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THE ROLE OF GROUNDWATER TO MITIGATE THE DROUGHT AND AS AN ADAPTATION TO CLIMATE CHANGE IN THE PHITSANULOK IRRIGATION PROJECT, IN THE NAN BASIN, THAILAND

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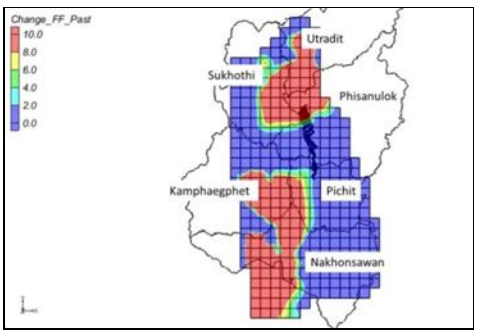
Graphical abstract



Abstract

The Phitsanulok Irrigation Project is located in the Nan Basin of the Upper Central Plain of Thailand where farmers depended on both surface water and groundwater. Land use and climate changes are the important factors to determine the runoff from the watershed. The changes also affected to runoff volume/pattern to the dam operation and may cause flood and drought situations in the downstream area. Sirikit Dam is one of the biggest dams in Thailand which cover about 25 % of the runoff into the Central Plain where the Bangkok Capital is located. Though there is the Sirikit Dams storing water to be used during dry period but water allocation is limited and still caused water shortage during dry season. The study aims to determine the role of groundwater to mitigate the drought situation from the past and to study the groundwater use for adaptation to climate change in The Phitsanulok Irrigation Development Project. In this study, the relationship of recharge rate with climate data was developed in terms of precipitation, evapotranspiration, temperature and soil type under monthly time series data and the study found that there were in good relationship. Groundwater will take an important role to alleviate from the water shortage situations in climate change conditions when compared with the situations based on the existing water use pattern. The limit of ground water to alleviate water shortage will be 80 and 77 MCM/year in average, in near future and far future periods to keep water table drawn down in the safe manner even when the Sirikit's reservoir operation rule is improved.

Keywords: Climate change, groundwater, MODFLOW, The Phitsanulok Irrigation, reservoir operation, Sirikit Dam, water shortage

1.0 INTRODUCTION

The climate change induced direct affects to irrigation area, e.g., Yom, Nan Basin or Chao Phraya Basin in the dry year when the storage amount is not adequate for summer rice and caused water deficit in many irrigation projects. Though in the central plain, two large reservoirs, i.e., Bhumiphol and Sirikit Dams store water to be used during dry period but most of agricultural area is in the rainfed area and water allocation is limited and caused water shortage during dry season and in the dry year. Most farmers turned to use groundwater to supplement irrigation water. This also caused groundwater drawdown and make farmers to dig deeper wells which made more cost for agriculture [7].

In The Phitsanulok Irrigation Project, the average water demand are 2,898, 2,968 and 3,110 MCM in present, near future and far future periods respectively, and the water shortage under existing condition impacted from the climate change considered only from surface water source is expected to be as in Table 1 [8-9] based on cultivated area as in present period. The water demand increase in near future and far future periods is due to higher of evapotranspiration. An mitigation measure for surface water operation is to improve Sirikit Reservoir Operation to comply with future climate and the results are shown in Table 1.

Table 1 Average Water Shortage in The Phitsanulok Irrigation Project in the future

Conditions	Water Shortage(MCM)	
	Near Future	Far Future
Existing ROC	-170	-170
improved ROC	-80	-77

*ROC is Reservoir Operation Curve of Sirikit Dam

The focus of the paper is to investigate the relationship of recharge rate with climate condition, to assess the impact on groundwater recharge in the Upper Central Plain and to determine the role of groundwater to mitigate the drought situation as an adaptation to climate change in additional to surface water source in The Phitsanulok Irrigation Project, which located in Nan River basin by applying MODFLOW and using the bias corrected MRI-GCM data.

Study Area

In this study, the study area, to investigate the relationship of recharge rate with climate condition, is in the Upper Central Plain, and focused in The Phitsanulok Irrigation Project, Nan River basin.

Upper Central Plain is in the Northern part of Chao Phraya Plain covering the areas of Uttaradit, Sukhothai, Pitsanulok, Kampangphet, Pichit, and Nakornsawan Provinces (Figure 1). Total area is 47,986 km^2 or 29,991,699 rais. Average height is approximately 40-60 meters above mean sea level. The areas consist of sediments which were transformed from erosion and decay of rock, then accumulated and generated as plain, terrace, and swamp.

