, the capacity assessments were conducted in each water use area to compare engagement level by number of characteristics (yes or no) before and after training process. The results showed that the training process helped improve the water management level at local level from low to intermediate or high in each area as shown in Table 1.

Table 1 Assessment of community participatory water management at local level by number of characteristic measured (before-after training process)

Target Area (Tambon)	Number of characteristic passed (Before)			Number of characteristic passed (After)		
	Low (1-4)	Intermediate (5-7)	High (8-10)	Low (1-4)	Intermediate (5-7)	High (8-10)
1.Khui Ban Ong Tambon, Phran Rabbit Amphur	✓	-	-	-	✓	-
2.Tham Kratai Thong Tambon, Phran Rabbit Amphur	✓	-	-	-	-	✓
3.Nong LuangTambon, Lan KrabueAmphur	✓	-	-	-	✓	-
4.Chong Lom Tambon, Lan KrabueAmphur	✓	-	-	-	✓	-
5.Bueng Thap Rat Tambon, Lan KrabueAmphur	✓	-	-	-	✓	-
6.Noan PhluangTambon, Lan KrabueAmphur	✓	-	-	-	✓	-
7.Sa KaeoTambon, Mueang Kamphaeng PhetAmphur	✓	-	-	-	-	✓
8.Nikom ThoongPhotalaeTambon, Mueang Kamphaeng PhetAmphur	✓	-	-	-	-	✓
9.Mahachai Tambon, Sai NgamAmphur	✓	-	-	-	✓	-
10.Nong MaikongTambon, Sai NgamAmphur	✓	-	-	-	-	✓
	10	**0**	**0**	**0**	**6**	**4**

Conclusions

From the research work, water distribution in the irrigation area from the upstream, midstream and downstream area created a new way of water sharing and became fairer and widespread especially the 4 sub-districts in zone 3 (Sor Bor. 3), consisting of Nikhom Thung Pho Thale Sub-district, Sa Kaeo Sub-district, Nong Mai Kong Sub-district, and Mahachai Subdistrict which covered the area of 126,280 rai (approx. 20,000 ha). The level of achievement assessed by number of characteristics proposed were improved via training process which reflected the result of the participation and networking of all sectors at the local level through developing people; developing information systems; developing processes, rules, and regulations; as well as developing additional water resources. All of these required good cooperation among stakeholders from all sectors including government officials, private agencies in the areas, groups of water users, and a network of affected canal users. The water user group or JMC (Joint Management Committee for Irrigation) has participated in the systematic planning throughout the value chain covering water use, agricultural production, productization, product distribution, and commercialization and marketing with the objective to maintain ecological balance. The participatory research process has developed community water management practices with 10 characteristics which shown good results of the new training approach in water management at local level in the irrigation area achieving a viable and more sustainable solution under the irrigation water deficits situation of the affected local communities.

Acknowledgement
The authors would like to express sincere thanks to Royal Irrigation Department, Groundwater Resources Department and agricultural staffs in Kamphaengphet Province for their collaborative participation in this action research. Thanks to TSRI-NRCT for their research funding and Chulalongkorn University for research facility supports.

References

(1) Jal Bhagirathi Foundation (2010). Good Practices in Water Security, UNDP India.
(2) The Institution of Civil Engineers (2011). Managing water locally: An essential dimension of community water development, Oxfam GB and WaterAid.
(3) Nepal in WaterAid (2011). Training manual on Water resource management: Integrated planning and management at community level, September.
(4) UNRISD (2016). Understanding Transformation for Sustainable Development. Flagship Report Chapter 1, 28 pp. (www.unrisd.org).
(5) Derk Loorbach, et al., (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annual Review of Environment and Resources 42(1) DOI:10.1146/annurev-environ-102014-021340. Nov.
(6) Ellie Chowns (2017). Is Community Management an Efficient and Effective Model of Public Service Delivery? Lessons from the Rural Water Supply Sector in Malawi. Public Administration and Development Public Admin. Dev. 35, 263–276 (2015). Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/pad.1737.
(7) Henry Bikwibili Tantoh, Danny Mulala Simatele, Eromose Ebhuoma, Kwabena Donkor, Tracey J. M. McKay (2019). Towards a pro-community-based water resource management system in Northwest Cameroon: practical evidence and lessons of best practices, GeoJournalhttps://doi.org/10.1007/s10708-019-10085-3(0123456789(), Vol 01234567, Nov.
(8) Chitsanuwat Maneesrikum, et al.,(2020). Water Use Efficiency Improvement in local level within Tor Tong Daeng Irrigation Project area, Final Research Report submitted to TSRI-NRCT, September (in Thai).
(9) Sucharit Koontanakulvong (2020). Summary of TSRI-NRCT Spearhead Research Program Year 1. Research Brief Document. Chulalongkorn University, December (in Thai).

TC-341S

Indicators of Water User Association for Sustainability Transition:
A Preliminary Model[1]

Jitraporn Somyanontanakul
College of Politics and Governance, Mahasarakham Universityjitraporn.s@msu.ac.th

Surangrut Jumnianpol, Ph.D.
Chulalongkorn University Social Research Institutesurangrut.j@chula.ac.th

Sirinon Suwanmolee, Ph.D.
Department of Environmental Engineering and Disaster Management,
Mahidol University, Kanjanaburi Campussirinon.suw@mahidol.ac.th

Abstract
In this paper, the researchers review criteria and indicators of water user associations to provide a preliminary model of water users who can manage water following the concept of sustainability transitions. The definitions of Water User Association (WUA) and the concept of sustainability transitions are starting points to design the desirable characteristics of WUA. Methods used in the paper are documentary research and in-depth interviews with key informants from twelve case studies. The paper will then propose indicators for assessing a water user group’s organization and performance with relation to water management. The authors expect that, apart from identifying shortcomings of a water user group in question, we will also specify capacity-building needed to uplift the water user group’s performance. Therefore, the indicators would increase the water user group's capacity for managing water in sustainable ways.

***Keywords*--** Water User Association, Indicator, Sustainability Transition

I. Introduction

From the Water Resources Act, B.E. 2018[2] and the Ministry of Water User Organization Rules B.E. 2021, water user organizations become one of the key mechanisms for improving water management. The movement in Thailand is in line with the development of water management at the international levels which all strive to create measures, criteria, and mechanisms of water governance to create the transition towards sustainability. However, when considering the details of water user organizations in Thailand, there is a lot of missing detail, particularly, the detail about the characteristics and elements of water user organizations which will create the potential for the water users to take part in sustainable water management. That is, they can play a critical role in creating water management that is consistent with the ecological and eco-cultural characteristics of each area and/or watershed. In fact, people basically form a group to manage water at different levels before the Water Resources Act. There were five types of water user groups in managing water for the irrigation project (19). For example, *the Muang Fai* group is the traditional water user group managed in the Northern region of Thailand.
In this paper, we define a Water User Association (WUA) or a water group as the grassroots player engaging in water management. The paper seeks to assess the active Water User Association or an active water user group with its aims to enhance the capacity of local water communities to be able to manage water sustainably in relation to ecological and eco-cultural diversity. Therefore, our key assumption is that the success of WUA in water management sustainability

[1] This paper is the part of the ongoing research project entitled 'Capacity Building for Sustainable Water Management at Local Level: A Case Study of Participatory Assessment of Community Water Management' funded by the Water Management Program, under the Social Spearhead of National Research Council Office,2021
[2] The Ministerial Regulation under National Water Resource Act B.E.2018 authorized WUAs as local agenciesfunctioning in protection the member benefit, recommendation to Water Basin Committee about water management in the area including the nomination of the representative to be the Water Basin Committee.

consists of 3 'Es': Efficiency, Equity, and Environmental consideration. The concept of Water Governance and Sustainability Transitions are used to outline the indicators. The authors also reviewed other international concepts of water management such as IWRM, as well as international and national practices and experience to create the preliminary version of the indicators. There are four parts to the paper. After this introduction, the second part is the conceptual framework constructed from water governance and sustainable transition. The third part will show the preliminary version of our indicators. We will conclude the paper with our observations.

II. Conceptual Framework: *Defining Sustainability Transition for Water Management*

The Dublin Principles states that water is an economic resource (as an economic good). This concept then become the basis for developing Integrated Water Resources Management (IWRM) principles. These principles focus efficiency and effectiveness of water management on increasing productivity in the agricultural system. However, many scholars criticize the IWRM, especially for its neglect of social and cultural characteristics and a political process of water resource allocation. The water community, which is those involved in the development of water management, began to see that water management cannot be a ready-made tool to bring sustainability to water management. It was also noted that the way of thinking or understanding of water-related matters is complex, and many socio-cultural and political factors influence the success of the process (6)(9).

