# *SPATIAL VARIABILITY OF PRECIPITATION AND SOIL MOISTURE ON THE 2011 FLOOD AT CHAO PHRAYA RIVER BASIN*

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## ABSTRACT

The catastrophic flood occurred in 2011, caused enormous economic losses and human damage on Thailand. Water demand has been growing due to population growth and the main sectors of the demand include drinking water, agriculture, industry, hydropower generation, and the navigation. Thus, a better understanding of hydrological processes plays a key role not only in the water resources management, but also in the protection of Thai society from the water-related disasters. This study aims to examine 2011 flood status by a distributed hydrological model (DHM) coupled with dam operation at Chao Phraya basin, Thailand. The DHM was set-up at the contributing area to Chao Phraya dam for inflow estimation in order to protect the lower region. The model was calibrated in 2008 and validated in 2011, respectively, by rain gauged network and satellite based precipitation. By the numerical simulation, time series of river discharge, the distribution of soil water content, and water balance were obtained at the target basin. The validity of the model was demonstrated by comparing simulated and observed river discharge at each key branch: Ping River, Wang River, Yom River, and Nan River. The simulated soil moisture showed its effects on the flooding peak and timing of runoff processes. This approach might be beneficial information for actual dam operation and river management to include potential extreme flooding due to climate change.

**Keywords:** flood simulation, soil moisture distribution, dam operation, distributed hydrological model, Chao Phraya River

## 1 INTRODUCTION

The risk of flood and drought are likely to become more severe in the future due to climate change and population growth around the world (Field et al., 2012). The seriousness degree depends on the region's climate locality and infrastructure development. Especially for south-eastern Asia, it seems inadequate to prepare coming serious flooding damage because the water storage facilities area vulnerable. In fact, severe flooding that had occurred in Thailand since the beginning of September, 2011 caused great damage on livelihood, social and economic of the nation. It is estimated that total flood volume was 15 billion $m^3$ and the total damage reached more than 1.36 trillion baht (approximately 3.5 trillion Japanese yen) (Komori et al., 2012). Moreover, lately flooding is becoming even a serious concern for Chao Phraya basin by extreme events with climate change (Jarupongsakul and Kaida, 2002). Therefore, flood simulations by using hydrological model have been implemented to manage water resource; to support dam operation and forecast floods in Thailand. However, they mainly focus on the relationship between the river discharge and precipitation. In 2011 flooding, the extraordinarily high rainfall is also one of main reason. In addition, flooding peak should be related to land use pattern, groundwater level fluctuation and soil moisture's distribution. Soil moisture especially plays the important role in the interaction between land surface and atmosphere especially in the region which has high evaporation. The purpose of this paper is to examine the flooding characteristics in terms of hydrology by simulating DHM at upper Chao Phraya River Basin. This paper is organized as follows. First of all, the model calibration was implemented in 2008 with dam operation module. Secondly, flood simulation with dam effect was performed by local rain gauge network and satellite based precipitation in 2011. Thirdly, we discussed about 2011 flooding characteristics based on the calculated output form DHM; time series of river discharge, the distribution of soil water content, and water balance.

## 2 STUDY AREA

Chao Phraya River basin covers about one third of Thailand (Figure 1). It encompasses approximately 160,000 $km^2$ and its annual precipitation is about 1,200 mm/year. The basin is traditionally the center of rice production because monsoon weather typically brings more rainfalls from May to October. Chao Phraya River is composed with four major tributaries, namely the Ping River, the Wang River, the Yom River, and the Nan River, which confluent at Nakhon Sawan. In the northern mountainous region, there are valleys covered by forest or bare soil. These valleys, stretching south to north, lead to headwaters. Moreover, two major dams, Sirikit and Bhumipol, are in operation there. The flood control point is set at Chao Phraya dam(C2 at Figure 1). The operations of these dams might reduce the effect on flooding at lower areas where large cities like Bangkok and Ayutthaya are located. In Thailand, generally, rivers in upper basins have steep slopes while lower reaches have very mild ones. It might cause flash flooding in upper basin and the long-period flooding in the lower basin.