The climate of Upper Central Plain is under the influences of monsoon winds i.e. southwest and northeast monsoon. From the meteorological point of view, the climate of Upper Central Plain can be divided into three seasons that are summer (mid-February to mid-May), rainy season (mid-May to October), and winter (November begin to mid-February). The study area is composed of 5 basins that are Lower Ping basin, Lower Yom basin, Lower Nan basin, Upper Sa-Grae-Grang basin, and Upper Chao Phraya basin, as shown in Figure. 1.

The Nan River Basin is the main water resource of the central region of Thailand. The SIRIKIT Dam is important because the release of the SIRIKIT dam, has supplied to the central plain including Bangkok area.

The Phitsanulok Irrigation Project, located in the Nan river basin, that receives water from Sirikit Dam with coverage area of 659,876 rais. This project includes Naraesuan Dam Operation and Maintenance Project 94,000 rais, Plaichumpol Operation and Maintenance Project 211,476 rais, Dongsatti Operation and Maintenance Project 186,000 rais and Thabua Operation and Maintenance Project 168,400 rais. The medium-scale reservoir projects are about 16 projects with a total combined active storage of 90.5 million m^3 and a total irrigated area of 229,650 rais. The small-scale reservoir projects are about 375 projects that have a total combined storage of 90.52 million m^3 and a total irrigated area of 329,646 rais. In addition, the pumping irrigation projects are about 299 projects with the irrigated area of 389,010 rais

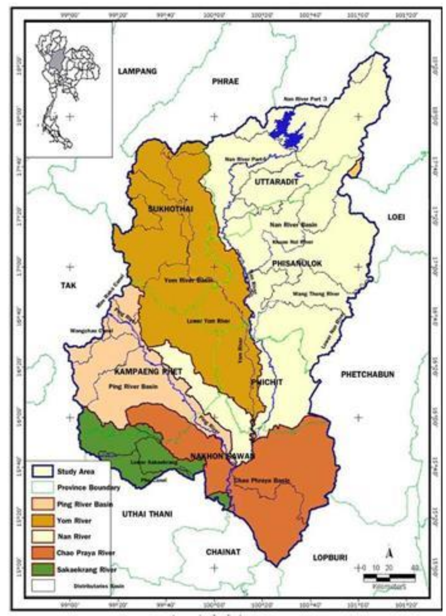


Figure 1 Upper Central Plain Basin

2.0 METHODOLOGY

There are two parts in this study. First part is to find the relationship of groundwater recharge rate from climate data. Seven groups of soil data series and groundwater model [12,20] results and to simulate the impact from climate change using the recharge relationship derived and the bias corrected the MRI GCM's climate data [13] in two future time frames, i.e., near future (2015-2039) and far future (2075-2099) periods. A linear regression method was applied to develop relationship between recharge flux and value of monthly precipitation minus evapotranspiration via groundwater model recalibration. The improved groundwater model (MODFLOW) was applied to assess the impact of climate change on groundwater recharge and ground water table in the study area. Second part is to simulate the cases using two types of dam rule curve (existing and improved) to relieve the water shortage situations in the Phitsanulok Irrigation Project and to quantify the role and the limits of groundwater to alleviate from the water shortage situations.

Groundwater Model

Groundwater model used in this study is MODFLOW (the USGS's three-dimensional (3D) finite-difference groundwater model). MODFLOW is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. The three-dimensional movement of groundwater of constant density through porous earth material may be described by the partial-differential equation

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_s\frac{\partial h}{\partial t} \quad (1)$$

where

K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes (space function).

h is the potentiometric head (hydraulic head).

W is a volumetric flux per unit volume representing sources and/or sinks of water, where negative values are water extractions, and positive values are injections. It may be a function of space and time (i.e. W = W(x, y, z, t)).

S_s is the specific storage of the porous material (space function).

t is time.

Recharge Equation

From the water budget analysis in the soil layer, the simple water budget is

$$P = ET+\Delta S+R_{off}+D \quad (3)$$

where

P is precipitation:

ET is evapotranspiration:

ΔS is change in water storage in soil column:

R_{off} is direct surface runoff: and

D is drainage out of the bottom soil which is equivalent to recharge(R)

From the above relation, The recharge can be approximated simpler by using following equation[16]:

$$R = P-ET-Q_0 \quad (4)$$

Equation (4) can be written again as follow:

$$R/P=a_i*(P-ET)/P +b_i \quad (5)$$

where

a_i and b_i are constant and can be found by using goodness fit test for each soil group.

P is precipitation, and ET is evapotranspiration and can be calculated by equation of temperature (T) [18]:

$$ET = c*T+d \quad (6)$$

where c and d are constants and can be found by using goodness fit test for each month.

