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Paper:

Approach to Estimate the Flood Damage in Sukhothai Province Using Flood Simulation

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Thailand was hit by a great flood in 2011 resulting from irregular rainfall during the typhoon season that was estimated at 140% more than average. The flood began in the north and slowly moved to the central region, where it remained for more than 4 months. The flood caused great damage to the economy because it adversely affected industrial estates and agricultural areas. In the north, there are four main rivers in the region that combine into a river called Chao Phraya in the central region. The Yom River is one of the northern rivers where no large-scale dam has been constructed, resulting in frequent flood and drought. Sukhothai Province is located in the Yom Basin, where flood and drought occur on a regular basis, and the province was also severely damaged in the 2011 flood. In order to estimate flood damage cost in 2011, a simple regression curve is presented first to relate flood areas and damage cost based on past records. The 2011 flood in Sukhothai province was then simulated by using a Rainfall-Runoff-Inundation (RRI) model with satellite based rainfall (TRMM). After simulation results were compared with the observed stream flow water level, discharge and inundation extent, this study estimates damage cost for the 2011 flood based on the simulated flood area. The proposed approach could be a useful guideline in damage cost computation.

Keywords: flood damage estimation, rainfall-runoff-inundation model, sukhothai province, satellite based rainfall

1. Introduction

In 2011, rainfall in Thailand set an extreme record of 140% greater than average due to many typhoons. This caused floods and inundation in the northern and central part of Thailand, resulting in immense damage. This mega flood resulted in a lot of casualties among local residents and also to logistics of the world's supply chain.

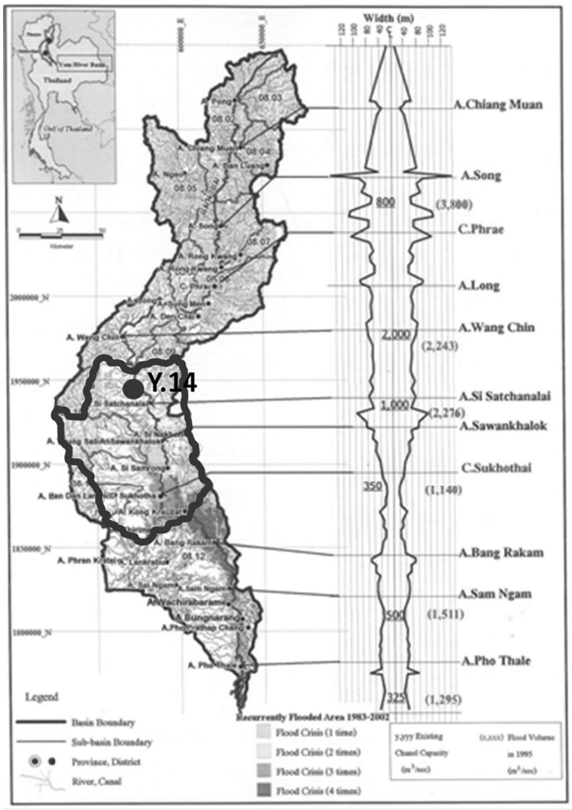
The Yom Basin is host to one of the four main tributaries of the Chao Phraya River, and is one of the main areas of Thailand's food and export production. The Yom Basin is also the only basin that has no large-scale dams regulating water flow throughout the year. Flood and drought phenomena are therefore common in this basin and cause regular damage to farmers and communities. During 2011, Sukhothai Province suffered many flooding events almost everywhere, including Sukhothaithanee Municipality, where the main functional authorities are located. This caused huge damage in terms of government authority functions, housing, crop production, and human lives.

This study proposes an approach for estimating flood damage cost in Sukhothai Province in the Yom River Basin. Information on inundation area and economic damage collected from the provincial Department of Disaster Prevention and Mitigation is used as the basis for relating inundation area and flood damage cost in Sukhothai province. The 2011 flood in the Yom River Basin is simulated by using a Rainfall-Runoff-Inundation (RRI) model (Sayama et al., 2010 [1]; 2012 [2]) with TRMM satellite-based rainfall data to estimate 2011 flood area, which is then used to estimate flood damage cost. This will be used a guideline in estimating flood disaster damage cost in this region.