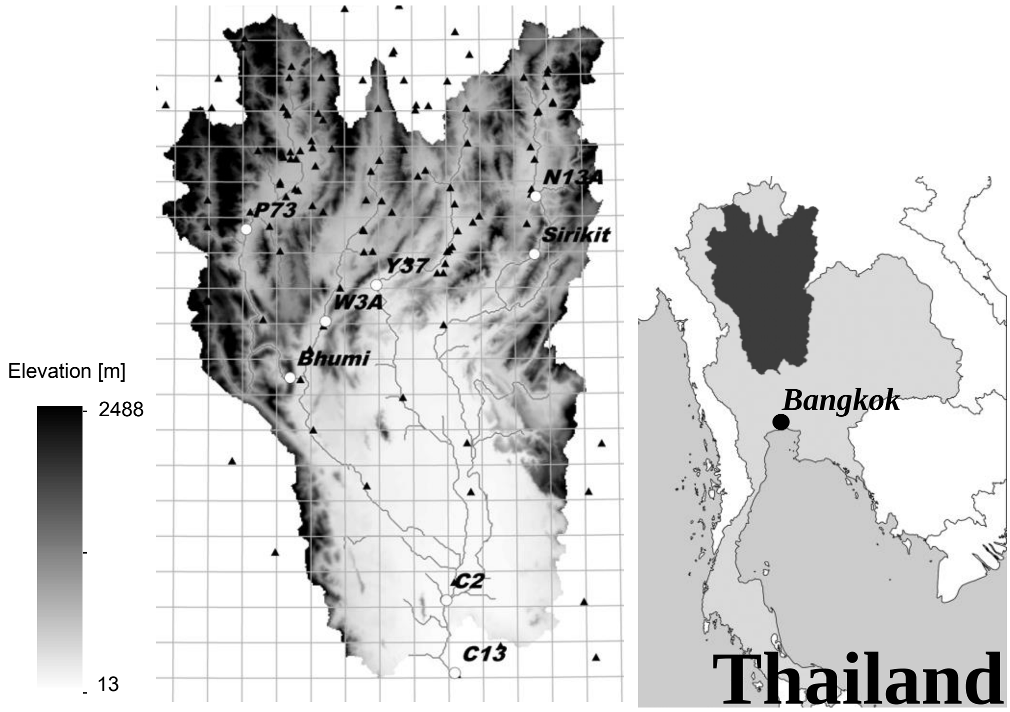


**Figure 1. Chao Phraya River Basin**

## 3 MATERIAL AND METHOD

### 3.1 Datasets

Daily precipitation data were collected from two kinds of rain gauge network systems. The first one is an open-source rain gauge network data provided by the Royal Irrigation Department (RID), Hydrology and water management center for upper northern region. The other one is managed by the Thai Meteorological Department (TMD). The temporal resolution is one day for both data. The spatial resolutions are shown as triangles in Figure 1. Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis product, namely 3B42 Version 7 is also used as input for a hydrological model. TRMM (URL: http://www.eorc.jaxa.jp/TRMM/index_j.htm) launched by the National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) in

1997 provides rainfall data in tropical area with three hour interval. The spatial resolution is 0.25°×0.25° latitude-longitude (approx. 25 km) shown in Figure 1 as grid line.

Geographical information (e.g., topography, soil type, land use) were collected for a hydrological model. Digital Elevation Model (DEM) was obtained from Shuttle Radar Topography Mission (URL: http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/), which has 90 m spatial resolution. As for soil type classification, Digital Soil Map of the World version 3.6 was used from Food and Agriculture Organization of the United Nations (FAO/UN). The dominant soil found out was clay sandy in upper region while sandy silt in lower region. As land use data, we used global land cover characterization (http://edc2.usgs.gov/glcc/glcc.php) provided by U.S. Geological Survey. The dominant land type is evergreen and deciduous broad trees in upper region while bare soil in lower region.

## 3.2 Model used in the study

The DHM employed in this study is a geomorphology-based hydrological model (Yang et al., 2002). It solves the continuity, momentum and energy equations using two modules; hillslope model and river routing model. We used 1 km grid as a computational element. Each unit is viewed as a rectangular inclined plane with a defined length and unit width. The inclination angle is given by the surface slope. In hillslope model, the vertical plane is divided into several layers, including canopy, soil surface, unsaturated zone and ground water. This module calculates hydrological processes such as canopy interception, evapotranspiration, infiltration and surface flow as well as exchanges between groundwater and surface water. In river routing model, we assumed accumulated lateral flow from hillslopes into the stream to simplify the process. Then, the water routing of the river network is determined along the river stream using one-dimensional kinematic wave equations. It allows us to compute discharge at each gauge point even in large catchments. Moreover, this hydrological model is effective for the risk assessment of flooding in basin scale because of the capability to consider heterogeneity within the whole basin.

# 4 RESULTS AND DISCUSSIONS

Flood simulation by using DHM was performed with different precipitation products; raingauge and TRMM at some stream gauge stations shown in Figure 1 as white dots after calibration. The model parameters were calibrated by comparing the simulated discharge with rain gauge against the observed discharge target the rainy season (from June to November) in 2008.The validation period focused in 2011, which had severe flooding damage. To evaluate the behavior and performance of hydrological model, we used three efficiency criteria: the Nash-Sutcliffe Efficiency (E), Coefficient of Determination ($r^2$) and Root Mean Square Error (RMSE).