3.0 RESULTS AND DISCUSSION

Impact of Climate Change Towards GW

Precipitation

The average precipitation (Figure 2) in present period was 1,392 mm./year [7]. The precipitation in near future and far future were collected from bias corrected GCM-MRI data [7], the average of precipitation in near future will more decreased than in far future (1,255 mm/year and 1,354 mm/year, respectively).

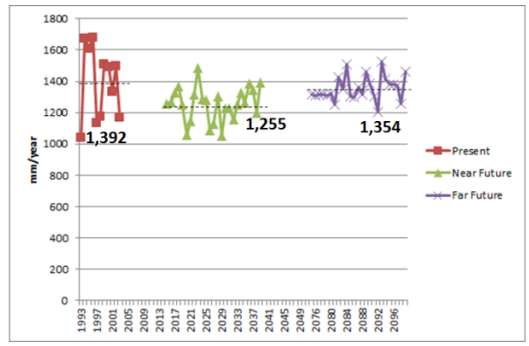


Figure 2 The average precipitation in present, near future and far future periods in the study area

Evapotranspiration

Evapotranspiration during the period 1979-2003 were collected from the report GCM Data Comparison and its application to water disaster adaptation measures in Thailand and the project on "The Impact of Climate Change on Irrigation Systems and Adaptation Measures" [7]. A comparison of evapotranspiration and mean temperature show that two variables have linear relationship as shown in Table 2 and shows good relation in rainy season where recharge occurs.

Table 2 Coefficients of linear function expressed relationship between evapotranspiration and mean temperature of each month

Month	c	d	R^2
Jan	8.428	-107.57	0.43
Feb	8.428	-107.57	0.43
Mar	8.428	-107.57	0.43
Apr	2.9665	70.568	0.97
May	4.0509	27.342	0.99
June	2.9895	22.826	0.99
July	3.0688	23.886	0.99
Aug	2.9941	23.959	0.99
Sep	3.129	23.413	0.99
Oct	3.4886	23.991	0.86
Nov	5.0792	-20.275	0.99
Dec	3.9656	-0.8793	0.87

Groundwater Model Recalibration

Groundwater flow model (MODFLOW) was used to simulate groundwater flow conditions in the area during the period 1993-2003. This model was developed by [2, 12]. Input data included river water level, observation groundwater level, and well abstraction used from the former study [17]. In former study, recharge rates were defined by percent of rainfall in each soil group zone. In this study, soil zone was grouped in 7 zones by the similarity of soil series property as shown in Figure 3. The model was recalibrated compared with observation data using recharge equation derived. Results of recalibration model show that simulation values were closer with observation data compared with the former model calibration results as shown in Table 3.

Table 3 Comparison error and recharge rate of the former model and this study model

Error(m)	Former model	This study	%Difference
Mean Error	2.85	2.11	26.16
Abs mean error	3.13	2.3	26.44
RMS error	4.59	3.9	15
Recharge rate(cu.m/day)	1,157,597	995,113	-14.04

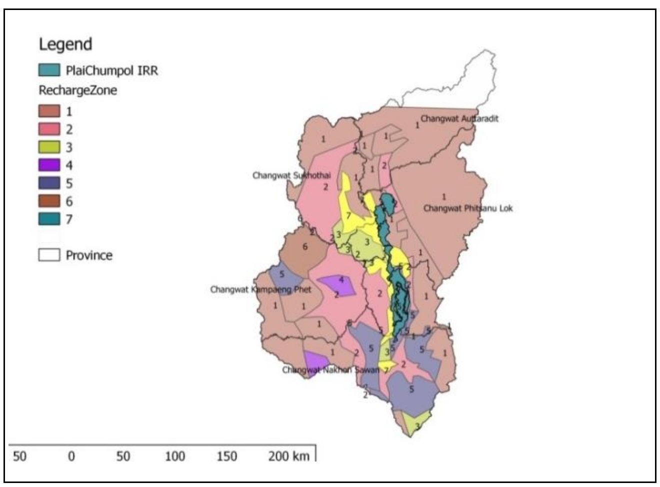


Figure 3 The soil group represent the recharge zone

Recharge Function

The rates of groundwater recharge in each soil group zone from the above step were used to develop relationship between recharge and amount of monthly precipitation minus monthly evapotranspiration per precipitation (Equation 5). Results demonstrated good relationship between groundwater recharge fluxes with amount of monthly precipitation minus monthly evapotranspiration as shown in Table 4.

