TA-102S

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

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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.

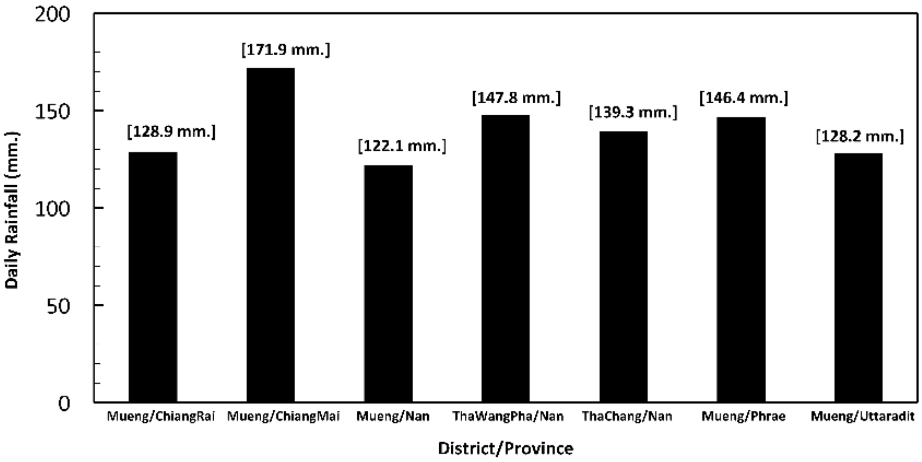

Fig. 1 Daily rainfall during August 2-5, 2020

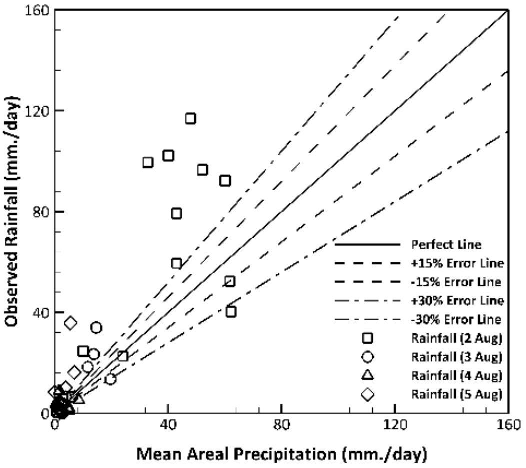

Fig. 2 Comparison results between MAP and observed data during August 2-5, 2020

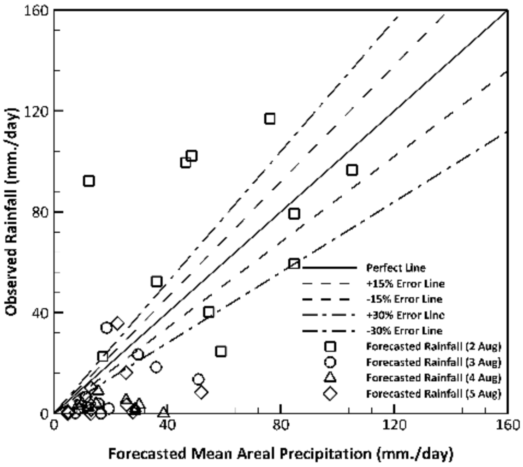

Fig. 3 Comparison results between FMAP and observed data during August 2-5, 2020

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.