Table 1 shows the simulation results with local rain gauge network and TRMM in 2008 and 2011. In 2008, the calibration of model parameters was conducted from information about soil, land use and vegetation. The value of E at Ping River is the closest to 1 compared among other drainage basins. There is still room for model improvement. In addition, it is tested to calculate river discharge in 2011 using parameters modified in 2008. As a result, RMSE has increased. That means simulated discharge overestimate observation in most cases. There are two reasons for the overestimation. First one is the difference of the amount of rainfall in 2008 and 2011. Thailand in 2011 had unexpected high rainfall, which is 140 % of average year. The soil parameters arranged in 2008 makes soil saturated earlier and the precipitation cannot infiltrate into ground. That would lead increasing surface water and high flooding peaks. Secondly, overestimated discharge might overflow to the land. Basically, flooding occurs somewhere every year in Chao Phraya River. As for the results from TRMM, its performance was lower than simulation with rain gauges. Figure 2 shows the time series of simulated discharge and soil moisture at Y37, which is located in Yom river basin. From 1 to 172 days, ground can capture and store precipitation enough in soil layer. After that, the discharge peaks get quite sharp because the high soil moisture. Actually, saturation of top soil layers lasted 101 days from 178 day time step (2011/6/27) to 278 day time step (2011/10/5) at Y37 station. It can be noticed that high rainfall intensity have an influence on the flood peaks; however, peaks can occur easily even by weak rainfall once the topsoil is already saturated or close to saturation.

**Table 1. Comparison of efficiency criterions in the model calibration and validation periods with two products; local rain gauge network and TRMM**

| | | 2008 with Raingauge | | | 2011 with Raingauge | | | 2011 with TRMM | | |
|---|---|---|---|---|---|---|---|---|---|---|
| River | Station | E | RMSE | $r^2$ | E | RMSE | $r^2$ | E | RMSE | $r^2$ |
| Ping | Bhumipol | 0.81 | 114 | 0.86 | 0.07 | 510 | 0.69 | -0.56 | 658 | 0.56 |
| | P73 | 0.64 | 94 | 0.74 | 0.64 | 94 | 0.74 | 0.12 | 361 | 0.46 |
| Wang | W3A | 0.30 | 46 | 0.32 | 0.25 | 182 | 0.63 | -0.67 | 272 | 0.33 |
| Yom | Y37 | 0.49 | 98 | 0.56 | 0.62 | 241 | 0.68 | 0.22 | 346 | 0.31 |
| Nan | N13A | 0.49 | 322 | 0.57 | 0.55 | 458 | 0.62 | 0.15 | 630 | 0.32 |

