FLOOD RISK ASSESSMENT FOR THE CENTRAL RIVER BASIN OF THAILAND

NUANCHAN SINGKRAN
Faculty of Environment and Resource Studies, Mahidol University, Thailand

ABSTRACT

The cumulative flooding frequencies and the cumulative floods' consequences on lives and properties/ public utilities, observed over the 16-year period (2001–2016) in the Chao Phraya River Basin (CPRB) of Thailand, were used to preliminarily assess flood risks for the river basin. The estimated index (0–1) of flood risks was categorized into four classes, including low (≤ 0.12), moderate (0.13–0.32), high (0.33–0.62), and very high (0.63–1.00), and was mapped across the river basin using the ArcGIS program. Of the 151 districts located in the CPRB, four, three, and 10 districts showed very high, high, and moderate risks of flooding, respectively, whereas, the remaining 134 districts showed a low flood risk. Land use activities and man-made disturbances could influence the severity of the flood risk in the river basin. The findings are useful for the decision making by local administrations to prepare proper measures for flood risk management on a river basin scale.

Keywords: Chao Phraya River, floodplain, land use, natural disaster, risk assessment, Thailand.

1 INTRODUCTION

Flood risk assessment is one of essential tools for managing floods. It can be simply quantified in terms of the likelihood of flooding in an area of interest and the flood's consequences in that area [1]–[3]. Flood risks may be assessed at different scales depending on the characteristics of data availability, areas of interest, and the purposes of flood risk management on the associated scales (e.g., [4]–[7]). Recently, flooding has been one of the severest natural disasters in Asian countries, particularly the 2011 flood in China and Thailand that considerably affected lives and properties in these countries [8], [9].

Focusing on Thailand, 79 major flood events were recorded over the 53-year period from 1966 to 2018 [10]. Of these, 21 major floods (about 26.6% of the total) occurred in central Thailand including the country's severest flood in 50 years that occurred in 2011 [9], [11]. The 2011 flood inundated about 110,554 km^2, 21.5% of the total area of Thailand [12]; and most of the area was in the Chao Phraya River Basin (CPRB). This flood affected 13.57 million people [13], caused 813 casualties [10], and inflicted property damage amounting to about 46.5 billion USD [13].

The CPRB shows spatial heterogeneity in relation to human activities spanning agricultural through commercial to industrial sectors that influence the likelihood and consequences of the flooding [11], [14]. Other than the agricultural (paddy fields, aquaculture, livestock and poultry farming, etc.) and residential sectors, the industrial sector was considerably affected by the 2011 flood, particularly the seven industrial estates (IEs) located in the river basin, i.e., alphabetically, Bangkadi, Bang Pa-in, Factory Land, Hi-tech, Nava Nakorn, Rojana, and Saha Rattana Nakorn. A total of 804 companies were located in these inundated IEs [15].

Although the CPRB has often faced annual floods [16], the areas at risk of flooding in the river basin were rarely assessed [17]–[19]. Therefore, flood-related studies should be conducted, particularly flood risk assessment and mapping. According to the historic flood data available, not all districts located in the river basin experienced flooding or they experienced different risks. Consequently, an assessment of the flood risks by district is

WIT Transactions on Engineering Sciences, Vol 129, © 2020 WIT Press
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/RISK200101

mandatory across the CPRB. The observed flood-related data at district level were available for the period from 2001 to 2016; and these could be used for the preliminarily assessment of flood risks across the entire basin.

The objective of this study was thus to apply the likelihood in terms of flooding frequency and the floods' consequences in the CPRB to spatially assess and map flood risks across the river basin. The results will be useful to assist local administrations to prepare specific measures for effectively managing flood risks in relation to their severity across the river basin.

2 STUDY AREA

The CPRB is situated between 13°28'N, 99°33'E and 16°6'N, 101°5'E and covers a 21,604 km^2 area, around 4.2% of the 25 river basin areas (511,657 km^2) of Thailand. There are 151 districts in 19 provinces located in this river basin. The river basin's major river is the Chao Phraya River (CPR) with a length of 379 km, starting from the mouth of the Pak Nam Pho in Nakhon Sawan Province. The river flows in a north–south direction through the river basin to the Gulf of Thailand (Fig. 1). The monthly mean discharge of water into the CPR (Royal Irrigation Department, unpublished data) was used to classify the seasons in the river basins into the wet season (May–November) with a mean discharge of 12–500 million m^3/month and the dry season (December–April) with a discharge of 0.6–11 million m^3/month.

