AN INVESTIGATION OF FACTORS INDUCING GROUNDWATER RECHARGE IN THE UPPER CHAO PHRAYA'S FLOOD PRONE AREA IN THAILAND

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1. INTRODUCTION

Groundwater is a crucial water source for buffering surface water stress (insufficient of surface water to demands), and has been explored worldwide. However, overused of groundwater will cause negatively impacts, e.g., depletion of groundwater level, land settlement, salt water intrusion in coastal zones, and so forth. To protect the problem as mention above, sustainable groundwater use, which defined as the extraction amount of groundwater should not over its recharge for this study, need to be implemented. In fact, groundwater recharge is one of hydrological variable which is difficult to evaluate since it is depended upon many factors such as rainfall, evaporation, land cover, soil types, and so on.

Thus, a flood prone area in Upper Chao Phraya River basin (UCP) that is located in the northern part of Thailand (**Fig.1**) was investigated of factors inducing of groundwater recharge. According to the facts that the UCP usually faces to both flood and drought problems and groundwater trends to increasing use; therefore, basis assessment of groundwater recharge from rainfall, flood inundation, and river induced infiltration will be benefited for water resources management. Furthermore, clear understanding of the interconnection and factors inducing of groundwater recharge might be enhanced more options or management strategies in order to gain more groundwater resources in the study area.

2. UPPER CHAO PHRAYA'S FLOOD PRONE AREA

Fig.1 shows the UCP and its flood prone area which is located along Yom and Nan Rivers (red dot line). Based on our main objective that aims at revealing flood inundation to groundwater, thus only the flood prone area (read shading area in **Fig.1**) was focused on. There are 3 rivers, i.e., Ping, Yom, and Nan Rivers as the main rivers in the study area. And more than 80% of land area are paddy field. In fact, the Ping and Nan Rivers are subjected to operation of Phumibol and Sirikit reservoirs, respectively, which are huge reservoirs in Thailand− approximately 23 km^3 in total storage. In contrast, there is no reservoir on the Yom River. Therefore, this river usually faces to flood and drought disasters.

In the long term study, there is approximately 990 mm in average annual rainfall and 82% of that amount is loss through the evapotranspiration (Pratoomchai et al., 2014). In 2011, which was abnormal year of hydrological event, the amount of annual rainfall was observed higher than the average of 140% (Komori et al., 2012) and caused extremely flood disaster that never experienced in Thai recorded. In the dry season (November-April), an area along the Yom River usually needed to extract groundwater for growing rice in the dry season since surface water is not enough to demand.

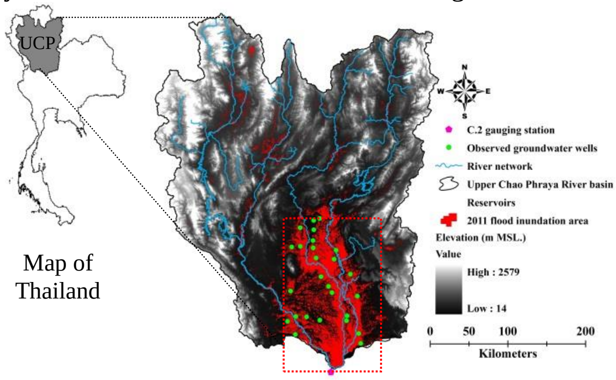

Fig.1 Study area: Upper Chao Phraya's flood prone area

3. METHODOLOGY

To investigate the factors inducing groundwater recharge and storage in the UCP's flood prone area, sets of mathematical models, i.e., rainfall induced recharge, river-flood inundation, and riverbed induced infiltration were constructed. Following are governing equations for each particular model.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}-q=0 \tag{1}$$

$$\frac{1}{g}\frac{\partial v}{\partial t}+\frac{1}{2g}\frac{\partial v^2}{\partial x}+\frac{\partial H}{\partial x}+\frac{n|v|v}{h^{4/3}}=0 \tag{2}$$

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \tag{3}$$

$$\frac{\partial M}{\partial t}=-gh\frac{\partial H}{\partial x}-gn^2\frac{M\sqrt{M^2+N^2}}{h^{7/3}} \tag{4}$$

$$\frac{\partial N}{\partial t}=-gh\frac{\partial H}{\partial y}-gn^2\frac{N\sqrt{M^2+N^2}}{h^{7/3}} \tag{5}$$

$$SMD=SMD'-(R+Nsss'-E-Ro)\times(1-FNSS) \tag{6}$$

$$Qr=\frac{P'}{m'}\Delta hA_s \tag{7}$$

$$\frac{\partial}{\partial x}\left(T\frac{\partial d}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial d}{\partial y}\right)=S\frac{\partial d}{\partial t}+Qi \tag{8}$$

where A is cross-sectional flow area, Q is river discharge, q is side flow, v is flow velocity, h is flow depth, n is Manning's roughness, g is gravitational acceleration, M is water flux along x-direction, N is water flux along y-direction, R is rainfall, E is evapotranspiration, Ro is runoff, SMD' and SMD are soil moisture deficit at the starting and ending of a computation, $Nsss'$ and $FNSS$ are coefficients to estimate groundwater recharge from rainfall, T is