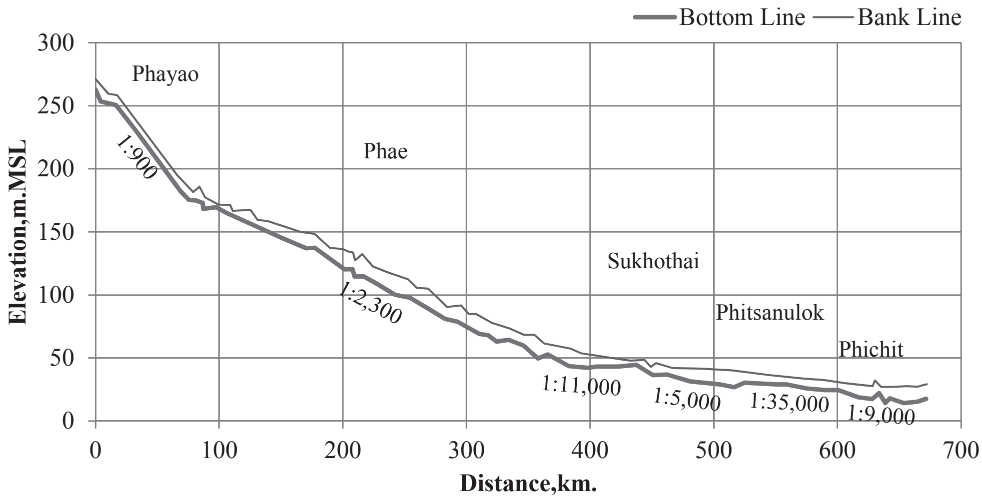
2. Study Area and Flood History

2.1. Study Area

The flood simulation study area is the Yom River Basin, which is located in the northern part of Thailand. Its main river flows from north to south and the location of the basin is at 19°25′N to 15°15′N latitude and 99°16′E to 100°40′E longitude. The catchment area covers 23,616 km^2 and 11 provinces (RID, 2004 [3]) as shown in **Fig. 1**. The Yom River is about 736 km long from origin to outlet. The average flow capacity of the main channel varies from 220 m^3/s to 2,000 m^3/s as shown in **Fig. 1**. The part from Phrae Province to Sukhothai Province has a capacity of 1,000-2,000 m^3/s,



a) Area of Sukhothai Province



b) Longitudinal section

Fig. 1. Sukhothai Province area in the Yom River Basin and location of the station Y.14 (RID, 2004 [3]).

whereas the part from Sukhothai Province to Phitsanuloke and Phichit has a capacity of only 220-300 m^3/s. This causes flood problems on the lower part of the Yom River every year, especially in Sukhothai Province.

Sukhothai Province covers an area of 6,596 km^2 and is located in the lower Yom River Basin, or 26.9% of the whole Yom Basin. Most of the 602,813 provincial residents are farmers. The average annual income of Sukhothai Province residents is 40.3%, less than Thailand's median US$500, making it the lowest among northern region provinces (RID, 2004 [3]).

2.2. Floods in Sukhothai Province

2.2.1. Causes of Floods

In general, floods in the Yom River Basin occur for many reasons, including insufficient water storage for retention in the upper watershed, ineffective drainage capacity due to a shallow river bed and its small cross-section, and land-use changes such as deforestation. Specifically, the shape of the river itself causes some flood problems because the cross-section of the Yom River upstream from the Sukhothai border with Phrae

Table 1. Flood areas and damage cost in Sukhothai Province up to 2011.

Year	Peak Discharge (m^3/s)	Flood Area (km^2)	Damage cost (MB)	Damage cost in Present Value* (MB)
1995	2,272	741.2	394.32	1,061.21
1997	693	126.1	49.71	118.21
1998	629	95.7	19.73	44.10
1999	1,089	251.9	174.73	367.14
2002	1,201	293.4	300.02	523.60

Remarks: *Damage cost is converted to the present value at a discount rate of 6% (about MLR), and the base year is 2011.