3 METHODOLOGY

The likelihood and consequences of flooding and a weighting average technique were used to assess the flood risks [1]–[3] by district across the CPRB. The flood risk index for each of the 151 districts was estimated according to the availability of the flood-relevant data over the 16 year-period (2001–2016). These data were obtained from the Department of Disaster Prevention and Mitigation (DDPM), the main Thai government agency that has the responsibility of managing all kinds of disasters in Thailand. The existing flood-relevant data in the CPRB were available upon request only from 2001 to 2005; whereas the latest data from 2006 to 2016 can be accessed online [20].

The retrieved data over the 16-year period were compiled in terms of the cumulative flooding frequencies (f_{flood}) and the cumulative consequences on lives (L_{cons}) and the properties/public utilities (P_{cons}) for each district. The DDPM categorized the L_{cons} into four groups including dead/disappearance (L_1), injured (L_2), evacuated (L_3), and affected (L_4: not dead/injured/evacuated, but were suffering from other flood-related consequences). The DDPM appraised the P_{cons} for each flood event in a flooded area as a monetary unit for the loss/damage of properties/public utilities (e.g., residential and agricultural areas, livestock and poultry farms, streets, bridges, levees/dikes, schools, government buildings, etc.).

In this study, the flood risk index (F_{ri}) for each district was assessed as the multiplication of the three flood risk variables (i.e., $f_{flood} \times L_{cons} \times P_{cons}$) divided by the maximum flood risk (i.e., $F_{r,max}$) in the CPRB, so that the estimated F_{ri} is dimensionless and ranged between 0 and 1. For instance, the floods occurred 10 times in Lop Buri's Mueang District over the 16-year period (2001–2016). These caused L_{cons} as follows: 34 deaths, 25,862 people evacuated, and 353,595 people affected. The P_{cons} from the 10 flood events appraised by the DDPM was 23,300,878 US dollars. The F_{ri} for Mueang District of Lop Buri Province were then estimated as follows:

$$F_{ri} = (f_{flood} \times L_{cons} \times P_{cons}) \div F_{r,max}, \quad (1)$$