Key words: Flood control, Groundwater, Thailand, Water resources management
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transmissivity, S is storage coefficient, d is groundwater level, Qi is recharge, Qr is recharge/discharge through streambed, Δh is a difference of water levels between the river and the nearby aquifer, A_s is streambed area, and P' and m' are streambed conductivity and thickness, respectively. Eq. (1 to 5) are used for calculating river-flood routing and inundation over a floodplain. Eq. (6 and 7) used for estimate groundwater recharge from rainfall and river induced recharge/discharge, respectively. And Eq. (8) used for calculating groundwater flow. Details of the finite difference technique for the governing equations were provided by Kazama et al., 2007, Prickett and Lonnquist, 1971, Rushton, 2003, and Pratoomchai et al., 2014.

4. RESULTS AND DISCUSSION

Fig.2 shows spatial distribution of extending flood inundation areas (a-c) in the UCP's flood prone area and a comparison of annual flood inundation area (d). Over the period of 2005-2012, the areas of approximately 1,300 to 8,873 km^2 (observation) were subjected to flooding. In addition, we would note that the area long the Yom River is highly risk to flood since flooding are take place in that area every year. From **Fig.2**, our model revealed flooded areas over the same period of 1,106 to 4,165 km^2. At this point, the model performed lower estimation. Complexity of the topography and the satellite observed data that might consider areas which have high soil moisture content as flooded areas could be potential causes of the missed match especially the events of flood inundation larger than 2,000 km^2. However, for small floods such as the 2005, 2007, 2008, 2009, and 2012 events our model showed reasonable results of annual flooded areas to the observations.

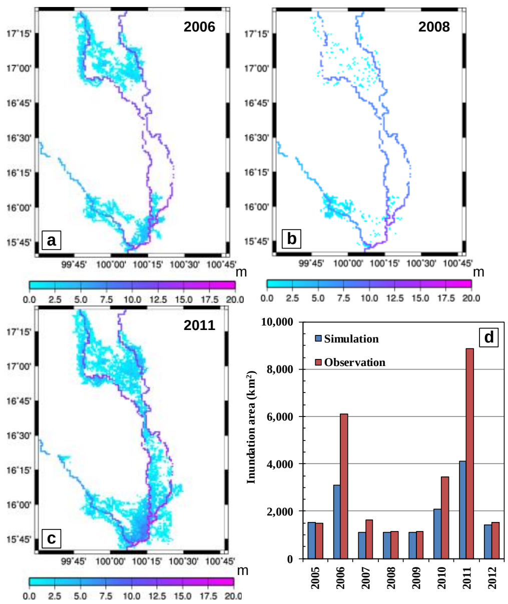

Fig.2 Comparison of annual flood inundation areas in the UCP's flood prone area

From Eq. (6), the estimation of groundwater recharge induced by rainfall was approximately 93.3 mm or 9.4% of mean annual rainfall (Pratoomchai et al., 2014). However, this factor has likely wide varied from 46.4 to 125.8 mm of recharges for drought years and wet years, respectively, over the whole UCP. The coupling integration of groundwater recharge, i.e., rainfall, inundation, and streambed induced infiltration were implemented in groundwater flow model as written in Eq. (8).

Our results showed approximately 2.5 to 8.2 km^3 of groundwater storages were estimated based on different hydrological conditions (flood magnitudes). Approximately 1.9 km^3 of the storage was induced by rainfall and slightly certain amount since rainfall in the UCP's flood prone was not much variation from year to year. Thus, it might be assumed that the rest of groundwater storage after subtracting of 1.9 km^3 (inducing by rainfall) was consequence of flood inundation and river induced infiltration. The above figures can be used for monitoring groundwater extraction for protecting over use of its capacity.

5. CONCLUSIONS

The integrated of mathematical models that coupling of river routing, simplification of 2 dimensional inundation flow, groundwater flow, and groundwater recharge estimation were constructed. Even the models still need to find tune of its parameters; however, their performance so far is quite good enough and help us to understand the characteristic of groundwater in the study area. For instance, comparing the big flood event like the 2011 (8,873 km^2 of inundation area) with the almost same flood magnitudes (e.g., 2005, 2008, 2009, and 2012 events− which were approximately 1,030 to 1,628 km^2 in the flooding areas) shows that increasing of approximately 6.7 times in inundation areas turn out approximately 10.5 times in groundwater storage.

ACKNOWLEDGEMENTS

We are very pleased to express our appreciation for the Integrated Study Project on Hydro-Meteorological Prediction and Adaptation to Climate Change in Thailand, Monbukagakusho scholarship for the first author, and observed data from Department of Groundwater Resources, Thailand.

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