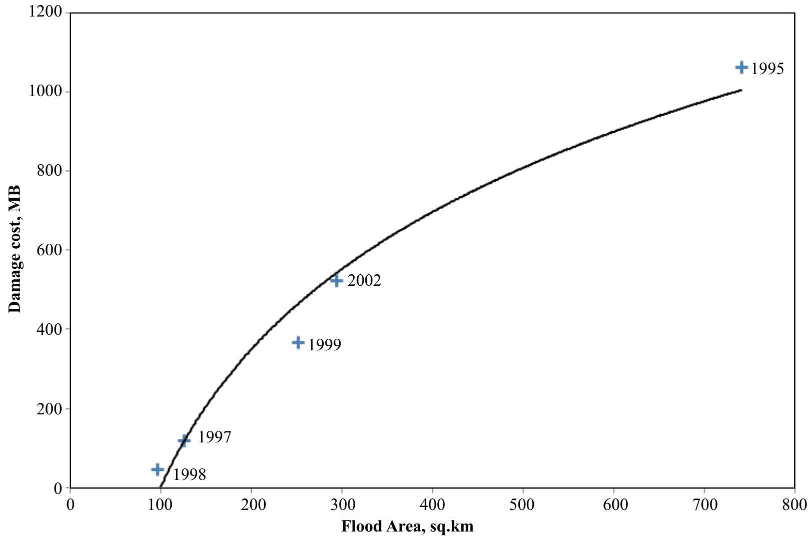


Fig. 2. Flood area and damage cost in Sukhothai Province up to 2011.

Province in Srisatchanalai and Sawankhalok districts is larger than that at the main stream in Srisamrong and Muang Sukhothai districts and that at the Phitsanulok Province downstream border in Kongkrailart district. This "bottleneck" leads to long flood duration during the rainy season. Flooding in the basin usually takes place in Sri Samrong, Sri Satchanalai, Muang Sukhothai and Kong Krailat districts during the southwestern monsoon season from July to September, leading to huge losses in agricultural and residential areas along the Yom River.

2.2.2. Flood Damage in Sukhothai Province Up to 2011

Flood and damage information on Sukhothai Province collected from the provincial Department of Disaster Prevention and Mitigation includes peak discharge, flood area and flood damage in flood events summarized in **Table 1**. Damage cost accounts for only that which Sukhothai Province actually paid to farmers in compensation and for rebuilding infrastructure, meaning that damage cost in the private sector is not included in the cost reported. The unit cost of compensation is decided, moreover, by the central government lacking local surveys. Since flood damage occurred in different years, the present value concept is required for an equality comparison. The assumption of a constant 6% discount rate is applied for value conversion in this study, and the base year is 2011 (Koontanakulvong et al., 2012 [4]).

To represent the magnitude of flood events, we selected a maximum flood inundation extent as an explanatory variable to estimate flood damage cost, since it is considered related more directly to flood damage than other variables, such as peak river discharge. The relationship between inundation area in square kilometers (A) and present damage cost in millions of baht (DC) is estimated by using best fit with a logarithm function as presented in Eq. (1), where coefficient of determination R^2 is 0.97. **Fig. 2** illustrates this relationship, which will be used to estimate damage cost when flooded area is known.

$$DC = 499.26 \cdot \ln(A) - 2294.8 \qquad (1)$$

3. 2011 Flood Simulation

3.1. RRI Model

The model that was used for flood simulation in this study is a two-dimension Rainfall-Runoff-Inundation (RRI) model (Sayama et al., 2010 [1]; 2012 [2]), which deals separately with surface flow, named slope, and river channels. The river channel is located on a grid cell and

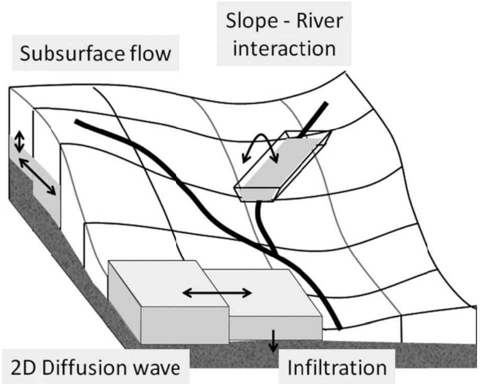


Fig. 3. RRI model.

the model assumes that both the slope and river are positioned within the same grid cell. A channel is discretized as a single vector along the center line of the overlying slope grid cell. The channel represents an extra flow path between grid cells lying along the actual river course as shown in **Fig. 3**. Lateral flows are simulated for slope cells on a two-dimensional basis. The governing equations of slope computation are derived based on the following mass balance Eq. (2) and momentum Eqs. (3) and (4) for gradually varied unsteady flow:

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=r \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial u q_x}{\partial x}+\frac{\partial v q_x}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_w} \quad . \ . \quad (3)$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial u q_y}{\partial x}+\frac{\partial v q_y}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_w} \quad . \ . \quad (4)$$

where h is the height of water from the local surface, q_x and q_y are unit width discharge in the x and y directions, u and v are flow velocities in the x and y directions, r is rainfall intensity, H is the height of water from a datum, ρ_w is the density of water, g is gravitational acceleration, and τ_x and τ_y are shear stress in the x and y directions. Second terms on the right side of Eqs. (3) and (4) are calculated using Manning's equation. To solve the two-dimensional equation, the RRI model adopts diffusive wave approximation. Details on components, including vertical infiltration and lateral subsurface process calculations, are given in Sayama et al. (2012) [2].

Slope grid cells on the river channel have two water depths: one for the channel and the other for the slope, or flood plain. Inflow-outflow interaction between the slope and river is calculated based on different overflow formulas, depending on water-level and levee-height conditions.

3.2. Model Setup

Input data for the RRI model consists of rainfall, topography, river channel parameters and land-use information on the study area. Satellite-based rainfall data (TRMM) was used to simulate the 2011 flood. Topography data on the Yom Basin was prepared using the Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) provided by the U.S. Geological Survey (USGS), in which a resolution of 30×30 arc-seconds or approximately 1×1 km (CGIAR-CSI, 2008 [5]) was used. Since the position of the channel generated from SRTM DEM had errors in the actual position on a normal map, flow direction and flow accumulation data from hydrological data and maps based on Shuttle elevation derivatives on multiple scales (HydroSHEDS) (USGS, 2008 [6]) are used to improve better river location on SRTM DEM. Even then, elevation at the bottom of the channel still required a smoothing procedure for eliminating unpredictable humps in the main channel due to the combine use of SRTM and HydroSHEDs data. Smoothed DEM, flow direction and flow accumulation are presented in **Figs. 4** and **5**.

Main channel parameters, i.e., width and depth, come from a 1996 survey by the Royal Irrigation Department (RID, 2004 [3]). The width and depth of tributaries are calculated from flow accumulation data by using Eqs. (5) and (6) from Sayama et al. (2012) [2],

$$W = 16.93 \cdot A_{basin}^{0.186} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (5)$$

$$D = 16.93 \cdot A_{basin}^{0.120} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (6)$$

where W is the channel width in meters, A_{basin} is the catchment area in km^2, and D is the channel depth in meters. Land use for the Yom River Basin was collected by the Land Develop Department in 2009. In this study, land use types were divided into five types, i.e., agricultures, forest, miscellaneous, urban and water body areas, as shown in **Fig. 6**. Simulation was from March 1 to December 31, 2011, and covered Thailand's extreme 2011 flood.

4. Results and Discussion

4.1. Simulation Results

A comparison of simulated and observed water level and discharge at station Y.14 is presented in **Figs. 7** and **8**. We mainly focused on water level at Y.14 because observation is direct. Discharge is estimated by using a rating curve. From **Fig. 7**, it shows that the water level at the beginning of simulation (March until June 2011) agreed reasonably well with observed data, whereas the simulated water level is lower than that observed after June 2011 when the land was flooded. This may have been caused by inundation in simulation occurred almost slope grid cells as shown in **Figs. 9b)** and **10b)**. Water was then collected to the river as the simulated water level reached a maximum peak around the end of September when the last storm of the season occurred.

Discharge from simulation is higher than that observed for all simulation, a fact that could be caused by underestimating observed discharge from extrapolation of the rating curve. Specifically, water overflowed the riverbank. We found good agreement, however, between simulated and observed river discharge on August 4, 2011, which

