NumericalExperimentofChangeinFloodedAreaUsing GriddedRainfallDataDuring 1981-2017 inTheMunandTheChiRiversBasin,Thailand

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***Abstract*— Thailand is concerning that the effects of climate change such as strong drought during the dry season and massive flood during the rainy season and unseasonable weather may increase. Especially, there is a possibility that the occurrence frequency and scale of flood damage will be increasing. Heavy flooding caused serious damage in the eastern region in 2011 and 2017. In the large flood of 2011, extensive flooding occurred in Yasothon, Sisaket and Ubon Ratchathani Provinces, where the Mun and Chi Rivers joined. Furthermore, the river slope was very gentle and the discharge capacity was small, which was considered to have caused extensive flooding. The impact of the flood has been causing serious damage to Thailand's major industries, manufacturing, agriculture and tourism. That is an urgent task to suppress such chronic flood damage.The purpose of this study is to clarify the historical change in flooded area in the Mun and Chi Rivers basin using numerical simulation during 1981-2017. This study used the rainfall gridded data obtained by interpolating the point rainfall data observed by the Thai Meteorological Department (TMD) during 1981-2017 into 0.5 degree grid using the Kriging method. RRI (Rainfall Runoff Inundation) model, which is a rain runoff model capable of integrating analysis of river basin and river flow from rain runoff to flood, was selected for this study. Model parameters had been tuned by the rainfall event in 2011. Using these parameters, the maximum-flooded area of each year for 37 years was calculated and trend analysis was conducted.**

Keywords—Numerical simulation, Flood, Thailand

I. INTRODUCTION

According to the International Panel on Climate Change (IPCC) Fifth Assessment Report (AR5, 2013), the frequency and intensity of heavy rainfall over all land areas may increase with future climate change. In Southeast Asia, the frequency of flooding events associated with excessive daily rainfall is predicted to increase, from the end of the 20th century to the middle of the 21st century, from once in 20 years to once in 10 years.

Floods are among the most serious and frequent hazards in Thailand (CFE-DM, 2018). Recent flooding events include large floods in 2011 and 2017. The large flood of 2011 caused serious damage in a wide area, extending from the middle to the downstream of the Chao Phraya river basin (TWB, 2012).

