Impacts of the 2011 Thailand Flood on Groundwater Recharge Potential in Flood Retention Area in the Middle Reach of Tha Chin River

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Abstract. *The non–structural flood control measures under concept of "room for the river" were addressed and contained in the national master plan of flood management of Thailand due to unprecedented flooding occurrence in 2011. Some specific areas particularly in the upper and lower east of the Phanom Thuan, Song Phi Nong, and Bang Len Operation and Maintenance Projects in the middle reach of Tha Chin River were assigned as large flood retention area to retain excessive floodwater and reduce flood peak from the Chao Phraya and Tha Chin River Basins. Consequently, this study aims to explore the potential of groundwater recharge in the assigned flood retention area due to the 2011 Thailand flood. Groundwater flow modelling was then carried out and 4 scenarios of assigned flood stages of 0.50 m, 0.80 m, 1.50 m, and 2.00 m above the land surface were then simulated. The increase in hydraulic heads was investigated and compared with the spatial distribution of groundwater recharge rates done by WetSpass model in the same area. The results show that groundwater recharge potential in flood retention area along the right bank of the Tha Chin River is definitely low due to inappropriateness of hydro–geologic properties and high thickness of clay soil. In addition, the effects of downslope topography on local hydraulic gradient would influence the direction of groundwater flow discharging into the Tha Chin River and adjacent area. The simulated results performed by WetSpass model also show that average groundwater recharge rate in critical flood year in 2011 is 198.54 mm which is quantified as 19.43% of average annual rainfall. Moreover, the lowest value of average groundwater recharge rate is found especially in the lower east of Bang Len Operation and Maintenance Project which is considered as the assigned flood retention area.*

Received by	26 September 2021
Revised by	10 March 2022
Accepted by	12 March 2022

Keywords:

The 2011 Thailand flood, flood retention area, groundwater recharge potential, Tha Chin River

1. Introduction

The 2011 Thailand flood has been recognized as the worst flood in a half century creating tremendous damages and losses of economics, lives, properties, and fundamental infrastructures. It is pointed that the tropical location of Thailand and influences of excessive seasonal monsoon rainfall and local topography are key factors causing this severe flood [1–4]. The 2011 flood affected more than 69 provinces with flood inundation area of 41,383 km^2 or 9.1% of the total land area of the country [1]. The World Bank estimated that the recovery and reconstruction due to the 2011 flood would cost more than 50 billion US dollars. The total expected damages and losses were amounted to 46.5 billion US dollars [2]. Most of the affected area was sparsely scattered in the Chao Phraya and Tha Chin River Basins, and surrounding areas. To cope with the extreme floods and build up public confidence and security at the national level, the concept of "room for the rivers" comprising large flood retention areas and Monkey Cheek reservoirs (so–called "Gamling") was stated and contained in a master plan on water resources management of Thailand [2]. Some districts in Suphanburi and Nakhon Pathom Provinces such as Bang Len, Song Phi Nong, Bang Li, and Bang Pla Ma, etc. were assigned as the potential flood retention areas to reduce flood peak and slow down flooded water in the Chao Phraya River, as shown in Fig. 1. The impacts of flooding in the potential flood retention areas were broadly questioned by relevant stakeholders as well as local people in both positive and negative manners. Importantly, the influence of flood spreading on groundwater recharge in these flood retention areas in the middle reach of the Tha Chin River was addressed and needed to be explored and answered. Groundwater recharge is the foundation of hydrological processes of subsurface water system that replenishes water in aquifer system. It is recognized that information on groundwater recharge is highly necessary for the evaluation of the groundwater resource status and risk of groundwater depletion [5]. Accordingly, this study aims at investigating the impacts of the 2011 Thailand flood on groundwater recharge potential in flood retention areas occupying the irrigated land area of the Phanom Thuan, Song Phi Nong, and Bang Len Operation and Maintenance Projects in the Maeklong and Tha Chin River Basins.