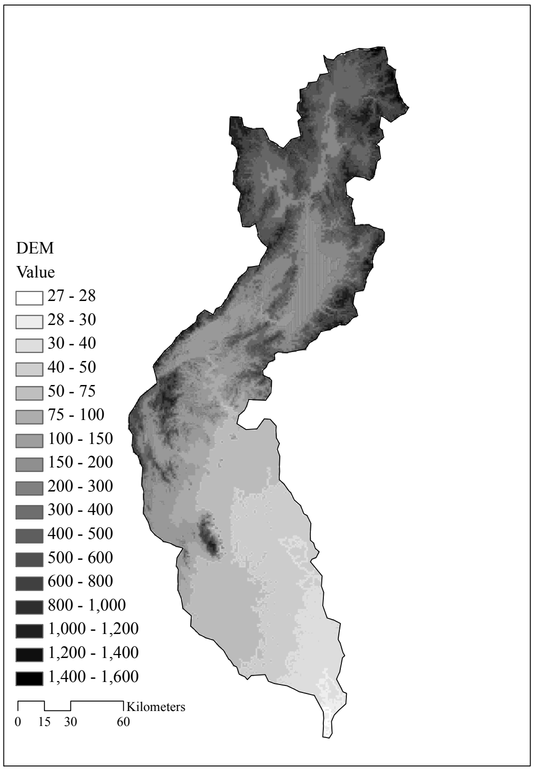


Fig. 4. SRTM DEM after adjustment by channel smoothing.

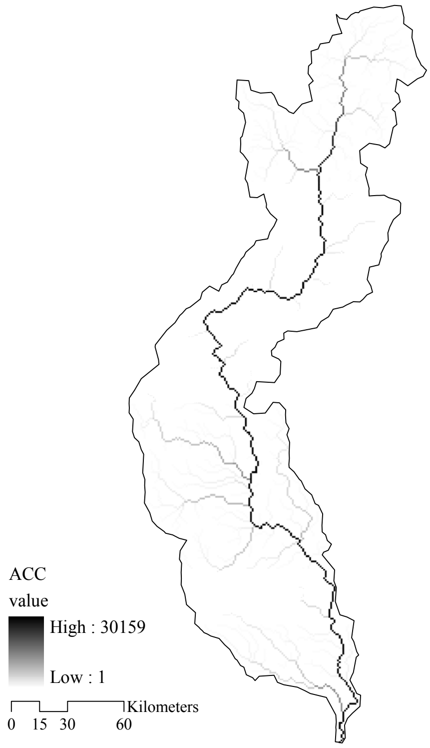


Fig. 5. Flow accumulation based on HydroSHEDS.

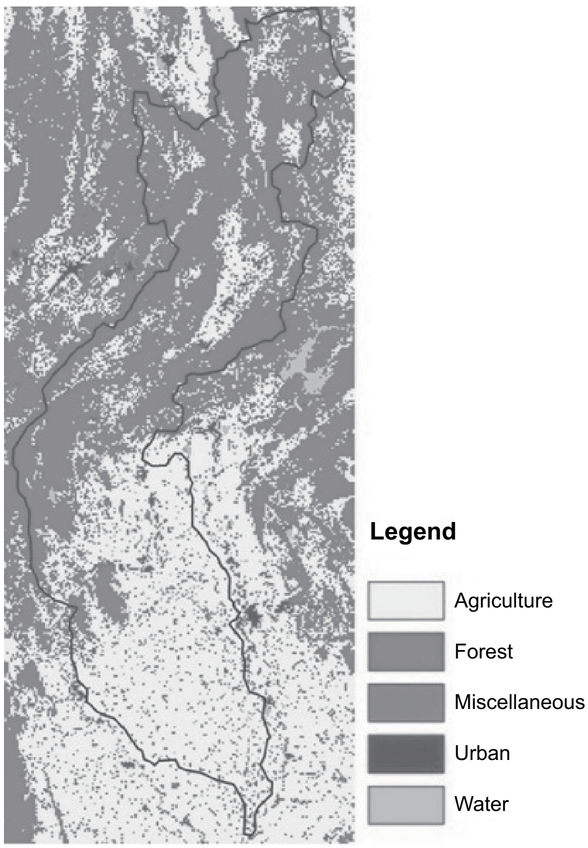


Fig. 6. Land use in the Yom river basin divided into 5 types.

is the highest observed peak flow during 2011 at station Y.14.