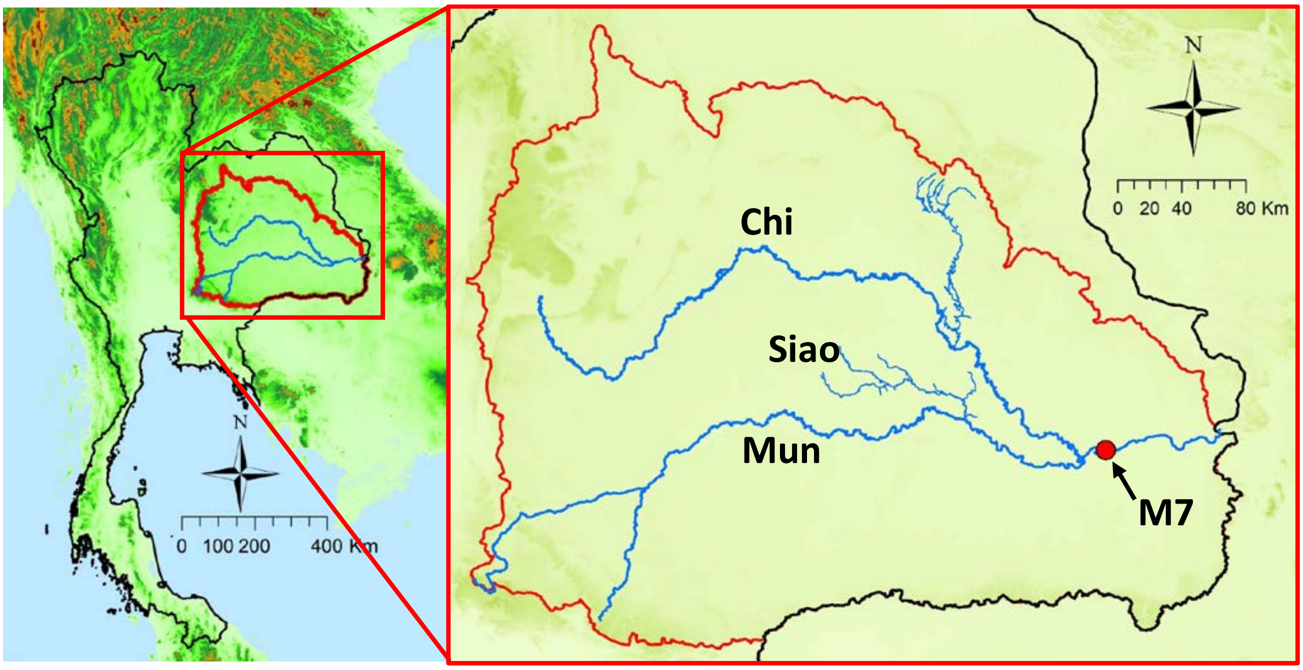

Fig. 1. Map of the Chi–Mun river basin area.

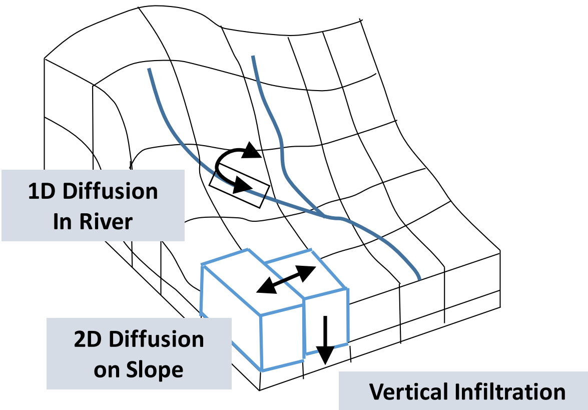

Fig. 2. Schematic diagram of the rainfall–runoff–inundation (RRI) model.

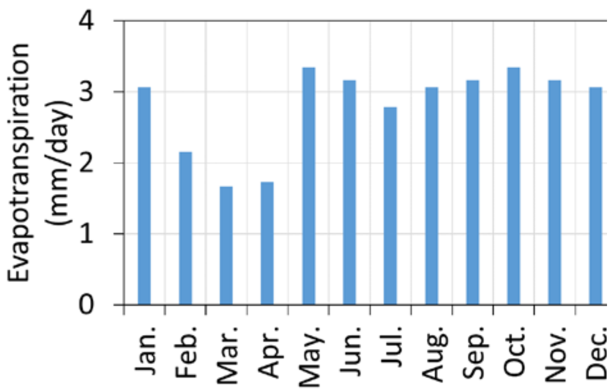

Fig. 3. Monthly variation in evapotranspiration.

As the population along the Mekong River increases, there is a high risk that flooding damage will also increase. Unless measures are taken in response to the anticipated climate change, both economic costs and the cost to human life are expected to rise following flooding disasters (MRC-a, 2017). Agriculture is a major industry in northeastern Thailand, which is part of the Mekong river basin; this region is therefore particularly susceptible to damage in the event of severe flooding. The largest changes in flooding area are projected to occur in response to smaller floods with return intervals of 1 in 2 years and 1 in 5 years. Under the highest emissions scenario (IPCC model RCP 8.5), by 2060 the increase in flooded area is expected to reach 38% for floods occurring once every 2 years and 28% for floods occurring once every 5 years (MRC-b, 2017). Floods have already caused major damage to the manufacturing, agriculture, and tourism industries in Thailand, all of which are major industries, and there is an urgent need to prevent further chronic flood damage. Therefore, the objective of this study was to capture the spatial features of flooding by analyzing the flooded areas in the Chi–Mun river basin over a 37-year period from 1981 to 2017, as well as the maximum inundation area and depth.

II. TARGET BASIN(JICA,2010)

In this study, we focused on the Chi–Mun river basin (Fig. 1), which is located in northeastern Thailand and is a tributary of the Mekong river basin. The bed slope is extremely gentle, with a falling capacity of 1/7,000 in the upstream area and 1/50,000 in the midstream area.

The catchment area of the Chi river basin is 49,500 km². It contains a large forest (ca. 3,680 km2, 27% of the basin area) overlapping the Petchabun Mountains at the upstream area. Forests in the middle and downstream reaches cover an area of 1,440 km2 (8%). Therefore, the water-holding capacity of the Chi River is low, and the risk of flooding is high in the rainy season. Paddy fields cover an area of 8,640 km2 (45%) in the middle watershed and 5,440 km2 (37%) in the lower watershed.