From the permeability class [1, 20] and classification properties of each soil series [19], Table 5 shows the classification of each soil series group of this study and Figure 4 shows the relationship of the hydraulic conductivity/permeability and the coefficient of recharge per precipitation which shows good correlation. Figure 4 could be used to estimate the coefficient of recharge for other soil series from hydraulic conductivity value.

Table 4 Coefficients of linear function expressed relation between (P-ET)/P and R/P

Soil series group	a	b	R^2
1	0.0034	0.0009	0.93
2	0.0045	0.0012	0.93
3	0.0057	0.0015	0.94
4	0.0068	0.0018	0.94
5	0.008	0.0022	0.94
6	0.0091	0.0025	0.93
7	0.0113	0.0031	0.93

Table 5 Classification of hydraulic conductivity of each soil series group of this study

Permeability Class(O'Neal 1952)	hydraulic conductivity(cm/hour)	Soil series Group(This Study)
Very Slow	<0.125	1
Slow	0.125-0.5	2
Moderately Slow	0.5-2.0	3
Moderate	2.0-6.25	4
Moderately Rapid	6.25-12.5	5
Rapid	12.5-25.0	6
Very Rapid	>25.0	7

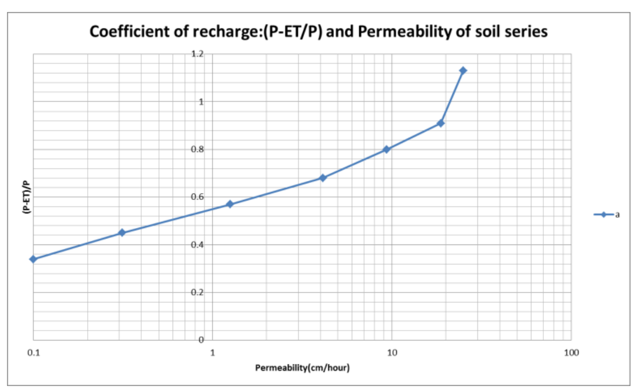


Figure 4 The relationship of coefficient of recharge and permeability of soil

The impact of climate change is considered from the change of recharge and groundwater table compared with present period. The groundwater recharge rate from the above relationship for each soil series group, were calculated and input to groundwater model to simulate the impact of climate change with future climate data. Figure 5 and Table 6 show that recharge tend to decrease in the periods of both near future and far future and will be lower than in the past due to the increase of the temperature and evapotranspiration. The ratio of average recharge rate in near future and far future compared with present is 0.42, and 0.50 respectively. The heads of groundwater in the selected stations in the study area are shown in Figure 6. It can be seen that climate change will induce lower water table in the north due to higher temperature (including the area of Plaichumpol Operation and Maintenance Project), i.e., water table will decrease approximately 0.23, 0.16 m/year in near future and far future periods respectively.

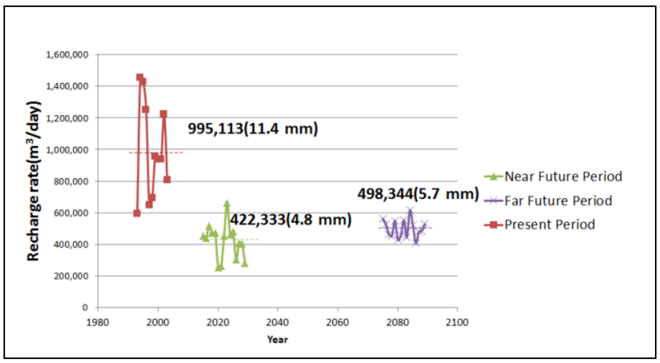


Figure 5 Average groundwater recharge rate from projected future climate data

Table 6 The % Difference of Rain, ET, P-ET and Recharge Rate in Near Future, Far Future compare with Present Period

%Difference compared with Present Period	Rain(P)	ET	P-ET	Recharge Rate
Near Future	-9.87	2.74	-48.71	0.42
Far Future	-2.73	8.78	-39.9	0.5