This requires a comprehensive analysis framework flexible with more aspects of human well-being (1)(4)(7)(13).

With regards to the term Sustainability Transitions, it means the process of structural transformation in the (sub)systems of society (5) (15). The sustainability transitions occur when the dominant structure in society is pressured by external changes and innovations occurring within the society (11). For sustainability transitions, three factors are necessary: the emergence of system innovation, the emergence of social technology, socio-technical transitions, and the emergence of sustainable technologies (12).

Hence when thinking about how to shift unsustainable water management into a more sustainable way, we propose to look at the community/local level. As in the sustainability transitions, creating and developing water management innovations at these levels is the key to sustainability. It also encourages multi-level stakeholders to engage in a water policy process with its aims to create effective, equitable, and sustainable water management at different levels.

III. Outlining the Indicator

From the two concepts, we define a WUA for sustainability transitions as an organization to manage water effectively within the community/local area. It also must promote and develop a water management process in which local people can engage in the organization and the policy process, horizontally (between water user organizations) and vertically (at a higher level, such as the Watershed Committee). Then, it is our ambition to cover water user groups or organizations both inside and outside the irrigation areas under the '3Es' principles: Efficiency, Equity, and Environmental considerations. In this respect, water user organizations/ water groups are also involved in creating local action. It is also based on the idea that such management will increase equity, effectiveness, and sustainability (14). This concept is in line with the World Bank's focus on promoting local participation as a critical engine or intermediary in creating sustainable livelihoods, promoting good governance, and alleviating poverty. Initially, the authors broadly classify the indicators as the performance of the water user associations (WUA) on sustainability transitions into three stages under a policy process in each stage; it composed of the indicators as follows

1) Input section. Indicators include the nature and structure of the water user organization, including a sub-metric about the number and proportion of members of a group; past group/organization action plans, rules, and regulations; community data preparation and infrastructure.

2) Process section. Indicators include the operational processes of the water user organization; the level of participation; usage of diverse knowledge/technology and innovation; self-monitoring and assessment process; use of information and sharing of information between members and network partners.
3) Output/Outcome section. Indicators include the achievement of efficient use of water; capacity building and sharing between network partners

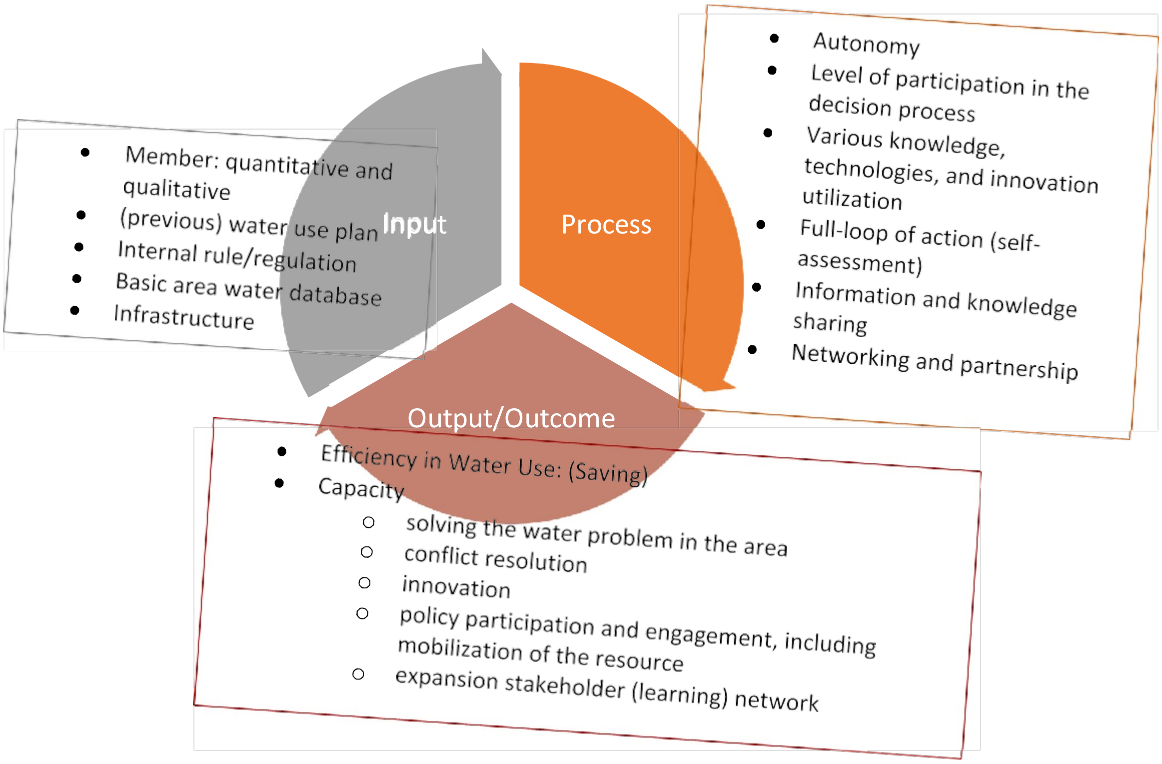


Figure 1: Outline of the indicators

We give 1, 2, or 3 for each indicator: 1 is the lowest point and 3 is the highest point. Then, we will calculate the overall performance of a water group.

Table 1: Preliminary Indicators for WUA for Sustainability Transition

Indicator	Indicator Name	Description	Level
Input			
Member			
	1. Number of members	The Water Act indicated that at least 30 members formed to be a water user association	1- minimum 30 members 2- 31-50 members 3- 51 members above
	2. Proportion of marginalized member	the inclusion of the marginalized group as to guarantee the equality of water management	1- none 2- few marginalized members 3- 1/3 of members are marginalized
	3. Proportion of members in a management position	The marginalized group included in the management position, e.g., female, the poor,	1-restrict to a traditional power/elite group, e.g., sub-district/village chief, local politicians

		younger generation	2- the traditional group of the elite plus with at least one of the marginalized
			3- inclusive group
	4. informed member	informed member considering their related knowledge and access to the knowledge	1-lack of knowledge and inability to access the knowledge
			2- have some basic knowledge but still lacking access to more knowledge
			3- have some basic knowledge and ability to access more knowledge

Indicator	Indicator Name	Description	Level
(previous) plan	5. water use plan	the water user groups write their plan and present it to the local governments or relevant authorities	1-no water use plan
			2- have an earlier plan but not up to date
			3- have an up-to-date plan
	6. Infrastructure plan	including the maintenance and rebuilding plan; logistic (dredging) organizational plan; and capacity development	1-no plan
			2- have an earlier plan but not up to date
			3- have an up-to-date plan
Rule and Regulation	7. (internal) rule and regulation	adaptable to integrate themselves into the shared values or common laws (16)	1- no draft or agreement of water usage among the member
			2- using the traditional (or customary) rule/regulations as an agreement among member
			3- integrating traditional (customary) regulation with the rule of the Royal Irrigation Department or other modern/ official regulations
Data and Information	8. Water supply database	The data was ready to use for water management, i.e., surface water, groundwater, underground water	1-none
			2-had old data (but not updated)
			3-having and always updated
	9. water balance database	Loss is calculated (water discharged from the system without being used). There is also agriculture that uses much water. A lemon orchard pumps water up to collect and then releases it like a village	1-no database
			2- have an earlier database but not up to date

		water supply (2). Kamphangphet has other areas that are not in the irrigation system. It uses themethod of drilling shallow wells. which also absorbs into the water system	3- have an up-to-date database
	10. water (route) map	GIS Spatial data or handwriting plot of water-map/water diagram	1-no map
			2- have an earlier map but not up to date
			3- have an up-to-date map
	11. cultivation map	The data displays what each family grows and the size of the plantation from the agricultural council, from thesubdistrict administrative organization	1-no map
			2- have an earlier map but not up to date
			3- have an up-to-date map
	12. calculation of waterfor cultivation	using the data from the crop map to calculate, including the handwriting data. Also, developing applications of the information system at the community level which	1-no data
			2- have earlier data but not up to date
			3- have an up-to-date data