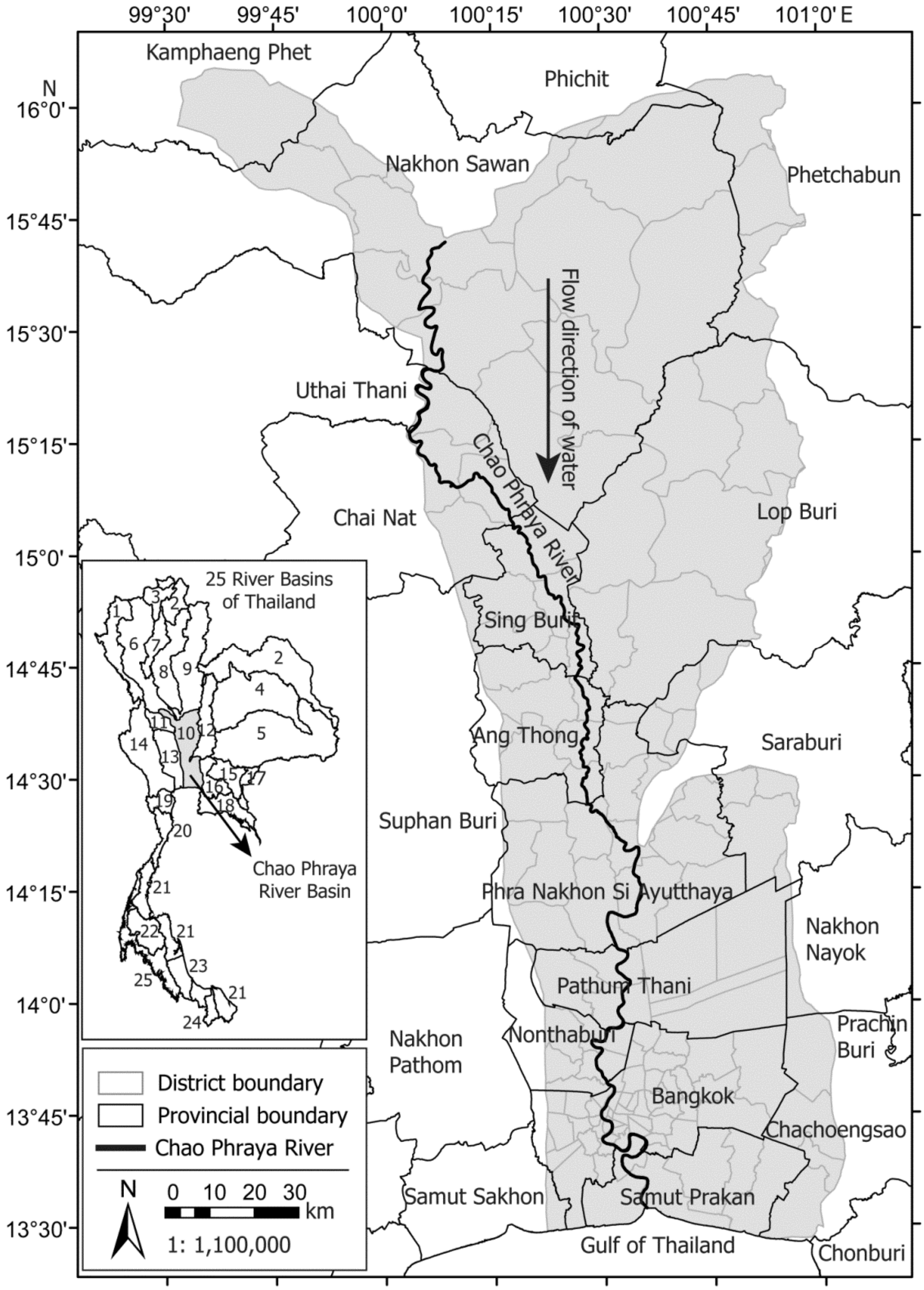

Figure 1: Location of the Chao Phraya River Basin covering 151 districts in 19 provinces and the Chao Phraya River.

where
f_{flood} = 10 ÷ 16 = 0.63 times per year (times/y);
L_{cons} = $\sum_{i=1}^{n} w_i L_i$;
= (1 × 34) + (0 × 0.8) + (0.6 × 25,862) + (0.5 × 353,595) = 192,349 people;
where
L_i = the cumulative consequences on lives group i (i, = 1, 2, 3, 4);
w_i = weight of severity (between 0 and 1) assigned to each L_i,;
= 1, 0.8, 0.6, and 0.5 for L_1, L_2, L_3, and L_4, respectively;
P_{cons} = 23,300,878 US dollars;
$F_{r,rmax}$ = (f_{flood} × L_{cons} × P_{cons}) which belonged to Pathum Thani's Mueang District;
= (.069 × 106,087 × 39,935,218);
= 2,923,259,155,657 (times/y × people × US dollar).

The F_{ri} for Lop Buri's Mueang District was derived as follows

$$F_{ri} = (0.63 \times 192{,}349 \times 23{,}300{,}878) \div 2{,}923{,}259{,}155{,}657 = 0.97.$$

The F_{ri} for the remaining 150 districts in the CPRB was estimated using a similar method. Afterwards, the F_{ri} across the river basin was categorized into four classes (i.e., low, moderate, high, and very high) using natural breaks in the ArcGIS program. The close values of the F_{ri} were categorized together at the same class, i.e., ≤ 0.12 = low, 0.13–0.32 = moderate, 0.33–0.62 = high, and 0.63–1.00 = very high. The four classes of flood risk index were mapped by district across the river basin using the ArcGIS program.

4 RESULTS AND DISCUSSION

Among the 151 districts located in the CPRB, four, three, and 10 districts showed very high, high, and moderate risks of flooding, respectively, whereas the remaining 134 districts showed a low flood risk (Fig. 2). The four districts with very high flood risk included the Mueang District of Lop Buri, the Bang Pa-in District of Phra Nakhon Si Ayutthaya, and the Mueang and Khlong Luang districts of Pathum Thani. The f_{flood}, L_{cons}, and P_{cons} over the 16-year period in these districts were in the ranges of 0.5–0.9 times/y, 106,087–192,349 people, and 19.1–39.9 million US dollars, respectively. The industrial and/or agricultural sectors mainly accounted for the P_{cons} in these districts. The Nava Nakorn and Bangkadi IEs are located in the Mueang and Khlong Luang districts of Pathum Thani, respectively, and the Bang Pa-in IE is located in the Bang Pa-in District of Phra Nakhon Si Ayutthaya. Livestock and poultry farms in Lop Buri's Mueang District, and both livestock/poultry and fish/shrimp farms in Phra Nakhon Si Ayutthaya's Bang Pa-in District were most affected by flooding over the 16-year period under consideration.