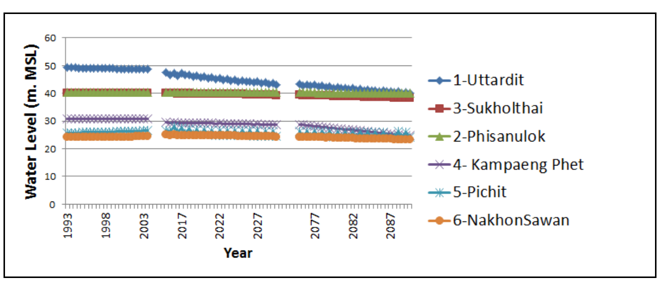


Figure 6 The groundwater level change at selected locations in each Province

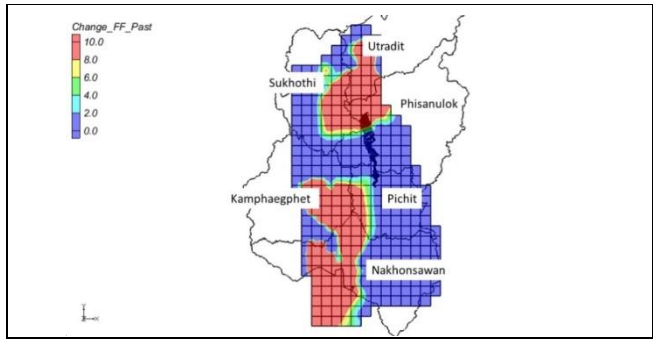


Figure 7 The change of water level (in meter) in the aquifer by the end of far future period

From Figure 7, the hot spot in lower water level will occur in some part of Uttraradit, Sukholthai, Phitsanulok, Kampaengphet, Pichit and Nakhonsawan Provinces, especially in upper part of Plaichumpol Operation and Maintenance Project and the decrease of water level is up to 10 m

The Role of Groundwater to Mitigate the Drought Situation Concerned with CC and Its impacts

The groundwater model is applied to quantify the role and limits of groundwater to mitigate the drought (conjunctively with surface water and caused from the impact from climate change) in The Phitsanulok Irrigation. There are 3 cases of groundwater simulation. Case a is for existing pumping condition. Case b is to increase pumping to cover all water shortage under existing ROC and Case c is to increase pumping to cover all water shortage under improved ROC.

The results show that the change of groundwater storage in cases of a, b and c in near future and far future periods are 1,247,679, 544,280, 1,170,543, 516,800.20 cum./day respectively. When compared with the future condition in case a, the water storage decreased in the ground water aquifer in case b and c in near future and far future periods are 34%, 26%, and 25% and 19% respectively. Figure 8 shows the groundwater head in each case and the Table 7 shows the maximum different head that will occur in The Phitsanulok Irrigation Project. The results show that if we use the groundwater to cover water shortage, in some area will have groundwater head below the safe limit that the farmers can pump the water from the ground surface (set to be 10 m from ground surface), and when we applied case C, the farmers can use groundwater to alleviate their water shortage as an adaptation measures and the limited volume of ground water pumping to alleviate water shortage will be 80 and 77 MCM in near future and far future period respectively.

Table 7 The maximum different heads compared with present period

Case	Max. Different head from present period (m)	
	near future	*far future*
Case a	-3.82	-3.84
Case b	-19.68	-28.08
Case c	-9.89	-10.9

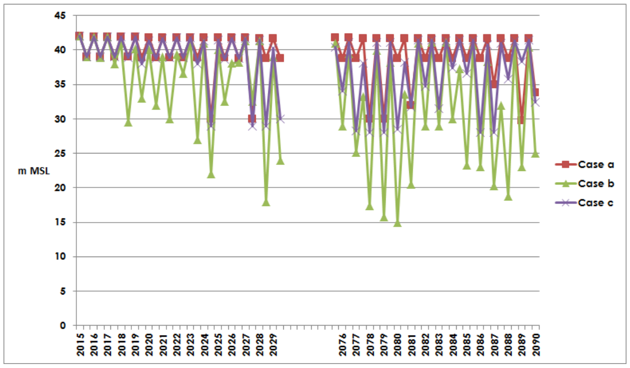


Figure 8 The groundwater head(in m MSL) in the study area in Plaichumpol Operation and Maintenance Project area

4.0 CONCLUSIONS

In this study, the relationship of recharge rate with climate data was developed in terms of precipitation, evaporation and temperature and soil type under monthly time series data and the study found that there were in good relationship and can be used to study the impact of climate change on groundwater recharge and water table based on future climate data.

The future recharge, compared with the present, will decrease 58% in near future and 50% in the far future periods due to climate change. The water storage decreased in the ground water aquifer in case of existing ROC(case b) and improved ROC (case c) in near future and far future periods are 34%, 26% and 25% and 19% respectively in order to alleviate from the water shortage situations. Climate change will also induce impact on groundwater level, i.e., water table will decrease approximately 0.23 m/year in near future and 0.16 m/year in far future periods, especially in upper part of Plaichumpol Operation and Maintenance Project, the decrease of the water level will be up to 10 m.

The limit of ground water to alleviate water shortage will be 80 and 77 MCM/year in average, in near future and far future periods to keep the water table in the safe manner even when the Sirikit's reservoir operation rule is improved.

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