Both the water level and discharge at station Y.14 and satellite images of the inundation area derived from the Geo-Informatics and Space Technology Development Agency (GISTDA), a public organization, are compared with simulation results. Since the satellite pathway circles the Earth, comparison dates are selected from days on which satellite images cover all of the Yom River Basin. Inundation areas from simulation results also have some numerical errors; so the definition of flooded area from simulation is defined as area having a water depth of more than 50 cm. Inundation areas from satellite images and simulation data are then compared by computing shape factor f as shown in Eq. (4).

$$f = \frac{A_{sat} \cap A_{sim}}{A_{sat} \cup A_{sim}} \quad \text{. . . . .} \quad (7)$$

where $A_{sat} \cap A_{sim}$ is the intersection of areas indicated by satellite (A_{sat}) images and simulation (A_{sim}), whereas $A_{sat} \cup A_{sim}$ is union area for both satellite images and simulation. The shape factor is equal to 1, which thus means that simulation matches satellite data perfectly. **Figs. 9** and **10** compare satellite images and simulation results on August 23 and September 21, 2011, where shape factors f are 0.32 and 0.41, respectively. Even though shape factor values are small, main flooded areas as seen from both observation and simulation are in nearly the same position as illustrated in **Figs. 9** and **10**. The reason for small shape factor values may be the quick response of inun-

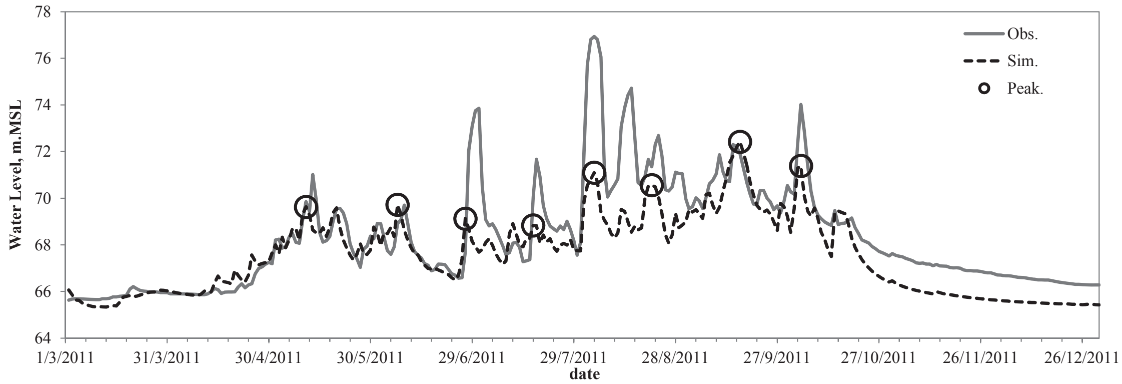


Fig. 7. Comparison of water levels at station Y.14 between observation data and simulation results.

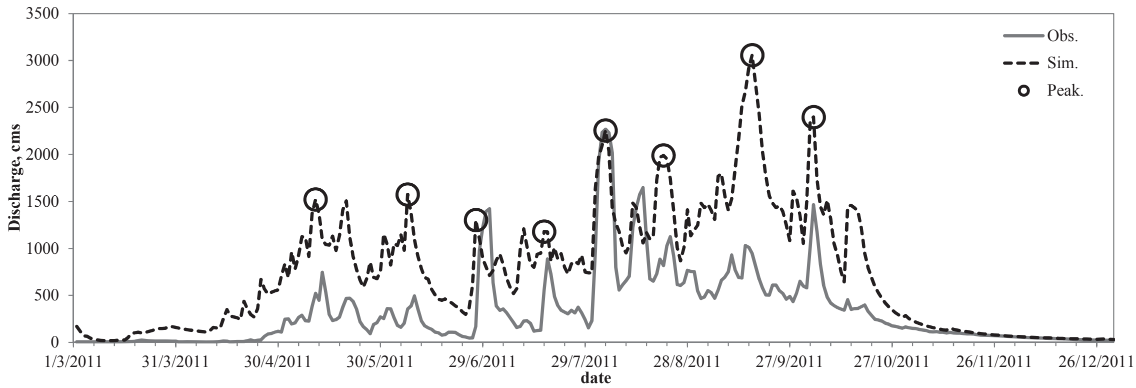


Fig. 8. Comparison of discharge at station Y.14 between observation data and simulation results.

dation at the surface, and water takes time to flow to the river, which is the reverse of riverbank overflow. Inundation areas from simulation thus spread out corresponding to A_{sim} larger than A_{sat} and the small shape factor.