Indicator	**Indicator Name**	**Description**	**Level**
		government agencies accept	
Infrastructure	13. well and enough infrastructure	Although the water user groups could not build their infrastructure, some may be responsible for infrastructure maintenance.	1- none or not distributed thoroughly
			2- have the infrastructure but not distributed thoroughly and not well maintenance
			3- have the infrastructure distributedthoroughly with regular maintenance
	14. sense of ownership	a sense of ownership	1- no sense of ownership
			2- some sense of ownership
			3- a full sense of ownership
Process			
Level of Participation in operation	1. Autonomy	degree of self-determinationand freedom	1- strictly follow the government orders
			2- be able to negotiate with the government agency and other organizations at some points/ degree
			3- fully engaging in a policy-making process and a decision-making process
	2. chairman/ group	the process for leader	1- being designed by the government agency

	leader selection	selection could identify thelevel and quality of participation in the group	2- Voting only
			3- full deliberation with voting
	3. decision-making process in the preparation of water useplan	levels of the participatory process.	1- no joint decision; follow the predetermined plan which is instructed by the authorities.
			2- collective decision-making effort
			3- full consultation and mutual decision-making in a policy process
Various knowledge, technologies, and innovation use	4. use of knowledge and database	It includes both modern andindigenous knowledge and database	1- none or but has never been used
			2- co-exist but not up-to-date or usedbut not very applicable.
			3- co-exist and applicable
	5. use of technology in water assessment and decision-making process	Indigenous technology such asthe construction of a sluice gate, Water diversion area, water retention, and digging the well by themselves (8)	1- no technology used
			2- have the technology, information technology, hydraulics used at some level
			3- have fully used the technology, information, hydraulics in thedecision-making process.
	6. use ofeconomic tools	Water fee is a kind of tool to raise the sense of ownership and responsibility (18).	1- no water fee
			2- collect water fee, but not a clear implementation plan
			3- collect water usage fees with a clear plan for maintenance and operation management of the irrigation system

Indicator	**Indicator Name**	**Description**	**Level**
A full loop of action	7. follow-up and self-assessment process	metrics for success have beenset, i.e., there is a significant increase in water efficiency	1- no follow-up plan
			2- have a follow-up evaluation but unplan
			3- planned and up to date monitoring and evaluation
Information and knowledge sharing among member	8. disclosure of information	transparency of the workinggroup	1-never disclosed or exchanged information
			2 disclosed but exchanged information only with some leaders or certain groups
			3- disclosed and exchanged information to different groups
	9. knowledge management with vulnerable members	knowledge improvement activities and public relations with vulnerable	1- no activities with vulnerable groups
			2- have activities with vulnerable groups from time to time

		members	3- have scheduled/ planned activities withvulnerable groups
	10. network and partnership	networking and partnership with other organizations, suchas the Royal Government Irrigation Office (10)	1- no relationship
			2- create a formal and vertical relationship with the authorities
			3- create a network/partnerwith multi-level sectors horizontally and vertically
Output/Outcome			
Effectiveness	1. water-saving and effective water use	Change plants that use less water or plant high-value crops with using the same amount of water	1- No measurement and improvement of water use
			2- measure water use but not regular and inconsistent with water usage improvement
			3- measure and improve water use regularly
Capacity	2. Solving problems at the community level	awareness and initiative to solve the community problem	1- no attempt to solve any problems
			2- address problems and ask others to solve problems
			3- manage problems themselves
	3. conflict resolution	fair water distribution from Upstream to Downstream, and the conflict resolution organ could become a Joint Management Committee forIrrigation-JMC	1- no mechanism for resolving disputes between areas/groups
			2-have a mechanism established and conflict mediatorsidentified clearly but not functioning
			3- have a mechanism established, conflict mediatorsidentified clearly, and have ability to settle conflicts

Indicator	Indicator Name	Description	Level
	4. creating community innovations and transferring to other groups	Create and share knowledge of watergate, ladder rice field, irrigation liner, any technique as lessons to other groups	1- None
			2- existing, but with limited/specific groups/ areas
			3- existing, and applicable to multi-level and multi-scale groups
	5. participation in policydecisions at the local level	willingness of the WUA and the acceptance of local authority for participating inpolicy decision making	1- not participate in the decision-making process
			2- occasionally participate in the decision-making process
			3- regularly participate in the decision-making process

	6. participation in policydecisions at a higher level	the willingness of the WUA and the acceptance of higherauthority for participating in policy decision making, e.g., the basin committee	1- not participate in the decision-making process
			2- occasionally participate inthe decision-making process
			3- regularly participate in the decision-making process
	7. policy engagement	water user groups' voice and requirements can approach the policy advocacies	1- None
			2- the local authority accepted and implemented the proposalat the local level
			3- higher-level authorities accepted and implemented the proposal
Partnership	8. sharing information/knowledge amongpartners	partnership and sharing the information/knowledge is theway for strengthening its capacity	1- no network
			2- share information/knowledge but with a limited network and areas
			3- share information/knowledge with broader network cross-sectors/areas

IV. Observation and Conclusion

Designing indicators for WUA is not new; there are attempts to develop many times and, in many countries[3]. Yet, the authors still seek for developing these indicators with our ambition to create indicators by applying a sustainable development approach consistent with the Thailand context. In this light, WUA is a local change agent for sustainability transitions.
In this paper, the authors review criteria, and indicators of water user associations to provide a preliminary model of water users who can manage water following the concept of sustainability transitions. The definitions of Water User Association (WUA) and the concept of sustainability transitions are starting points to design the desirable characteristics of WUA. The paper will then propose indicators for assessing a water user group's organization and performance with relation to water management.
However, we realize that outlining the indicators in the ivory tower has its limitations. The substance of the Thai Water Resource Act is also different from other countries, especially in the sense that water resource in Thailand is state ownership. Hence, stakeholders' first-hand experience is a must for us to look for both best and worst practices before revising our indicators. We expect that in the end, our indicators could identify the shortcomings ofa water user group in question and uplift the capacity needed for advancing the performance of the water user group. Finally, they can increase the water user group's capacity for managing water in sustainable ways.

Reference

(1) Akamani, K. (2016). Adaptive water governance: Integrating the human dimensions into water resource governance. Journal of Contemporary Water Research & Education, 158(1), 2–18.

(2) Benedikter, S., Waibel, G. (2013). The formation of water user groups in a nexus of central directives and local administration in the Mekong Delta, Vietnam. ZEF Working Paper Series

[3] For example, Wang et al. developed the indicator to assess WUA in China in terms of economic performance (Wang,Huang, Haung, & Rozelle, 2016)

No. 112, May 2013.

(3) Duhari, M. A. (2020). Irrigation management and Irrigation management transfer policy: Lessons from Mexico, Philipines, and Indonesia. In Paper Knowledge. Toward a Media History of Documents. Institute of Technology Bandung.

(4) Floress, K., Akamani, K., Halvorsen, K. E., Kozich, A. T., & Davenport, M. (2015). The role of social science in successfully implementing watershed management strategies. Journal of Contemporary Water Research & Education, 154(1), 85–105.

(5) Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8-9), 1257-1274.

(6) Ghosh, S., Kumar, A., Nanda, P., & Anand, P. S. B. (2010). Group dynamics effectiveness of water user associations under different irrigation systems in an eastern Indian state. Irrigation and Drainage, 59(5), 559–574.

(7) Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., & Yalcin, R. (2009). Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda. Ecology and Society, 14(1).

(8) Kanda, S., Naret, H., Dacumos, R., Furuzono, K., Satoh, A., Nda, T. C., Ueno, J., Prak, S. da, & Seakchhy, M. (2015). Participatory Irrigation Management in Cambodia: The Case of a Farmer Water User Community in Kampong Speu Province.

(9) Kumar, S. (2015). Water Resource Management through Collective Action: A Study in the Context of Water User Group Among the Tribes of Eastern India.

(10) Ky, S. (2015). Challenges of Farmer Water User Communities in Participatory Irrigation Management and Development in Pursat Province, Cambodia. 43.

(11) Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. Governance, 23(1), 161–183.

(12) Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research Policy, 41(6), 955–967.

(13) Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. Environmental Science & Policy, 23, 24–34.

(14) Rola, A. C., Pulhin, J. M., Tabios, G. Q., Lizada, J. C., & Dayo, M. H. (2015). Challenges of water governance in the Philippines. Philippine J. Sci, 144(2), 197-208.