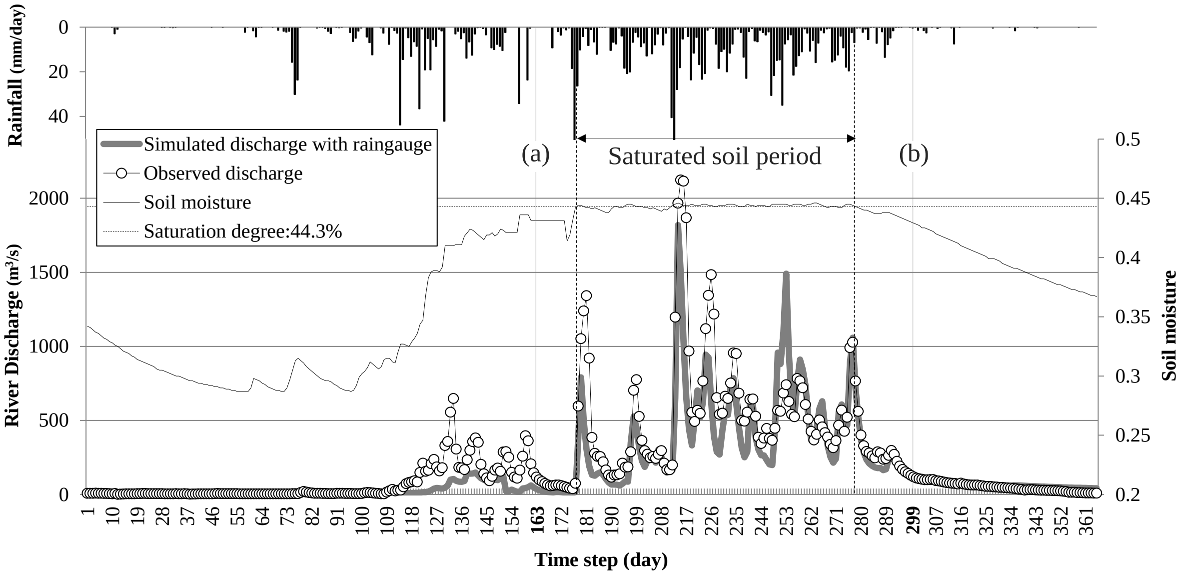


**Figure 2. Simulation result at validation period (2011) at Y37 station**

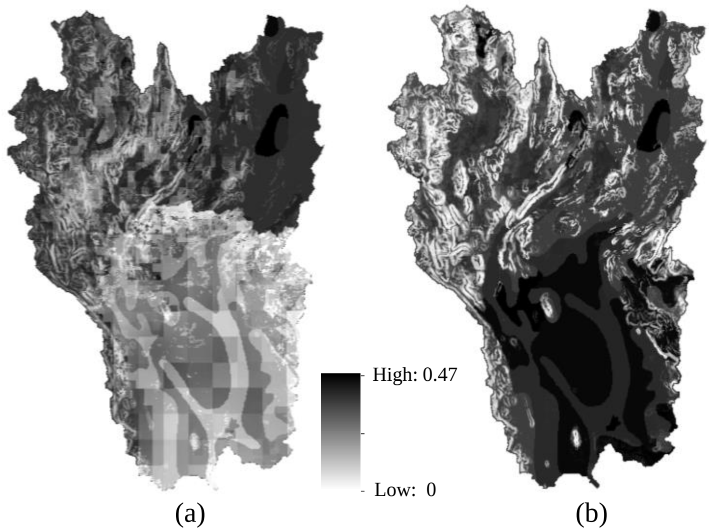


**Figure 3. Distribution of soil moisture; (a) on 12 June, 2011 (163 day time step) before flooding (b) on 26 October, 2011 (299 day time step) during flooding**

In Figure 3, the spatial pattern of soil moisture was compared focusing on two events; (a) and (b). Before flooding, soil moisture is higher in the upper region compared with lower region. However, the situation during flooding is opposite. That is because the stream gradient is quite low around 1/10,000 to 1/15,000; therefore, soil can store water at long term and it cannot flow out to river.

As mentioned above, there are two dams which have large capacity 13,420 billion $m^3$ and 9,510 $m^3$ for Bhumipol Dam and Sirikit Dam, respectively. Their operations have impacts on river discharge in lower region especially during flood. The summary of model performance indicators for the case with/without dam effect is given in Table 2. From the results, RMSE is decreasing while E value and

**Table 2. Comparison of efficiency criterions in the model calibration and validation periods with/without dam operation at C2 station**

| | | 2008 | | | | | | 2011 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River | Station | E | RMSE (with dam) | $r^2$ | E | RMSE (without dam) | $r^2$ | E | RMSE (with dam) | $r^2$ | E | RMSE (without dam) | $r^2$ |
| Chao | C2 | 0.62 | 383 | 0.69 | -1.33 | 950 | 0.59 | 0.06 | 1216 | 0.62 | -2.54 | 2360 | 0.40 |

$r^2$ get close to 1. That means discharge simulation with dam operation have the high performance compared with one without dam operation. However, simulated discharge still overestimates observation data. Normally river discharge overflow inundates every year during rainy season in lower region because the discharge capacity around Nakon Sawan is low. Therefore, it is possible for overestimated discharge to overflow. Moreover, there is problem from the slope and retardation in lower region. In upper mountainous region, surface water can inflow smoothly to river channel, then its discharge also flows down with steep hill slope 3.1 %. On the other hand, the average slope is 1.3 % in lower basin. Thus, that makes retardation time longer and river discharge stuck in lower one. In addition, water withdrawal for irrigation canal also has an effect on the problem; however, it is not considered in this study.

## 5 CONCLUSIONS

In this study, we set-up a distributed hydrological model coupled with dam operation module targeting Thai flooding in 2011. The flood characteristics were discussed based on the calculated output from DHM; the time series and distribution of soil moisture. The results confirm that high discharge peaks occurs after the topsoil layers reach saturation state. Actually, the flooding in Chao Phraya in 2011 lasted around 3 months in upper region and bit longer downstream. Moreover, in this study, it was identified how the soil moisture distribution moved from upper branches to lower main stream. Thus, it implies the long saturated soil period moving out to the lower basins, so serious and long-lasting flood around Bangkok could be expected affecting thousands of people. In addition, saturated soil in upper regions is likely to be washed out leading to erosion, land slide or even debris flood. The understanding of the spatial soil moisture is not only useful for reliable discharge simulation, but also useful in actual land use management plans.

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