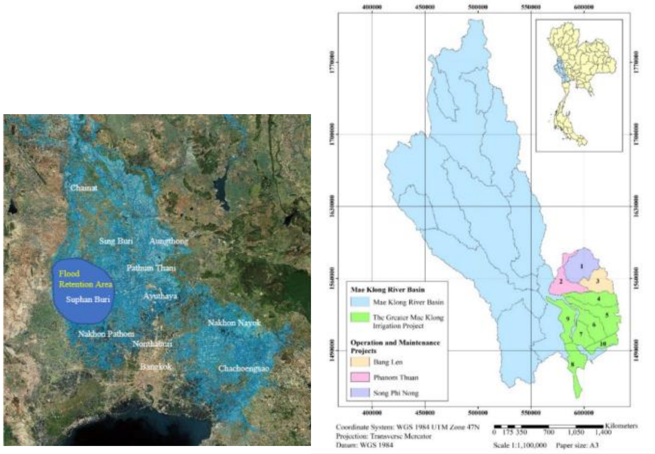
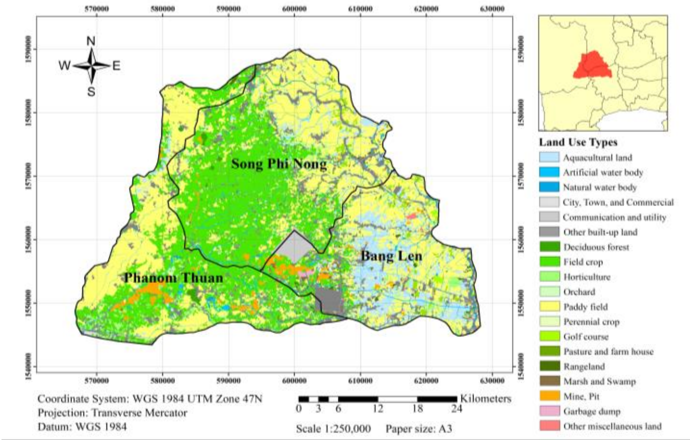


Fig. 1 Flood Inundation Map, Dated October 17, 2011 and the Study Area Map [3]

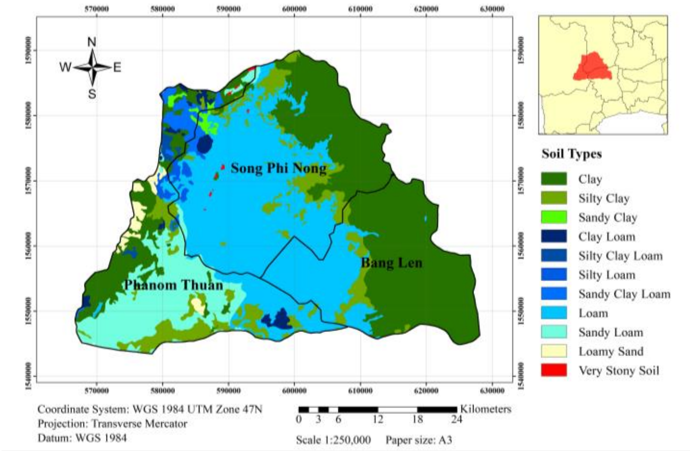
2. Study Area

The Phanom Thuan, Song Phi Nong, and Bang Len Operation and Maintenance Projects are located in the upper part of the Greater Maeklong Irrigation Project (GMKIP) on the right bank of the Tha Chin River. It covers an area of approximately 1,758 km^2 in the Maeklong and Tha Chin River Basins in Kanchanaburi, Suphan Buri, and Nakhon Pathom Provinces. The groundwater sources in the region have been used to supplement surface water particularly for agricultural and industrial uses. Surface water for irrigation has been supplied from Maeklong Diversion Dam through canal water distribution system.

During the great flood in 2011, some specific areas in the upper and lower east were considered as flood retention area to retain excess water from the adjacent basins and to drain water through Chorakae Sam Phan Drainage Canal. Most of the western part of study area is upland area having the highest surface elevation of +400 m msl and gradually become flat area in the east near the mean sea level. The main agricultural crops are rice and field crops which occupy 35.89% and 30.03% of the entire area, respectively. The remaining 34.03% are vegetables and water body. Distribution of land use is relatively subject to soil types. The paddy field and field crop areas lie on clay and loam and sandy loam soils, respectively as shown in Fig. 2.