The catchment area of the Mun river basin is 69,700 km². The total forest area is ca. 8,480 km2 (12%). In the middle watershed, forest covers only 2,080 km2 (9%), which leads to frequent flooding in the lowlands along the Mun River. Managed land covers 11,040 km² (36%) of the upstream area and 12,480 km2 (55%) of the middle area of the watershed. Overall, 40% of northeast Thailand is forested (JICA, 2010)

III. RAINFALL-RUNOFF-INUNDATION MODEL AND ANALYSES

In this study, we used the rainfall–runoff–inundation model (RRI; Sayama et al., 2010). Fig. 2 shows a schematic diagram of the RRI model. The flow in slope grid cells was calculated using a two-dimensional (2D) diffusive-wave model, and channel flow was calculated using a one-dimensional (1D) diffusive-wave model.The 1D diffusive-wave model was applied to river grid cells, using rectangular cross-section data. Cross-section data for the Chi–Mun river basin are scarce; therefore, river channel width, W (m), and depth, D (m) were approximated by the following formula (Sayama, 2017).

$$W = C_W A^{S_W}$$

$$D = C_D A^{S_D} \qquad (2)$$

where A (km²) is the flow accumulation area and CW, SW, CD, and SD are regression parameters whose values were estimated from river cross-section data.

IV. DATA INTERPOLATION

In this study, we used the 30-s digital elevation model (DEM) included in the HydroSHEDS mapping product (Lehner, 2008), with a rough resolution (120 s). The width and depth of the river channel were calculated by Equations 1 and 2, respectively. The cross-sectional parameters (Cw, Sw, CD, SD) obtained from topographic maps and satellite images were set to 0.0415, 0.7545, 2.48, and 0.12, respectively. We then obtained gridded rainfall data by interpolating point rainfall data collected by the Thai Meteorological Department (TMD) during 1981–2017 onto a 0.5° grid using the kriging method. Fig. 3 shows the evapotranspiration amounts used as input data.

V. REPRODUCTION OF FLOOD IN 2011

River discharge parameters at location M7 (Table 1) were identified and we obtained remote sensing (RS) satellite images of areas inundated during the 2011 Thailand flood. To quantify the inundation areas, we compared these images with RS data collected by the Thailand Flood Monitoring System (http://flood.gistda.or.th/indexEN.html) during 2005–2012. To evaluate the reproducibility of the inundation area data, we compared simulated inundation areas with those shown by the RS images. The Nash–Sutcliffe coefficient (NS; Nash and Sutcliffe, 1970) is an index of the fitness of a hydrograph; we used it to evaluate the reproducibility of our river discharge results. NS values close to 1.0 indicate high accuracy of the hydrograph, with values greater than 0.7 taken to indicate good fitness. Although there was a slight difference in peak discharge, the timing of the increase, peak, and decrease shown in the hydrograph were reproduced very accurately by our model (Fig. 4). The NS value for the comparison of simulation and observation results was 0.85, indicating sufficient accuracy. We then compared yearly simulated inundation areas with those obtained from RS images (Fig. 5). To estimate the inundation area, we counted the number of meshes with a maximum flooding depth exceeding 1.0 m, and then multiplied the total by the mesh size. The simulation results exceeded the RS results in all years except 2010, perhaps because a coarse mesh resolution was used for the calculation, which may have led to the inclusion of non-inundation areas among those calculated. Fig. 6 shows a comparison of inundation areas obtained by simulation (blue) versus RS images (red). The upper reaches of the Mun River contain innumerable small

TABLE1. Parameter sensitivity analysis results.