4.2. Damage Estimation in the 2011 Flood

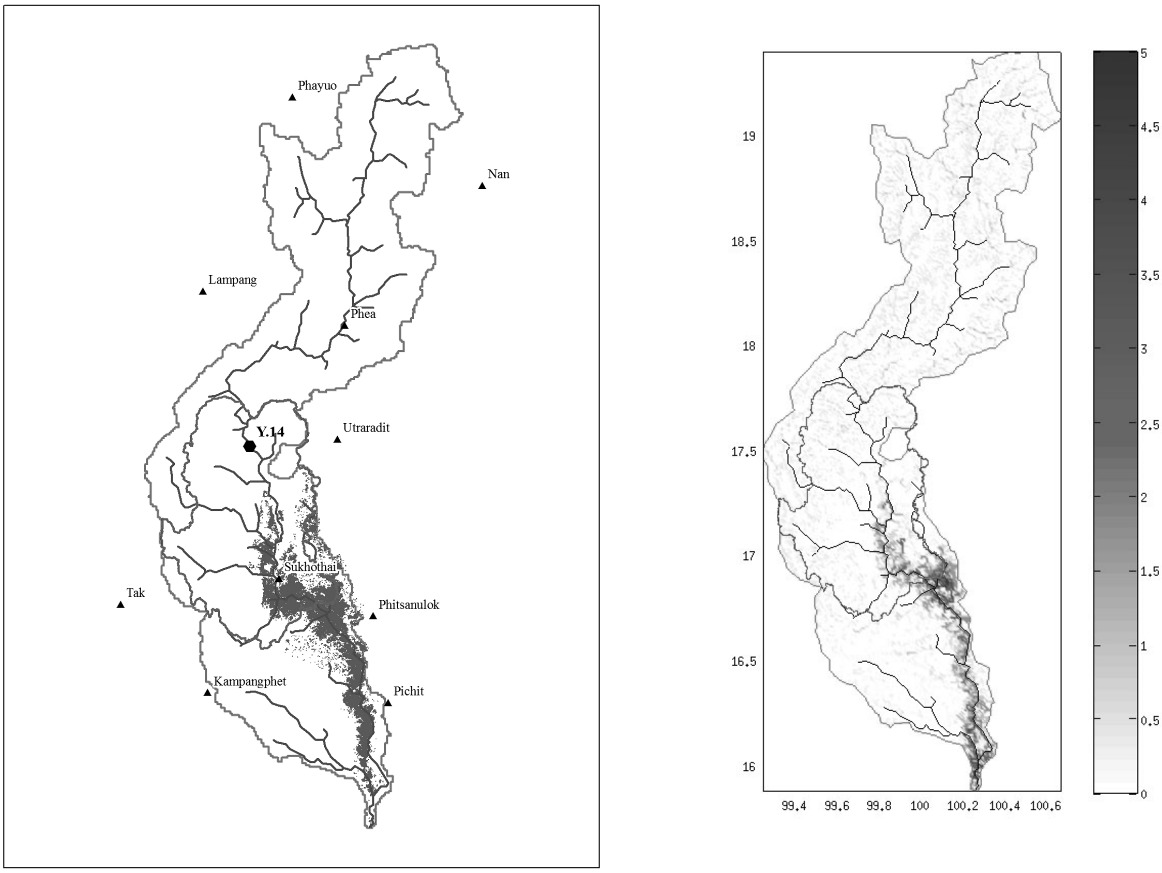
Based on flood simulation results for 2011 events, this study estimates flood damage cost based on simulated flood areas and Eq. (1) obtained from past flood events. According to simulation, flood inundation peaked at around mid-September in Sukhothai Province and the simulated flood area was 1,436 km^2. Hence, by using Eq. (1), estimated flood damage cost for 2011 was 1,335 million baht.

In 2011, the Sukhothai Province Department of Disaster Prevention and Mitigation reported that damage cost 1,050 million baht, indicating that our estimate was about 1.27 times larger than what the province reported. There are several possible reasons for this overestimation. Damage reported accounts for only the cost that was paid for compensations and infrastructure rebuilding. In reality, it may have missed some inundation areas in the government report because some people did not ask for compensations, some infrastructures were not immediately damaged during the flood, or limitations on the government budget paid only in important cases; whereas simulation accounted all inundated areas. These differences may cause actual damage cost to be even more than that reported. Simulated peak inundation area may also have been overestimated – an aspect that should be improved after more detailed model simulation with more local data, including ground gauged rainfall instead of satellite-based rainfall.