(a) Land use type



(b) Land use type

Fig. 2 Land Use and Soil Types in the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects

3. Methodology

Groundwater flow modelling was carried out [4] to simulate groundwater dynamics in the study area due to flood behaviors occurred in 2011. The study area was modelled horizontally on a two–dimensional grid and vertically as one unconfined aquifer on the top layers and 8 confined aquifer layers below. All aquifer layers were intervened by aquitard and the bedrock was identified in the bottom layer. The vertical layers were assigned as the heterogeneous layers having the specific hydrological properties. The grid was divided into rectangular cells (49 rows and 64 columns) occupying the entire area. Each rectangular cell has an area size of 1,000 x 1,000 m^2 equally. The 3D model of aquifer system and layered structure are shown in Fig. 3. Calibration process of the groundwater flow model was accomplished under both steady state and transient state conditions using 20 observation wells monitored during 2000–2016. The aim of the model calibration under steady–state flow is to determine the distribution of hydraulic conductivity required to match the observed water levels. The 3D hydraulic conductivity is the key hydraulic parameters of groundwater flow model describing the capacity of rock or soil to transmit water. In addition, model calibration under transient flow aims to calibrate the storage coefficient and recharge parameters. The storage coefficient explains the volume of water released from storage in a unit prism of an aquifer when the head is lowered by a unit distance. The accuracy of calculated hydraulic head in the model is presented by residual mean, absolute residual mean, standard error of the estimation, normalized root mean square, and correlation coefficient. Model calibration processes are qualified when accuracy level of normalized RMS is less than 10% [6]. The results of model calibration under steady–state flow condition show that the value of normalized RMS is 7.48% which is in an acceptable range. The maximum residual, minimum residual, and correlation coefficient are –6 m, –0.14 m, and 0.97, respectively. The results of model calibration under transient flow condition show that the value of normalized RMS is 8.69% which is in an acceptable range. The maximum residual, minimum residual, and correlation coefficient values are –6.8 m, 0.5 m, and 0.96, respectively which can be reasonably acceptable.

Layer	Type	Layer no.	Thickness and other characteristics
Bangkok Clay (BKclay)	Unconfined aquifer	1	Soft marine clay with 30 m thickness
Bangkok Aquifer (BK)	Confined aquifer	2	20–30 m
Phra Pradeang Aquifer (PD)	Confined aquifer	4	20–50 m
Nakhon Luang Aquifer (NL)	Confined aquifer	6	50–60 m
Nonthaburi Aquifer (NB)	Confined aquifer	8	60–70 m
Sam Khok Aquifer (SK)	Confined aquifer	10	50–70 m
Phaya Thai Aquifer (PT)	Confined aquifer	12	50–70 m
Thon Buri Aquifer (TB)	Confined aquifer	14	30–50 m
Pak Nam Aquifer (PN)	Confined aquifer	16	60–90 m
Rock	Confined aquifer	18	It consists of sedimentary, granite, basalt and metamorphic rocks.
Aquitard	Aquitard	3, 5, 7, 9, 11, 13, 15, 17	Hard stratum lying adjacent to aquifer layers that allows small amount of flow to pass it.

Table 1 The layered structure identified in groundwater flow model [7]

After groundwater flow modelling process was successfully made, flood inundation map in 2011 produced by the Geo–Informatics and Space Technology Development Agency (GISTDA), Thailand (as shown in Fig. 4) [8] and flood stages stated in the flood survey report [9]; were then used as the input data for groundwater flow simulation. Simulation of groundwater flow dynamics was referred to the actual situations of flood waterlogging and maximum flood depths. Therefore, 4 scenarios of assigned flood stages of 0.50 m, 0.80 m, 1.50 m, and 2.00 m above the land surface were then generated. To describe its potential in term of capability to recharge water into aquifer system, the increase in hydraulic heads was finally investigated and compared with the spatial distribution of groundwater recharge rates done by WetSpass model in the same area.