Parameter	Unit	Value	
ns_slppe	$m^{-1/3}$ s	3	
soil depth	m	1.5	
gamma a	-	0.3	
Ksv	m s^{-1}	3×10^{-5}	5×10^{-6}
gamma m	-	0.2	0.1
beta()	-	4	

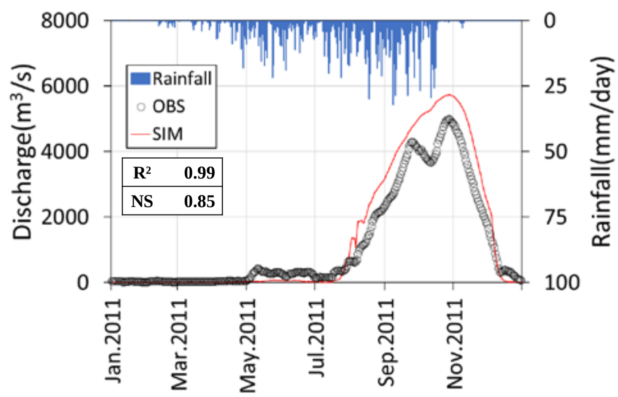

Fig. 4. Hydrograph data at location M7 in 2011.

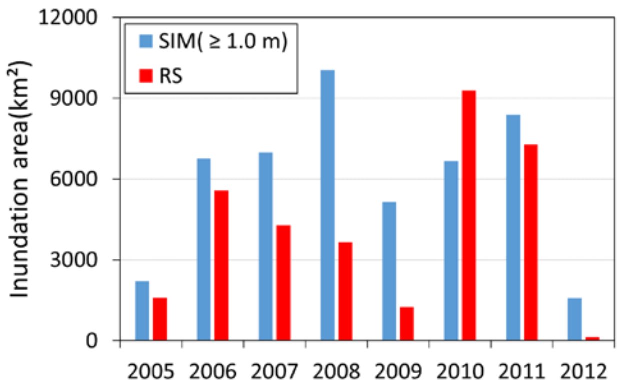

Fig. 5. Comparison of inundation areas over time.