5. Conclusions

This study has presented approaches to estimating flood damage cost value from simulation by using the RRI model. The estimated damage cost has been overestimated compared to values reported by government authorities. A 27% error in damage cost value is believed to be in a range acceptable for rough estimation. This shows that RRI simulation could be useful in assessing flood damage. With rough damage assessment, it could also serve as a good guideline for flood mitigation project studies. Since the RRI model gives flood area results, new implementation of flood mitigation measures can be considered in terms of flood area reduction corresponding to decreased damage cost value.

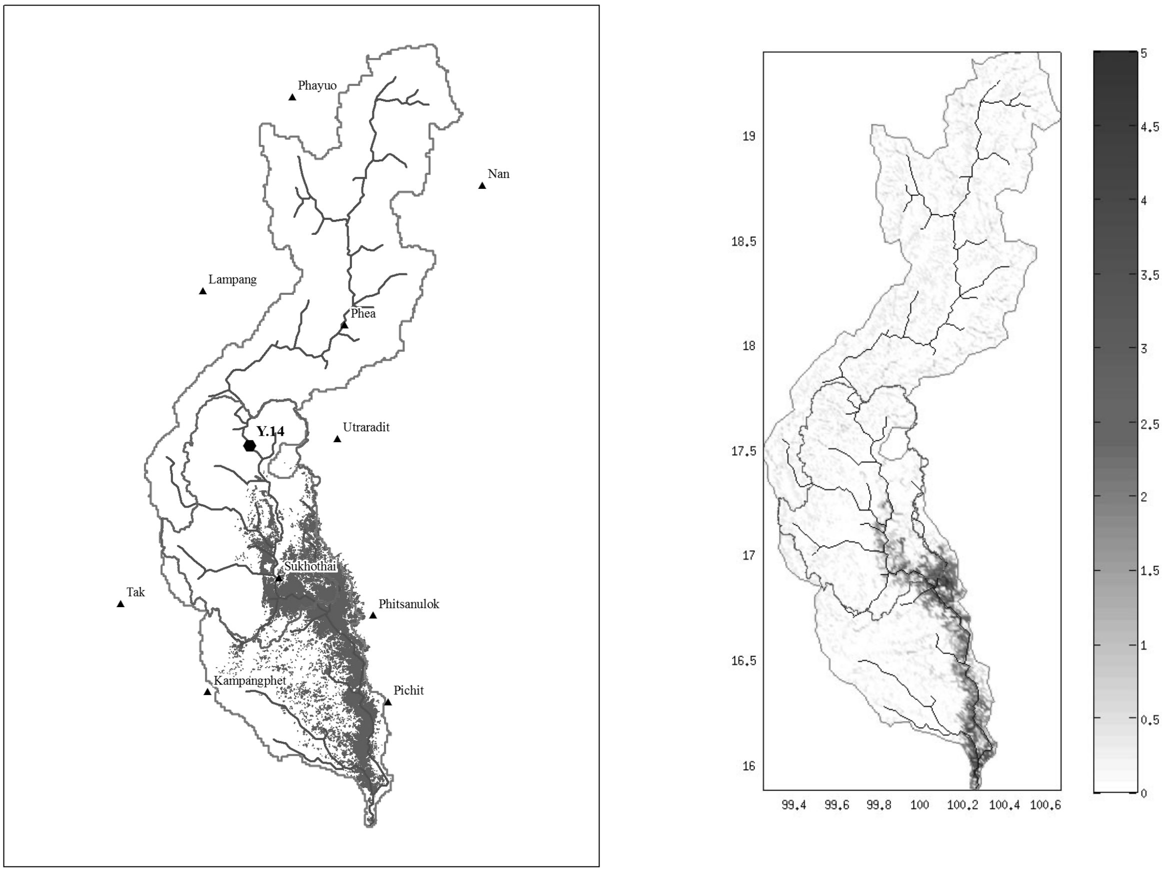
Model simulation could still be improved by utilizing more local data for better estimating flood damage cost. Damage cost could also be calculated by using different methods; for example, damage cost curves for different land cover. In this way, inundation duration parameters may be also taken into account in damage cost calculation. These examples for improving damage cost estimation should be implemented in future studies.



a) Flood extent by satellite image

b) Simulated flood inundation depth [m]

Fig. 9. Comparison of satellite images and simulation results for the 2011 flood on August 23, 2011.



a) Flood extent by satellite image

b) Simulated flood inundation depth [m]

Fig. 10. Comparison of satellite images and simulation results for the 2011 flood on September 21, 2011.

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