(15) Rotmans, J., van Asselt, M., Anastasi, C., Greeuw, S., Mellors, J., Peters, S., ... & Rijkens, N. (2000). Visions for a sustainable Europe. Futures, 32(9-10), 809-831.

(16) Roth, D. (2011). The Subak in Diaspora: Balinese Farmers and the Subak in South Sulawesi. Human Ecology, 39(1), 55–68. https://doi.org/10.1007/s10745-010-9374-7

(17) Banjongsiri Sajja. (2018). Guidelines for participatory water resource management of the people's sector: a case study of the Nan River Basin. Sukhothai Thammathirat Open University: Nonthaburi.

(18) Takahashi, S. (2017). Report Viet Nam: Central Region Water Resources Project Independent Evaluation. December.

(19) Thepkhachon, P. (2008). Law Supporting for the Establishment of Water-users' Groups in the Irrigation Areas. M.A. Thesis, Chulalongkorn University, Faculty of Law.

(20) Wang, J., Huang, Q., Haung, J., & Rozelle, S. (2016). Evaluation of Water User Associations. In J. Wang, Q. Huang, J. Huang, & S. Rozelle (Eds.), Managing Water on China's Farms (pp. 193-214). Academic Press. doi:10.1016/B978-0-12-805164-1.01001-0

TC-342L

Applying Prone Fields for Flood Management in Chao Phraya River Basin

Mr. Surachat Malasri
The Director of Project Management Bureau,
The Royal Irrigation Department
Bangkok, Thailand
Surachatmalasri39@gmail.com
Mr. Kritsanon Rugko
Plan and Policy Analyst, Project Management Bureau,
The Royal Irrigation Department
Bangkok, Thailand
Kvitsanon2@gmail.com
Mr. Siraphop Bunmeeprakob
General Administrative Officer, Project Management Bureau,
The Royal Irrigation Department
Bangkok, Thailand
Siraphop01544@gmail.com
Mr. Chakaphon Singto
Plan and Policy Analyst, Project Management Bureau,
The Royal Irrigation Department
Bangkok, Thailand
chakaphon.singto@gmail.com

ABSTRACT

Flood problems in the Chao Phraya River Basin cover the central area of the Thailand in 22 provinces, including Bangkok. Most of the areas, rice paddy including industrial and residential areas, invent dramatically agricultural values and economic growth of the country. Therefore, an idea to propose 13 potential lowlands was developed as flood-prone fields, consisting of Bang Rakam field in the upper and other 12 lower Chao Phraya fields. The concept is to allow the 13 prone fields to be able to store some parts of the water by diverting 1,454 million m^3 into the fields, meanwhile this amount of water cannot be drained into the existing drainage system during flooding season. To maintain the water level when the normal drainage system is over its capacity, diverting the exceeding water into the prone fields is an effective approach. Thus, farmers are required to modify their cropping patterns to harvest crop production before diverting the exceeded water to flood-prone fields. However, it is necessary to assess the gaps for the improvement of the new holistic management system.

There are two main factors cause floods in the Chao Phraya River Basin. One factor is the characteristic of the low terrain of more than 224,000 ha (1.4 million rai). Another factor is amount of rainfall influenced by monsoons during rainy season each year. Not only a systematic idea of keeping water retention in the flood prone fields to reduce the amount of water in the Chao Phraya River Basin, but also not to affect farmers in the flooded fields severely. Flood compensation payment has been adopted by the Royal Irrigation Department (RID). The compensation for damaged rice does not cover all expenses paid by the farmers. Hence, RID has proposed to shift the start crop calendar earlier in which it started around May to June normally, while the harvesting period began from late August to September. However, starting the crop season in April instead of the original plan causes a new problem, insufficient water storage to encourage the farmers in the fields to change.

Using flood prone fields has been proposed to solve flood problem in the Chao Phraya River Basin since 2017. These 13 fields provide full capacities of more than 1.9 billion m^3. Moreover, they are capable of storing the inflow mass of water diverting through regulating gates, canals and irrigation systems. To illustrate, the upper Chao Phraya River Basin, Bang Rakam fields in Phitsanulok and Sukhothai provinces, cover 42,400 ha (0.265 million rai) which it can retain 400 million m^3 of water. Bang Kung

and Chao Chet fields, for example, are the two of 12 flood-prone fields in the Lower Chao Phraya River Basin from Nakhon Sawan province downwards. Lastly, there is also a drainage plan to divert this bulk of flood from the northern region downwards from Nakhon Sawan to the sea via irrigation systems such as canals, rivers, and regulating gates. This combination of flood-prone fields together with irrigation systems can reduce the water level in the Chao Phraya River.

The Chao Phraya River Basin Management Plan in the dry season of 2021, it was found that the water storage was not enough to supply water for 12 lower Chao Phraya fields, covering an area of 184,000 ha (1.15 million rai). Flood plain situation in 2021, according to the plan, the flood-prone fields were expected to hold 1,200 million m^3 of water by start draining in late November 2021. However, an influence of the monsoon and depression "Tien Mu" (24-25 Sept. 21) together with storm "Kompasu" (14-15 Oct. 21) brought the intensity of rainfall 1,100-1,200 mm, equivalent to the average rainfall of the whole year in 2020. In comparison, this amount of rainfall was equivariant to the average rainfall of 1.098 mm/year of the Pa Sak Basin. The rainfall during these couple weeks exceeded the capacity of the existing flooding control infrastructure and management. Evidently, the potential of the Pasak River can usually support water volume of about 800 m^3/sec, but in 2021 the Pasak River system was used to drain the amount of 1,207 m^3/sec. However, numbers of rice fields could not be harvested during the flooding period. Then, two major protests pursued. The first protest was to open the water regulating gates draining to Bang Kung field, a prone-field in Chao Phraya River basin, while it was already receiving water beyond its capacity. Another protest was to open the regulating gates to lower flood level in Chao Chet prone field. These two events of conflicts were examples of flooding management issues in crisis. The relevant government agencies should take carefully the conflicts of affected people between upper and lower prone fields into consideration.

In conclusion, there are three lessons from flood-prone fields management in 2021 for improvement as follows; 1) Amount of water storage is guaranteed. Enough water supply can performed by diverting from another reservoir and supplying to the 13 fields via a closed water supply system to start planting in late dry season of April. 2) Negotiation is required with community leaders between the upper and lower fields to optimize the equality. Participatory process is a key success to ensure the understanding of community leaders about crisis management strategies. 3) The compensation criteria should be reviewed to reflect the real cost. The compensation rate, at 251.5 USD per ha (1,331 THB per rai), does not cover the investment cost. This amount of money is not sufficient to incentivize the farmers to agree with benefit sharing scheme. The recommendations from the flooding event of Chao Phraya River Basin in 2021 can be very challenging. Although they may not come true in the near future, the relevant agencies should study the feasibility of these recommendations further soon for adaptation and resilience to climate change.

Keywords—Flood-prone Fields, Bang Rakam, Flood impacts

REFERENCES

Royal Irrigation Department, https://www.facebook.com/ridreport (September-November 2021)

Applying Flood-prone Fields for Flood Management in Chao Praya River Basin, State Awards Participatory in Water Management Branch 2021, The Royal Irrigation Department, 2021

Office of Water Hydrology and Management, Lowland Water Management of 13 Thung Chao Phraya for a multi-water reception area. Handouts, Royal Irrigation Department, 2021

Office of Water Hydrology and Management, preparing for 13 low-lying areas. Handouts, Royal Irrigation Department, 2021

Office of Water Hydrology and Management, preparing low-lying areas in Bang Rakham and other areas to receive water, Royal Irrigation Department, 2021

TC-343L

THAICID Academic Network and their Supporting Roles on Irrigation and Drainage toward Sustainable Water Management

Chaiwat Prechawit
ICID Vice President Honoraire
Senior Expert Advisor of Royal Irrigation Department (RID)
Bangkok, THAILAND
chaiwatprechawit@gmail.com

Satit Maneepai
Chairman of THAICID Academic Working Group
Senior Expert Advisor of RID
Bangkok, THAILAND
nalayer02@gmail.com

Chaiya phoungphotisop
Vice Chairman of THAICID Academic Working Group
Director of Irrigation Development Institute (IDI)
RID Bangkok, THAILAND
ph.chaiya44@gmail.com

Noppadon Kowsuvon
Secretary of THAICID Academic Working Group
Irrigation Engineering (Senior Professional Engineer)
RID Bangkok, THAILAND
PrinceThai@gmail.com

Keywords— THAICID; Academic Organization; Irrigation and Drainage; Sustainable Water Management (key words)

ABSTRACT
Thailand is 1 of 11 founder-member countries who in 1950 established the International Commission on Irrigation and Drainage (ICID) and THAICID (Thai National Committee on Irrigation and Drainage).