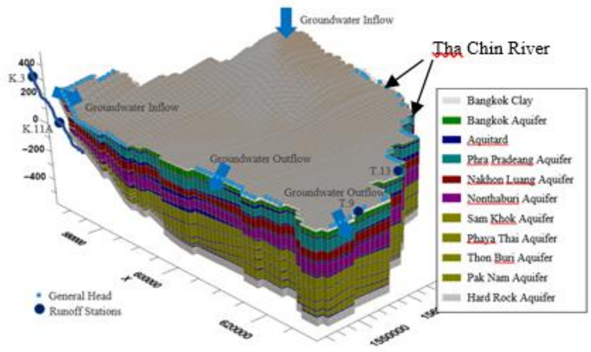


Fig. 3 The 3D model of Aquifer System in the study area

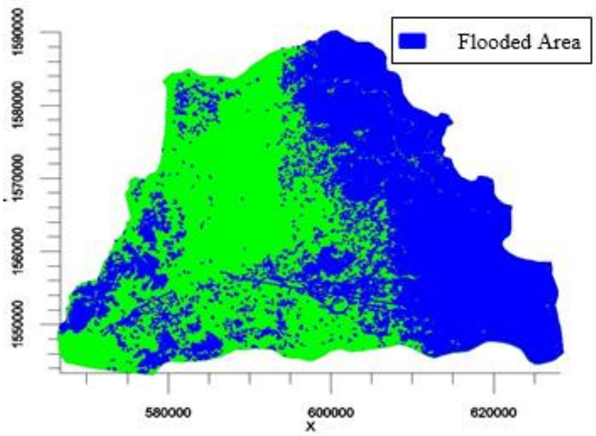


Fig. 4 The 2011 flood inundation map used in this study

4. Results and Discussions

To investigate the potential of groundwater recharge in the flood retention area due to flooding, the situations of flood waterlogging from the 1st August 2011 to 31rd December 2011 were simulated with different flood stages of 0.50, 0.80, 1.50, and 2.00 m above the land surface using groundwater flow model. The results show the spatial distribution of the increasing of simulated hydraulic heads in aquifers at the last time step (on the 31rd December 2011) which is accordingly referred to groundwater recharge potential, as shown in Fig. 5. When waterlogging with flood stage of 0.5 m is simulated, the average hydraulic heads in aquifer layers in Fig. 5(a) are increased over the entire area. The highest increase in hydraulic heads varying from 1.21–3.90 m is found in the Phanom Thuan Operation and Maintenance Project where soil textures are enormously loam and sandy loam. The increase in hydraulic heads in clay soil specifically in the Song Phi Nong and Bang Len Operation and Maintenance Projects becomes lower than in loam and sandy loam. It is also exhibited that the increase in hydraulic heads in aquifers is relatively subject to the thickness of Bangkok clay. The highest clay thickness is predominantly found in the lower east of the Bang Len Operation and Maintenance Project varying from 14.01–27.45 m as shown in Fig. 6. Consequently, there is no significant increase in the average hydraulic heads found in the lower east of the study area. Moreover, it is found that the average hydraulic heads are slightly increased when depths of flood waterlogging are assumed higher than 0.5 m as can be seen in Fig. 5(b-d). This might be because of soil conditions in reaching the saturation state.

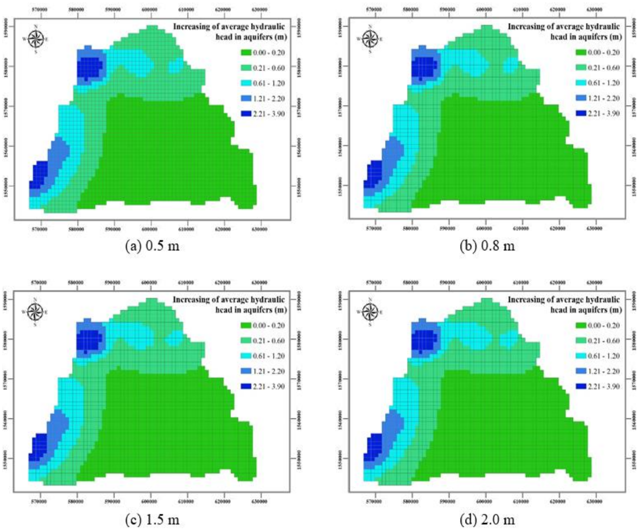


Fig. 5 Increasing of Hydraulic Heads in Aquifers with Flood Stages of 0.5, 0.8, 1.5, and 2.0 m

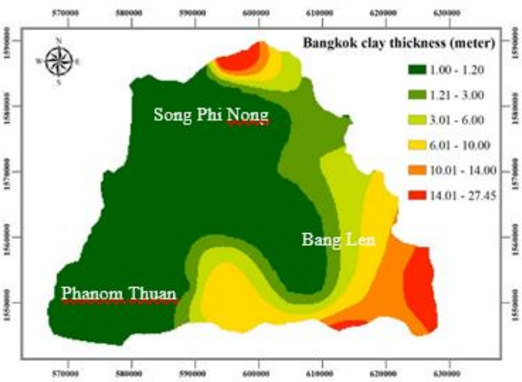


Fig. 6 Thickness of Bangkok Clay in the Study Area

According to the simulation result performed by groundwater flow model, it reflects that groundwater recharge potential in flood retention area along the right bank of the Tha Chin River is definitely low due to inappropriateness of hydro–geologic properties and high thickness of clay soil. In addition, the downslope topography on local hydraulic gradient would influence the direction of groundwater flow discharging into the Tha Chin River and adjacent areas inevitably.