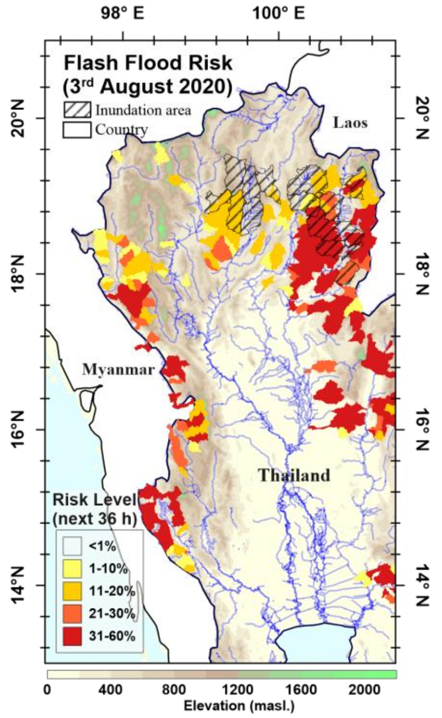

Fig. 4 Comparison results between FFR and the inundation areas on August 2, 2020

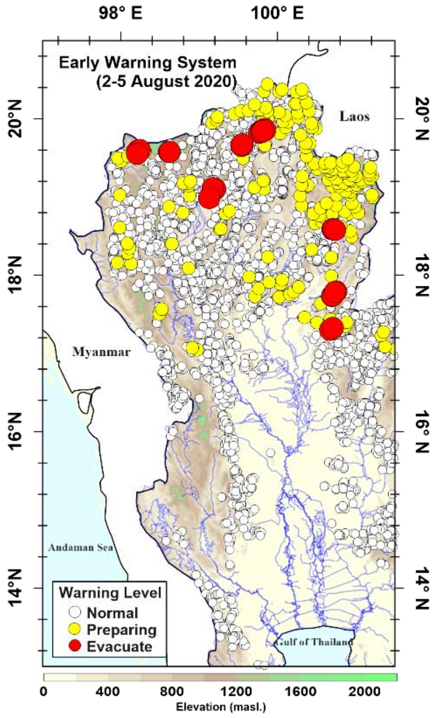

Fig. 5 Alarms of the EWS during tropical storm "SINLAKU" between 2-5 August 2020

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.

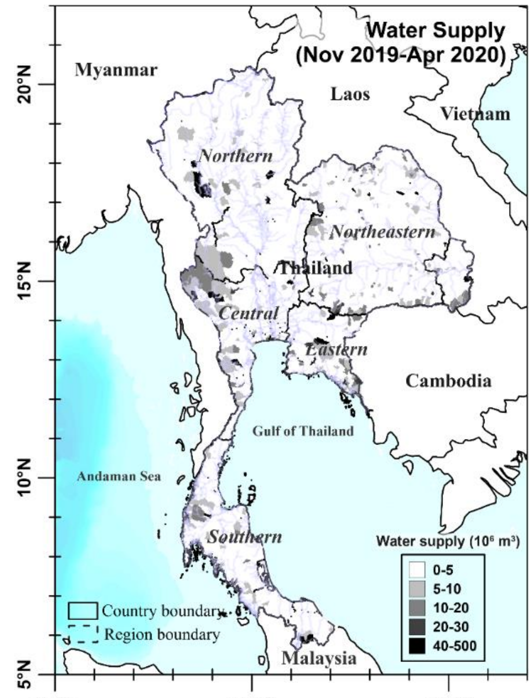

Fig. 6 Water supply in the dry season 2019/2020 in the rainfed agricultures

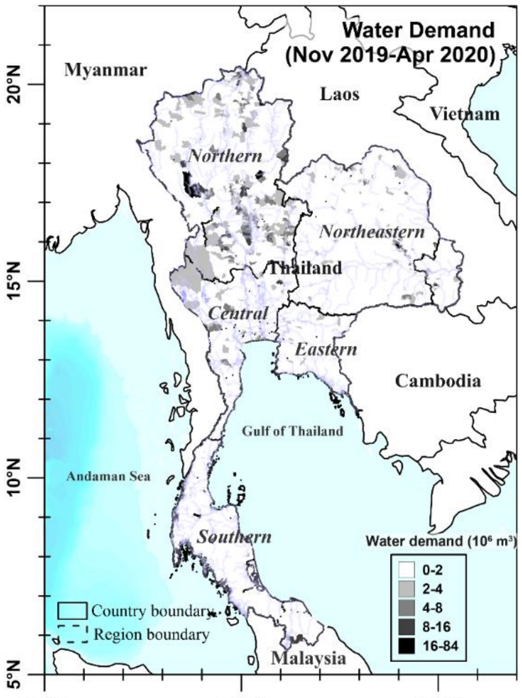

Fig. 7 Water demand in the dry season 2019/2020 in the rainfed agricultures

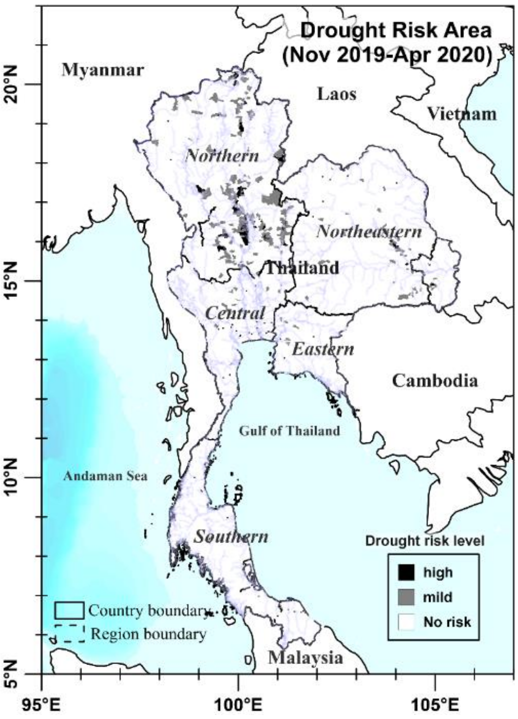

Fig. 8 Drought risk areas in the dry season 2019/2020 in the rainfed agricultures

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)