ICID is a leading scientific, technical, international not-for-profit, non-governmental organization. THAICID is the Thai subsidiary and supports the establishment of professional network consisting of experts from across the world in the field of irrigation, drainage, and flood management. The main mission is to promote 'Sustainable agriculture water management' to achieve 'Water secure world free of poverty and hunger through sustainable rural development' (*excerpted from https://www.icid.org/about_icid.html*). Three representatives from THAICID who were honored to be Vice President of ICID are M.L. Xujati Kambhu or "Father of Irrigationists", from 1964 to 1967, Captain Sunthorn Ruanglek, from 1983 to 1986 and Mr. Chaiwat Prechawit, from 2010 to 2013.

Since 2008, the THAICID National Symposium has been organized every year to be an ideal platform for the promotion and exchange of irrigation and drainage innovation in Thailand. The e-Symposium was recently organized in response to the Covid-19 pandemic.

In 2020, THAICID celebrated the 70th anniversary of ICID as well as THAICID, the 13th THAICID NATIONAL e-SYMPOSIUM was organized under the main theme "The ICID & THAICID 70th Anniversary Celebration our ongoing support to Secure The Future We Want under Sustainable Development GOAL 6 Focusing on Innovated Irrigation Water and Drainage Management".

To date, 14 Proceedings with 245 articles were published in hardcopies and digitally "green-proceedings" that cover the entire spectrum of agricultural water management practices ranging from rainfed agriculture to supplemental irrigation, land drainage, deficit irrigation to full irrigation, etc.

In addition, drainage of agricultural lands forms the core theme of commission's activities. Floods and drought; the two extremes of increasingly variable climate as a result of potential climate change, also form the focus of ICID's activities. The following table lists the number of articles published each year.

The Proceedings of 11 THAICID Symposiums & 3 THAICID e-Symposiums with 245 paper published						
THAICID 1st 2008	THAICID 2nd 2009	THAICID 3rd 2010	THAICID 4th 2011	THAICID 5th 2012	THAICID 6th 2013	THAICID 7th 2014
13	9	23	12	16	8	13
THAICID 8th 2015	THAICID 9th 2016	THAICID 10th 2017	THAICID 11th 2018	THAICID 12th 2019	THAICID 13th 2020	THAICID 14th 2021
17	23	11	24	26	22	28

Fig. 1. 12th THAICID National Symposium 2019

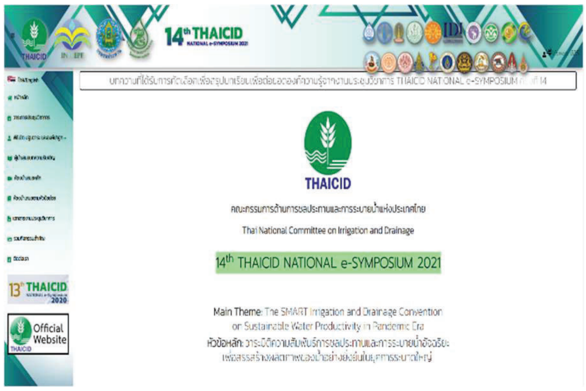


Fig. 2. 14th THAICID National e-Symposium 2021 (Online Platform)

Fig. 3. 70th Anniversary ICID&THAICID 2020

Fig. 4. Manuals on Planning of Non-Structural and Structural Approaches to Flood Management (English-Thai Translated)

Additionally, the English-Thai translated manuals on Planning of Non-Structural and Structural Approaches to Flood Management were published during the occasion of 70th Anniversary ICID&THAICID in 2020. The Manual on Non-Structural Approaches to Flood Management is the manual that explains about activities which are planned to eliminate or mitigate adverse effects of flooding without involving the construction of flow-modifying structures. While structural approaches to flood management may or may not be used conjunctively with non-structural approaches, but are not prerequisite to the use of non-structural measures because of the potential for synergistic enhancement of their effectiveness. Under some river basin conditions, the introduction of non-structural methods to limit flood damage may alone be more cost-effective than alternatives involving structural methods. The non-structural approaches to flood management covered by the manual are divided into 2 groups 1) Planning Measures: which comprises flood forecasting, sea flooding, control of floodplain development, flood insurance, flood proving, catchment management and decision making (The Song Pi Nong district in Suphanburi province was used as a good example of flood proving)

The Manual on Planning of Structural approaches to Flood Management involve the use of structures such as dams, levees, dikes, diversions, floodways, etc., which provide some control of flood water by storage, containment or flow modification or diversion. The purpose of this manual is to give planners and decision makers in flood management and flood control guide lines on the planning and design of flood control projects following certain basic principles. The chapters in the manual includes, the relationship between flood parameters and inundations, the relationship between flood parameters and damages, desires level of protection, and the use of hydrodynamic mathematical model for flood management.

SUMMARY AND ACKNOWLEDGMENTS

The past proceedings and mentioned manuals were archived and posted on THAICID website in Thai language at https://www.rid.go.th/thaicid/. THAICID would like to remind readers about the upcoming 15th THAICID 2022 e-symposium on July whose main theme is 'Improving water Governance for Flood and Drought in Response to the Post-Pandemic Phase under Climate Change'. The information will also be posted on the mentioned THAICID website.

Thailand remains proud to stand with likeminded nations heading into our 8th decade of water sustainability and management. In the year of COP26, we can respectfully remember that our nations have long worked towards sustainability in water management, and we humbly look forward to many more years of fruitful collaboration for the benefit of all life on Earth.

Finally, we would like to thank Mr. Chonnapat Meachasompop from Bureau of Water Management and Hydrology, Royal Irrigation Department (RID) for his hard work in coordinating this paper.

REFERENCES

(1) 2021,International Commission on Irrigation and Drainage, accessed 19 November 2021, <https://icid-ciid.org/home>
(2) Prechawit C.,Rittima A., 2019. *Manuals on Non- Approaches to Flood Management (English-Thai Translated)*. ICID New Delhi.
(3) Prechawit C.,Rittima A., 2020. *Manuals on Planning of Structural Approaches to Flood Management (English-Thai Translated)*. ICID New Delhi.

TC-344L

INWEPF-THAI Innovative Rice Cultivation to Sustain Green Approaches for food security and alleviate poverty under Global Warming Challenges

Vason Boonkird
Chairman of INWEPF-THAI Committee
Senior Expert Advisor of Irrigation Development Institute
Bangkok, Thailand
vason.boon@gmail.com

Watchara Suiadee
Secretary of INWEPF-THAI Committee
Senior Expert of Royal Irrigation Department
Bangkok, Thailand
watchara@rid.go.th

Somchit Amnatsan
INWEPF-THAI Committee
Royal Irrigation Department
Bangkok, Thailand
somnatsan@yahoo.com

Noppadon Kowsuvon
Secretary of THAICID Academic Working Group
Irrigation Engineering (Senior Professional Engineer)
Royal Irrigation Department
Bangkok, Thailand
princethai@gmail.com

Keywords— INWEPF-THAI; Academic Network; Alternate Wet and Dry Paddy; Rice Ratooning, (key words)

ABSTRACT

Thailand, by the Royal Irrigation Department (RID), is one of the seventeen countries that jointly founded the International Networks for Water and Ecosystem on Paddy Fields (INWEPF) in 2004. After the foundation, the RID has appointed the INWEPF THAI Committee by gathered the representatives of the relevant organizations from both government and private sector, which are engaging in the area of water for paddy field and ecosystem. The mission of THAICID mainly involves water and paddy field so adding the topic of ecosystem helps enhance the irrigation and drainage works to become more sustainable in every aspect. THAICID has its own Charter. So, in order to make more integrated and flexible implementation, the RID has appointed the INWEPF THAI Committee to work correspondingly as a part of THAICID. Nonetheless, Thailand will present itself as the “INWEPF THAI Committee” when communicates with the international networks.