As aforementioned, the finding on groundwater recharge potential in flood retention area during the 2011 flood is finally re-diagnosed by referring to the relevant results of groundwater recharge rates obtained from groundwater recharge model; WetSpass applied in the same area. WetSpass model (Water and Energy Transfer between Soil, Plants and Atmosphere under quasi Steady State), is one-dimension steady state spatial distribution water balance model which has been widely used for groundwater recharge estimation. WetSpass integrates the Geographic Information System (GIS) with the water balance equation to determine potential groundwater recharge [10]. It is revealed that the average annual recharge in the Phanom Thuan, Song Phi Nong, and Bang Len Operation and Maintenance Projects during 2010–2017 were 201.67, 200.46, 132.29 mm, which are about 22.5%, 22.4%, and 14.8% of average annual rainfall, respectively (as shown in Table 2) [5]. The average groundwater recharge rate in critical flood year in 2011 was 198.54 mm over the entire area which is quantified as 19.43% of average annual rainfall. It is found that groundwater recharge in wet season particularly in 2011 was quantified to be 80.30% of average annual rainfall which is much more than in dry season. The spatial distribution of average annual groundwater recharge performed by WetSpass model during 2010–2017 is shown in Fig. 7. It is apparent that the groundwater recharges in loam and sandy loam in the Phanom Thuan and Song Phi Nong Operation and Maintenance Projects are nearly the same due to the similarity in distribution of land use types and soil properties. Meanwhile, rate of groundwater recharge in clay soil, especially in the Bang Len Operation and Maintenance Projects, becomes the lowest. Furthermore, the lower rates of groundwater recharge is found along the Tha Chin river bank which absolutely corresponds to the results of the slight increase in groundwater heads obtained by groundwater flow model.

Irrigation Area	Annual Groundwater Recharge (mm)	% Rainfall
Phanom Thuan	201.67	22.5
Song Phi Nong	200.46	22.4
Bang Len	132.29	14.8
Soil Types	**Annual Groundwater Recharge (mm)**	**% Rainfall**
Clay	132.21	14.8
Loam	219.67	24.6
Sandy Loam	229.65	25.7

Table 2 Average annual groundwater recharge distribution during 2000–2017

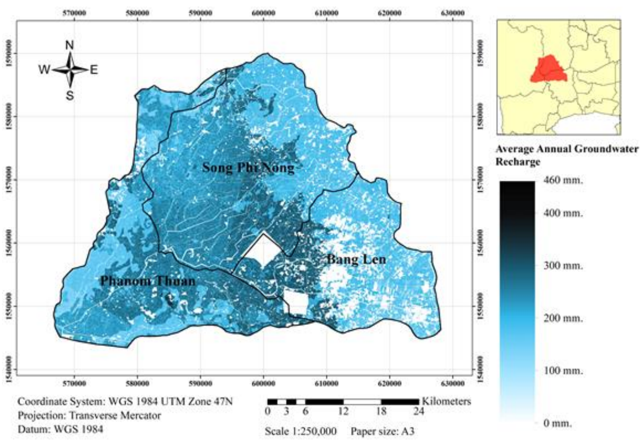


Fig. 7 Average Annual Groundwater Recharge Performed by WetSpass Model (2010–2017)

5. Conclusions

The positive impact of the 2011 Thailand major flood on groundwater recharge in flood retention area in the middle reach of the Tha Chin River was investigated in this study to deliver useful information to the public. The response of hydraulic heads in aquifer system is accordingly referred to the potential of groundwater recharge due to flooding. The Phanom Thuan Operation and Maintenance Project is found as a potential area for groundwater recharging. However, low potential zones of groundwater recharge are definitely found along the right bank of Tha Chin River due to inappropriateness of hydro–geologic properties and high thickness of clay soil. Moreover, the lowest values of hydraulic head increase in the aquifer system and average groundwater recharge rate are found especially in the lower east of Bang Len Operation and Maintenance Project which is considered as the assigned flood retention area.

Acknowledgements

This study was supported by the Agricultural Research Development Agency, Thailand (ARDA), granted No. POP6105021990.

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