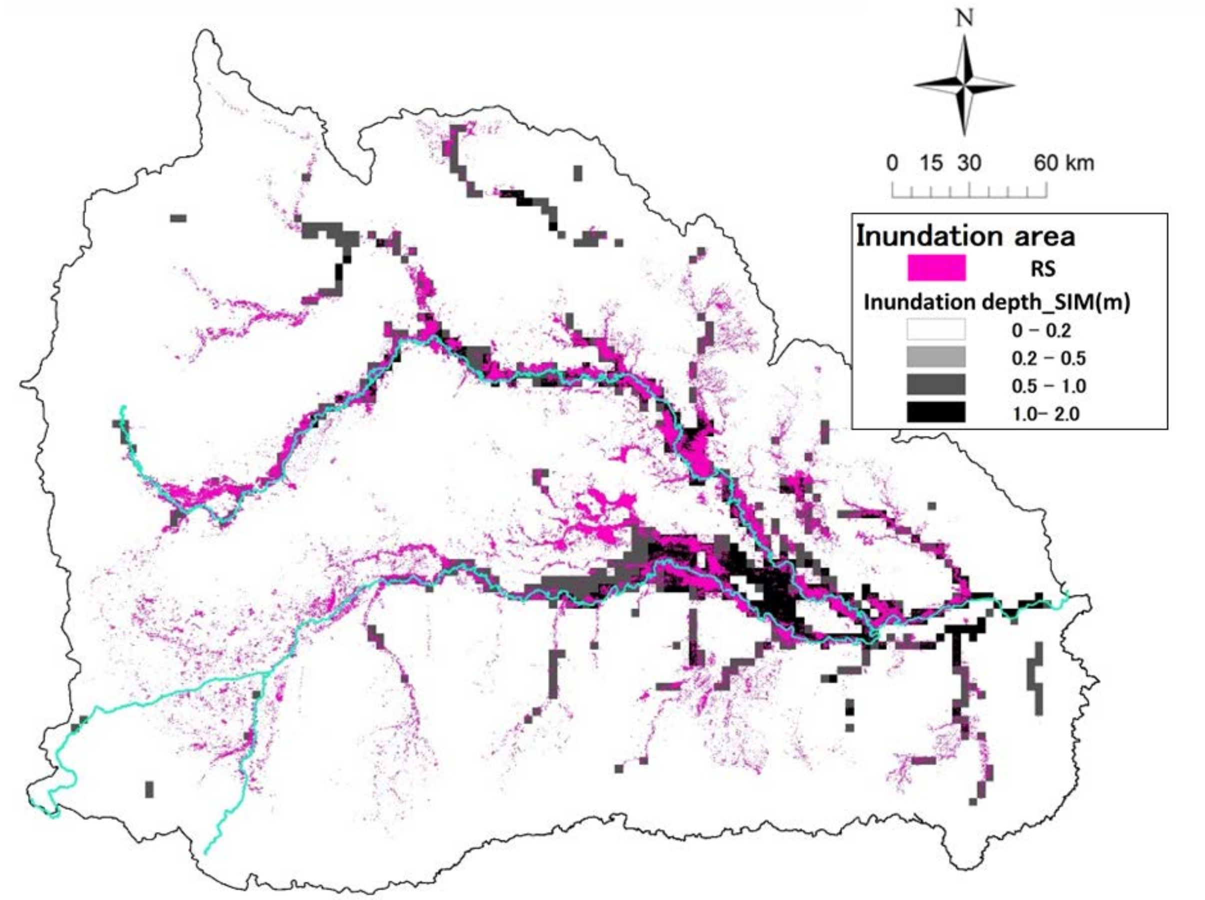

Fig. 6. Comparison of inundation areas during the 2011 flood.

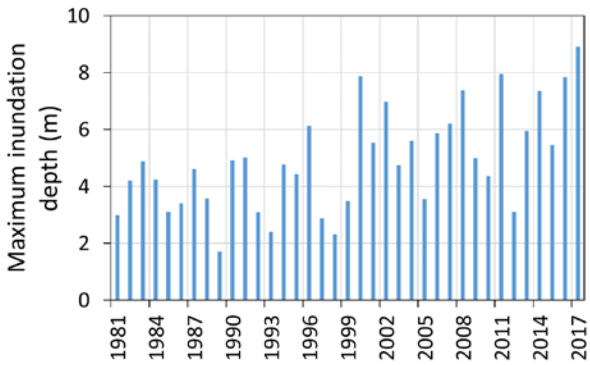

Fig. 7. Time series of simulated maximum inundation depth.

rivers that could not be reproduced at the coarse spatial resolution used in this study, such that the inundation area was underestimated by our simulation. However, the inundation area near the confluence point of the Chi and Mun Rivers was highly reproducible.

VI. Simulation of Flooding the 37-Year Study Period

Fig. 7 shows a time series of changes in maximum flooding depth during the 37-year study period from 1981 to 2017. The maximum inundation depth exhibited an overall increasing trend over time. Fig. 8 shows a time series of changes in the flooded area during the study period. For each of three classes of inundation depth (≥ 1 m, ≥ 3 m, and ≥ 5 m), inundation area showed an increasing trend over time. Fig. 9 of inundation depth during the 37-year study period. Areas shown in red experienced more than 20 floods during the study period. Floods greater than 1 m in depth occurred extensively above and below the confluence of the Mun and Chi Rivers. Red areas, where flooding was most frequent, are clearly most abundant in Ubon Ratchathani Province and Sisakate County, where the Mun and Chi Rivers join, and in Yasorton County where smaller tributaries join the Chi River. The high inundation depth class (≥ 3 m) was prevalent in three areas. The first area is at the point where the Mun and Chi Rivers join, where inundation occurred over a wide area. The second area is where the Siao River joins the Mun River in Sisakate Province; here, the inundation frequency exceeded 20. The third area is at the provincial border between Loayet Province and Yasothon County, where a small river joins the Chi River. Inundation frequency did not exceed 20 for inundation depths ≥ 5 m in this region. However, multiple inundations occurred where the Mun and Chi Rivers join, and at the meeting point of the Mun and Siao Rivers.

VII. Spatial Consideration of Flood Risk

We simulated flooding in the Chi–Mun river basin during the 37-year period from 1981 to 2017 to calculate yearly maximum inundation area and depth, with the objective of capturing the spatial characteristics of flooding in this basin. We found that both maximum inundation depth and area are generally increasing over time. Relatively small floods of ≥ 1 m occurred along the Chi and Mun Rivers every year, and large flooding events occurred frequently at confluence points between tributaries. Considering that the frequency and intensity of heavy rainfall are projected to increase due to