The committed mission of the INWEPF THAI Committee, which proceeds under THAICID by having the RID as the main coordination organization, is to corporate with the networks in order to exchange, study and to create innovations in the area of irrigation and drainage including ecosystem of the paddy field. In the past seventeen years, INWEPF THAI had been chosen as a host for the international INWEPF Steering Meeting & Symposium for two times: for the 4th Meeting in 2007 in Bangkok and for the 10th Meeting in 2013 in Chiang Mai Province. In the past meetings, the specialized agencies such as ICID, FAO, INPIM and IWMI etc. had attended to all INWEPF Steering Meetings & Symposium, in order to strengthen both the relationship between the organizations and the integration for sustainable cooperation.

The outstanding accomplishment of INWEPF THAI which relates to ICID is that, Thailand was once a host for the 2nd World Irrigation Forum (WIF) and the 67th International Executive Council Meeting (IEC) which took place in June, 2016. INWEPF THAI had also submitted the paper titled "Innovation, Implementation and Extension of the Water Saving Integrated Smart Farming - AWDI technique in Thailand" for the ICID WATSAVE Awards 2016 and received the 1st prize in the category of WATSAVE Innovation Water Management Award. The paper describes about the Alternate Wetting and Drying (AWD) Rice Farming initiated by the Weekend Farmer Networks illustrated in figure 1 and later extended the results by organized a seminar for Irrigation Offices in the irrigation area all over Thailand. Moreover, it helped enhance and regain the attentiveness of a young generation for the Weekend Farmer Networks' farming pattern, which could help them to become professional farmers in the future. In 2017, there was an enhancement to develop a new form of rice farming; it finally came up with the new means of innovation for rice farming by stubble or "One Seeding, More than Three Harvesting", which was researched and developed at the Huai Hong Khrai Royal Development Study Centre. The innovation was further developed from the SALIBU Rice Farming of Inndonesia which was presented to the INWEPF Meeting as the world's first initiation. At present, there are substantial further developments of the two innovations at an international level: presentations of the know-how to the international platforms, and the Thai Rice Nationally Appropriate Mitigatio Action (Thai Rice NAMA) Project, which are the cooperation between the Ministry of Agriculture and Cooperatives and the German Corporation for International Cooperation (GIZ). The Thai Rice NAMA project aims to enhance production efficiency and rice farming that helps reduce greenhouse gas emissions, including rice production with Thai GAP++ certification which primarily respond to the Sustainable Development Goals (SDGs) and the recent COP 26 UN Climate Change Conference aimed to increase climate ambition, build resilience and lower emissions stated in 2021 conference's framework.

No.	OVERALL RESULTS		
	The INWEPF THAI recognition events	**Titled**	**Year**
1	The international INWEPF Steering Meeting & Symposium for the 4th Meeting in Bangkok	Host Country	2007
2	The international INWEPF Steering Meeting & Symposium for the 10th Meeting in Chiang Mai Province	Host Country	2013
3	The 2nd World Irrigation Forum (WIF) and the 67th International Executive Council Meeting (IEC)	Innovation, Implementation and Extension of the Water Saving Integrated Smart Farming - AWDI technique in Thailand	November, 2016
4	The cooperation between the Ministry of Agriculture and Cooperatives and the German Corporation for International Cooperation (GIZ)	the Thai Rice Nationally Appropriate Mitigation Action (Thai Rice NAMA) Project supporting UN-Glasgow Climate Conference: COP26	August, 2018 – August, 2023

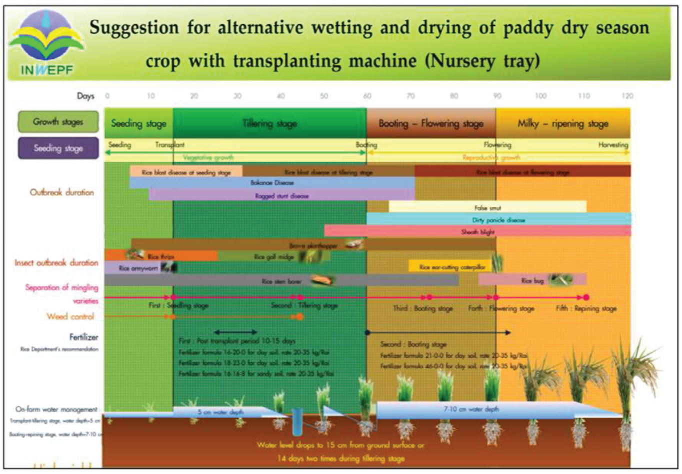


Figure 1 The Integrated Smart Farming - AWDI technique

Fig. 1. INWEPF-THAI

Fig. 2. AWD

Fig. 3. Rice Ratooning

Fig. 4. WATSAVE AWARD 2016

SUMMARY AND ACKNOWLEDGMENTS

INWEPF THAI would like to extend sincere thanks to the THAICID Committee, the Technical Working Group of THAICID, the Irrigation Engineering Alumni Association under His Majesty The King's Patronage, the Royal Irrigation Department, the Academic and Institutional Networks, as well as the relevant agencies from both government and private sector, including all the distinguished participants, for giving us your precious time to participate in THA2022 which benefit your further academic development, and altogether sustainably integrate and support the innovations of the THAICID and INWEPF THAI Networks.

Finally, we would like to thank Ms.Pantila Ramanandana, Regional Irrigation Office 11, Royal Irrigation Department for her hard work in coordinating this paper.

REFERENCES

(1) 2006, International Network for Water and Ecosystem in Paddy Fields, THAILAND, accessed 19 November 2021,<http://inwepf.rid.go.th/Organize.html>

(2) Boonkird Va-Son, Suiadee Watchara (Thailand) (2016), Innovative Water Management Award for "Innovation, Implementation and Extension of the Water Saving Integrated Smart Farming – AWDI Technique in Thailand"

(3) 2016, The rice ratooning manual, Huai Hong Khrai Royal Development Study Center

(4) Thai Rice (Nationally Appropriate Mitigation Action) NAMA (2018-2023)

TC-345S

Community based water resources management criteria towards SDGs

Chitsanuwat Maneesrikum
Creative Intelligence Co Ltd.
Samut Songkhram, Thailand
tanate091@hotmail.com

Piyatida Ruangrassamee*
Department of Water Resources Engineering, Faculty of Engineering
Chulalongkorn University
Bangkok, Thailand
Piyatida.H@chula.ac.th

ABSTRACT

With social and economic development and more climate variability, water allocation to different water user groups needs more coordination. Integrated Water Resources Management (IWRM) approach has been widely adopted to achieve the coordinated development and management of water resources. The objective of this study is to investigate the existing capacity of water user groups by carrying out the focus group at 33 subdistricts to assess community based water resources management capacity, studying the relationship between the capacity assessment and the Water Management Index from National Statistical Office, and examining the linkage to SDG 6.5.1 in order to promote more community water management in the future. Based on the assessment of the existing capacity of community based water resources management of 33 subdistricts in 15 provinces and 5 regions in Thailand and Water Management Index, the results demonstrate indicative relationship between water security and water governance. The ten attributes to assess community capacity used in this study are conformed with criteria used in SDG 6.5.1 for participation. Promoting community capacity building with the ten attributes proposed in this study can help community-based water resources management to improve and reach higher level of SDG 6.5.1.

***Keywords*—** IWRM; SDG 6.5.1; community-based water resources management; Water Management Index

INTRODUCTION

Integrated water resources management, good water governance, cooperation, and water financial sustainability are keys for water allocation among different water user groups under social and economic development and greater climate variability. Integrated Water Resources Management (IWRM) is defined by Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment." The IWRM principles had been developed based on the Dublin Principles and the key components of IWRM are enabling environment, institutions and participation, and management instruments (1). UN Water has encouraged IWRM implementation and defined Target 6.5 of SDG6 to "by 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate" and the indicator 6.5.1 is the assessment on "degree of integrated water resources management implementation."

To enhance policy coherency of Thailand's water resources management, the Office of National Water Resources (ONWR) was established in 2017 to be the main organization that systematically regulate and manage the policies of integrated national water resources management and the National Water

Resources Act was approved in 2018. For institutions and participation component, the progresses have been towards strengthening community-based water resources management. Water User Association (WUA) has been established to aim for better water allocation coordination and management (https://twuo.onwr.go.th/). In terms of quantitative assessment of water security of Thailand, National Statistical Office (NSO) developed Water Management Index (WMI) that includes 8 dimensions and the database can be accessed from http://wtc.nso.go.th/ WMI has been developed to evaluate status of water management at river basin, provincial, district, and subdistrict scales. WMI also includes participation assessment.

In this study, we aim to investigate the existing capacity of water user groups by carrying out the focus groups at 33 subdistricts to assess capacity of community based water resources management, studying the relationship between the capacity assessment and the Water Management Index from NSO, and examining the linkage to SDG 6.5.1 in order to promote more community water management in the future.

2 STUDY AREA

In this study, the research is carried out through network universities and node networks in 5 regions across Thailand. Each team identified target water user groups and communities based on the field survey. The study area of this study includes 33 subdistricts in 15 provinces and 5 regions as shown in Figure 1. The water user groups and communities in this study represent various water uses and conditions.

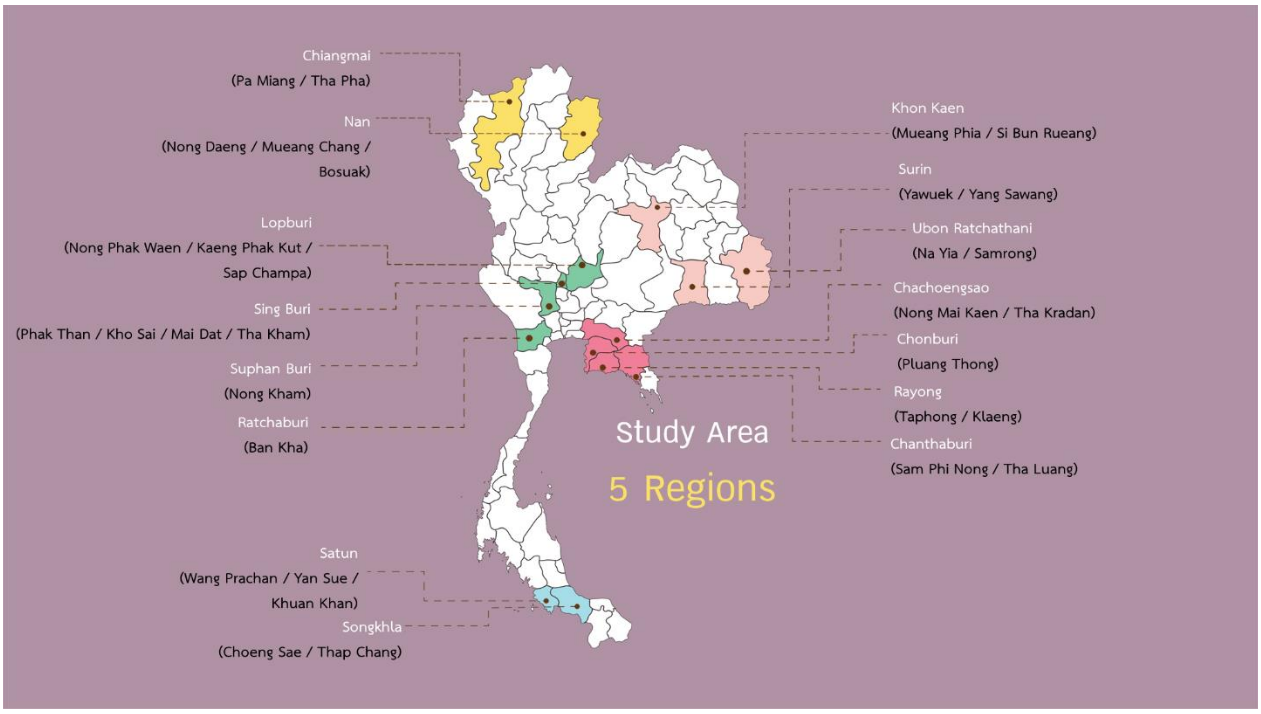


Fig. 1. Study area of 30 subdistricts in 15 provinces

3 METHODOLOGY

The focus groups of selected water user groups and communities of 33 subdistricts were organized by network universities and node networks in the 5 regions. The aim of this study is to assess existing capacity and objectives of each water user group and community by using questionnaire, focus group meetings, meetings via online platforms, and interviews during June – August 2021.

The good water management practices and necessary attributes at community level is derived from our previous work on the community-based action research carried out under the project "Water Use Efficiency Improvement in local level within Tor Tong Daeng Irrigation Project area" in Kamphaeng Phet as well as literature reviews (2,3). As a result, ten attributes of effective community-based water resources management are identified as follows:

1. Water user group with clear roles and responsibilities
2. Capable committee to manage community water resources
3. Community-based databases and information systems for water resources management
4. Platform for participatory planning
5. Eco-based water resources management plans
6. Approved measures for water resources management
7. Funds for water resources management
8. Monitoring and evaluation system
9. Collaborating mechanisms with other parties
10. Capacity development

These ten attributes are linked with degree of integrated water resources management implementation at community level. The focus groups in the 33 subdistricts were organized to gather information and supporting evidence for the assessment of community water resources management. This process is a preliminary assessment before our capacity building program is implemented. We classify the capacity level of community-based water resources management into three levels as follows:

Low capacity level: community has 1-4 attributes
Medium capacity level: community has 5-7 attributes
High capacity level: community has 8-10 attributes

In this study, the Water Management Index (WMI) from NSO was obtained for the 33 subdistricts. WMI includes 8 dimensions with 59 indicators and 92 variables. The data and scoring on the scale of 1-5 of each indicator are provided at river basin, regional, provincial, district, and subdistrict scales. The relationship between Water Management Index (WMI) (4) and our preliminary assessment is investigated in this study.

4 RESULTS AND DISCUSSIONS

The result based on the focus groups in the 33 subdistricts before implementing the training program to assess community capacity in water resources management is shown in Table 1. Out of 33 subdistricts, 8 subdistricts are assessed as medium capacity level and 25 subdistricts are assessed as low capacity level of community-based water resources management. There is no subdistrict with high capacity level.

The relationship between Water Management Index (WMI) (4) and our capacity assessment is shown in Figure 2. For the group of subdistricts with medium capacity level of community-based water resources management, their WMI is above 2.50 and less spreading when compared to the group of low capacity level. The average WMI of medium capacity level group is 3.2 with the standard deviation of 0.29 while the average WMI of low capacity level group is 2.8 with the standard deviation of 0.43. This could be indicative for causal relationship between water security and water governance.

TABLE 1 Assessment of community capacity for community-based water resources management before implementation of training program and Water Management Index

Province	Subdistrict (Tambon)	Assessment of community capacity (before training)			Water Management Index (WMI) (NSO, 2020)
		Low level 1-4 attributes	Medium level 5-7 attributes	High level 8-10 attributes	
Nan	Nong Daeng	✓			3.67
	Mueang Chang	✓			3.28
	Bosuak		✓		3.26
Chiangmai	Pa Miang	✓			3.42
	Tha Pha		✓		3.49
Ubon Ratchathani	Na Yia	✓			2.29
	Samrong	✓			2.90
Khon Kaen	Mueang Phia		✓		2.70
	Si Bun Rueang		✓		2.86
Surin	Yang Sawang	✓			2.67
	Yawuek	✓			2.86
Chachoengsao	Nong Mai Kaen	✓			2.93
	Tha Kradan	✓			3.09
Chanthaburi	Sam Phi Nong	✓			3.05
	Tha Luang	✓			3.57
Chonburi	Pluang Thong		✓		3.48
Rayong	Klaeng	✓			2.63
	Taphong	✓			3.32
Sing Buri	Phak Than	✓			2.44
	Mai Dat	✓			2.27
	Kho Sai	✓			2.33
	Tha Kham	✓			2.55
Lopburi	Kaeng Phak Kut	✓			2.59
	Tale Wang Wat	✓			2.46
	Sap Champa	✓			2.86
	Nong Phak Waen	✓			2.58
Suphan Buri	Nong Kham	✓			1.98
Ratchaburi	Ban Kha		✓		3.31
Satun	Wang Prachan		✓		3.41
	Yan Sue	✓			3.08
	Khuan Khan	✓			2.63
Songkhla	Choeng Sae		✓		3.08
	Thap Chang	✓			3.18
15 provinces	**33 subdistricts**	**25**	**8**	**0**	