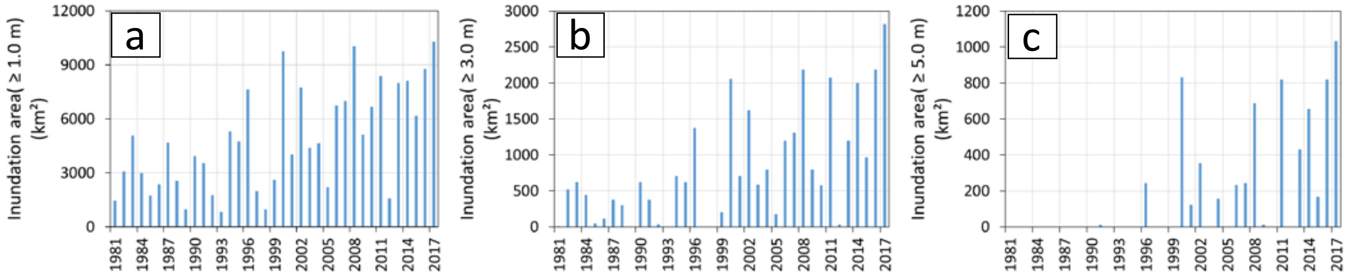

Fig. 9. Time series of simulated maximum inundation area: (a) ≥ 1 m; (b) ≥ 3 m; (c) ≥ 5 m.

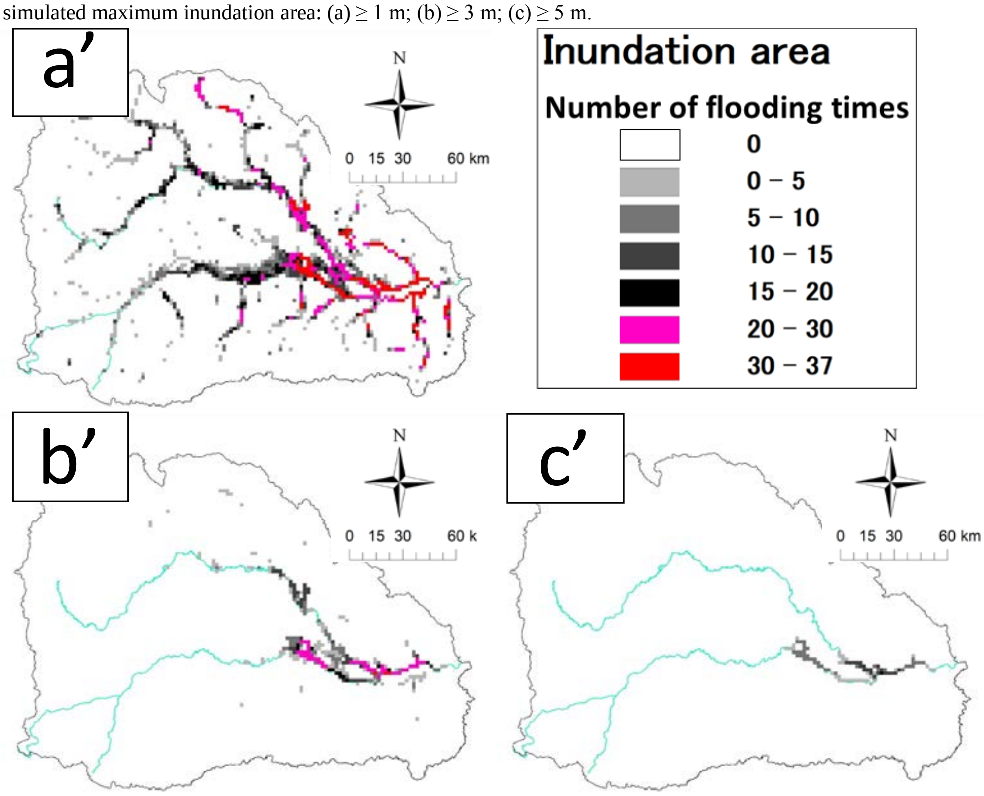

Fig. 8. Simulated flooding frequency results for various inundation depths: (a’) ≥ 1 m; (b’) ≥ 3 m; (c’) ≥ 5 m.

climate change (IPCC, 2013), large floods are expected to also increase in extent and frequency in Row Yet, Yasothon, Sisakate, and Ubon Ratchathani Provinces in the future.

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