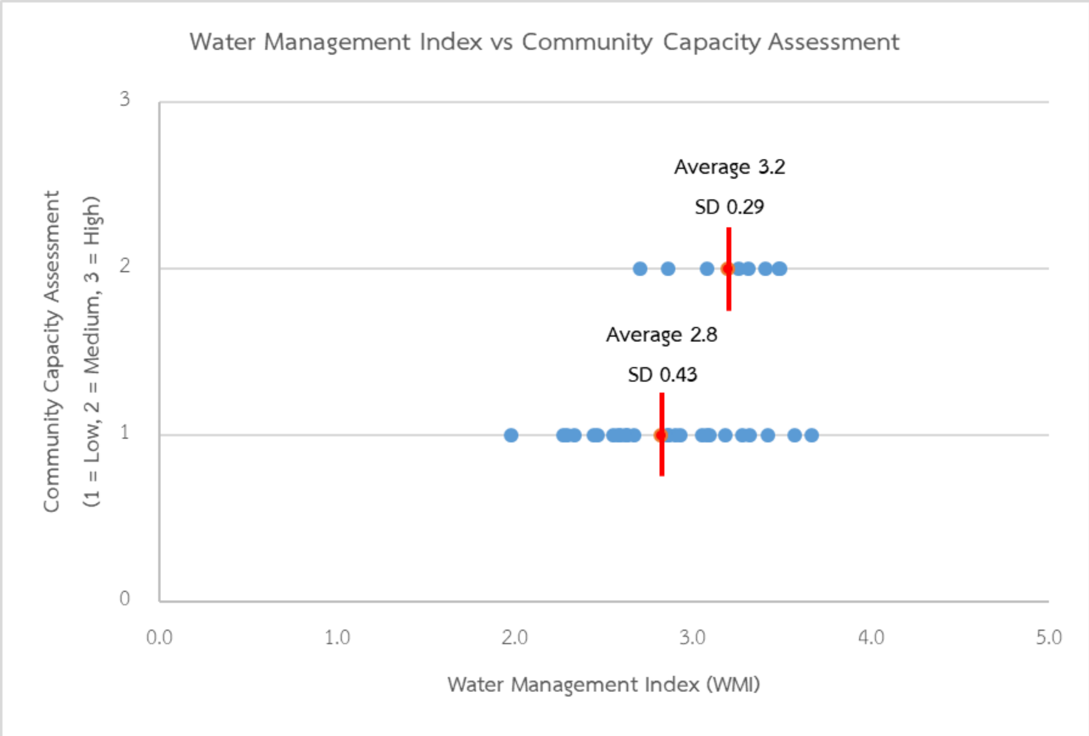


Fig. 2. Relationship between WMI and community assessment

In addition, the linkage between community-based water resources management capacity and SDG 6.5.1 is examined. Indicator 6.5.1 of SDG 6.5 tracks the degree of integrated water resources management (IWRM) implementation, by assessing the four key components of IWRM: enabling environment, institutions and participation, management instruments, and financing (https://www.sdg6monitoring.org/indicator-651/). The survey instrument is used for the assessment (5). For institutions and participation, the assessment focuses on the status of institutions for IWRM implementation. Relevant key components for roles of communities and water user association are developing IWRM capacity and public participation in water resources, policy, planning and management at the local level. An example of level of IWRM capacity is if long-term capacity development initiatives are being implemented, and geographic and stakeholder coverage is adequate, this will be considered medium-high. For high level, long-term capacity development initiatives are being implemented with highly effective outcomes, and geographic and stakeholder coverage is excellent. For public participation at local level, the evaluation moves from no information shared, information made available to public, communication, consultation, and collaboration (5).

Community-based water resources management capacity building will help strengthening public participation in water resources, policy, planning and management at local level. Capacity development of community is key for improving community-based water resources management, therefore, supporting network, data and information sharing, and financing with good governance are essential.

4 SUMMARY

The assessment of existing community capacity for water resources management based on the ten attributes carried out in 33 subdistricts in 15 provinces across 5 regions of Thailand shows that 8 subdistricts are assessed as medium capacity level and 25 subdistricts are assessed as low capacity level. There is no subdistrict with high capacity level. The relationship between Water Management Index (WMI) from NSO and our assessment could be indicative for relationship between water security and water governance. The ten attributes used in this study are conformed with criteria used in 6.5.1

for developing IWRM capacity and public participation. Promoting community capacity building with the ten attributes proposed in this study can help community-based water resources management to improve and reach higher level of SDG 6.5.1. Further research will be carried out to provide a training program to the water user groups in 33 districts and assess their capacities.

ACKNOWLEDGMENTS
This research is part of the research projects "Guidelines for the development of community water user organization to increase the ability of planning water management at the area level" and "Water security assessment based on development of water management system using technology in central region and the Eastern Economic Corridor" under NRCT Spearhead Research Program on Water Management supported by National Research Council of Thailand. We would like to thank National Statistical Office of Thailand for Water Management Index data.

REFERENCES

(1) GWP (2004), Integrated Water Resources Management, GWP Technical Committee (TEC) Background Paper No. 4 (www.gwpforum.org).
(2) Maneesrikum, C. et al. (2020), Water Use Efficiency Improvement in local level within Tor Tong Daeng Irrigation Project area, Final Research Report submitted to TSRI-NRCT, September (in Thai).
(3) Koontanakulvong, S. (2020), Summary of TSRI-NRCT Spearhead Research Program Phase 1. Research Brief Document. Chulalongkorn University, December, 44 pp. (in Thai).
(4) NSO (2020), Water Management Index, http://wtc.nso.go.th/ (accessed September, 2021) (in Thai)
(5) UNEP, GWP, UNEP-DHI Centre and Cap-Net (2020), Country Survey Instrument for SDG Indicator 6.5.1

Reviewers

1	Assoc. Prof. Dr. Sucharit Koontanakulvong	Chulalongkorn University
2	Asst. Prof. Dr. Supattra Visessri	Chulalongkorn University
3	Asst. Prof. Dr. Piyatida Ruangrassamee	Chulalongkorn University
4	Dr. Chokchai Suthidhummajit	Chulalongkorn University
5	Assoc. Prof. Dr. Bancha Kwanyuen	Kasetsart University
6	Assoc. Prof. Dr. Chaisri Suksaroj	Kasetsart University
7	Assoc. Prof. Dr. Wisuwat Taesombat	Kasetsart University
8	Dr. Chuphan Chompuchan	Kasetsart University
9	Dr. Ketvara Sittichok	Kasetsart University
10	Assoc. Prof. Dr. Areeya Rittima	Mahidol University
11	Asst. Prof. Dr. Chanyut Kalakan	Burapha University
12	Prof. Dr. Chaiyuth Chinnarasri	King Mongkut's University of Technology Thonburi
13	Asst. Prof. Dr. Chaiwat Ekkawatpanit	King Mongkut's University of Technology Thonburi
14	Dr. Supapap Patsinghasanee	Department of Water Resources
15	Dr. Winai Chaowiwat	Hydro-Informatics Institute
16	Prof. Dr. Sangam Shrestha	Asian Institute of Technology
17	Prof. Dr. Ashim Das Gupta	Asian Institute of Technology
18	Asst. Prof. Dr. Sarawut Ninsawat	Asian Institute of Technology
19	Dr. S. Mohana Sundaram	Asian Institute of Technology
20	Dr. Tuan Pham Van	Asian Institute of Technology
21	Prof. Dr. Tebakari Taichi	JICA / Chuo University
22	Assoc. Prof. Dr. Nakamura Shinichiro	JICA / Nagoya University
23	Assoc. Prof. Dr. Noda Keigo	JICA / Gifu University
24	Assoc. Prof. Dr. Yoshida Koshi	JICA / The University of Tokyo
25	Asst. Prof. Dr. Koyama Naoki	JICA / Chuo University
26	Prof. Dr. TANAKA Shigenobu	Kyoto University, Japan
27	Assoc. Prof. Dr. Yutaka Ichikawa	Kyoto University, Japan
28	Assoc. Prof. Kazuaki Yorozu	Kyoto University, Japan
29	Asst. Prof. Dr. Tomohiro Tanaka	Kyoto University, Japan
30	Prof. Dr. Li-Chi Chiang	National Taiwan University
31	Prof. Dr. Ming-Che Hu	National Taiwan University
32	Prof. Dr. Shu-Yuan Pan	National Taiwan University
33	Prof. Dr. Jui-Pin Tsai	National Taiwan University
34	Prof. Dr. Seongjin Noh	Korea Water Resources Association
35	Prof. Dr. Changhyun Jun	Korea Water Resources Association

Sponsors

Electricity Generating Authority of Thailand

CKPOWER PUBLIC COMPANY LIMITED

Metropolitan Waterworks Authority

AEON THAILAND FOUNDATION

TEAM Consulting Engineering and
Management Public Company Limited.

Siam Steel International PLC.

Southeast Asia Technology Co., Ltd.