The other three districts that showed a high flood risk are located in the same provinces that the four districts with a very high flood risk were detected. These included the Ban Mi District of Lop Buri, the Mueang District of Phra Nakhon Si Ayutthaya, and the Lam Luk Ka District of Pathum Thani. The f_{flood}, L_{cons}, and P_{cons} detected in these three districts were in the ranges of 0.5–1.0 times/y, 33,237–187,210 people, and 6.7–103.1 million US dollars, respectively. The f_{flood} for the districts with a high flood risk were close to those with a very high flood risk; however, the range of L_{cons} was lower. Likewise, although the Lam Luk Ka District of Pathum Thani had a higher P_{cons}, at 103.1 million US dollars, than in the four districts that had a very high flood risk, its observed f_{flood} (0.5 times/y) and L_{cons} (33,237 people) over the 16-year period were lower. The P_{cons} in the high flood risk districts were mainly as a result of flood damage on agricultural areas and livestock, poultry, fish, or shrimp farms; except in the Lam Luk Ka District, where it mainly resulted from flood damage in a

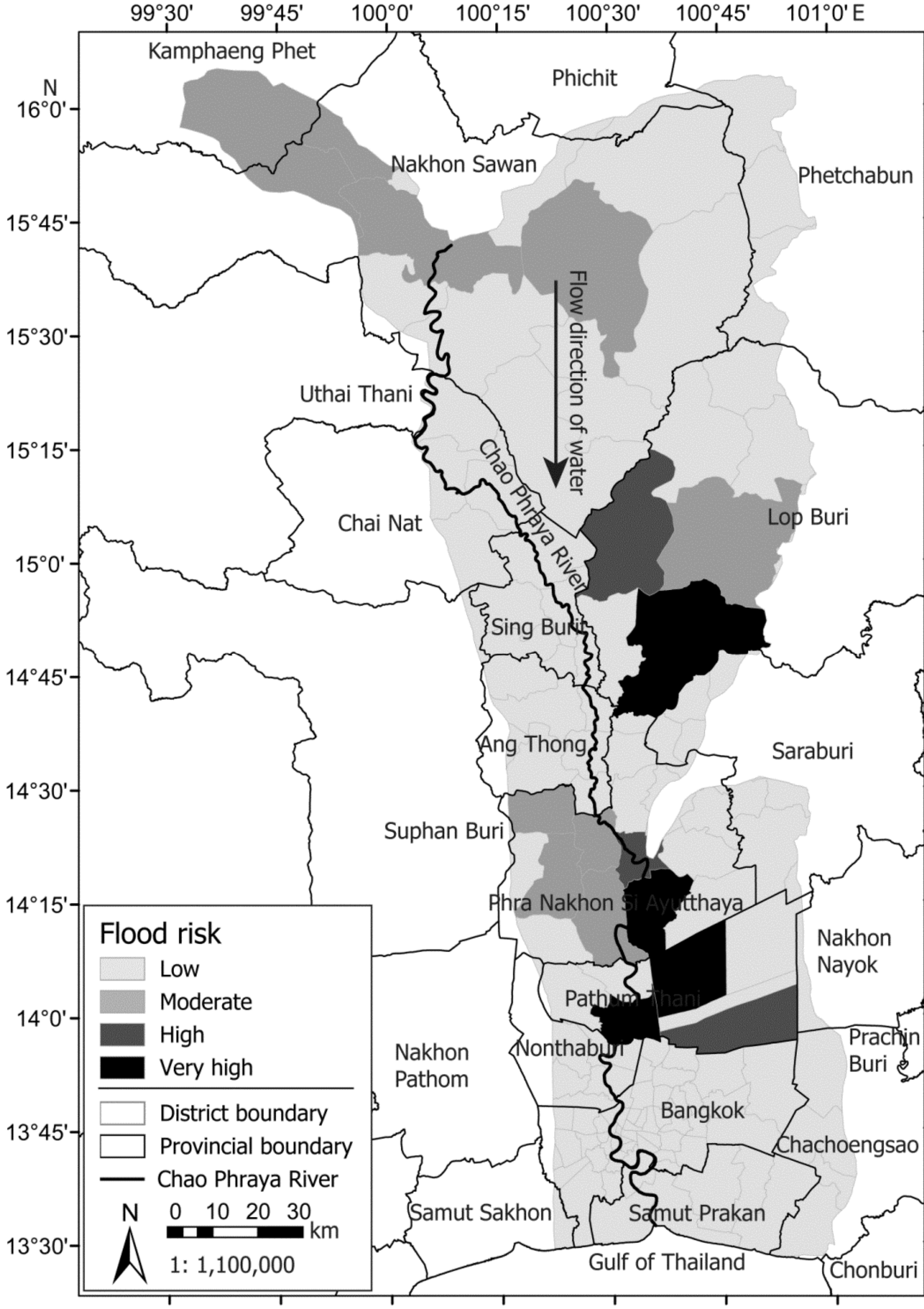

Figure 2: Flood risk index for the 151 districts across the Chao Phraya River Basin. Low (≤ 0.12), moderate (0.13–0.32), high (0.33–0.62), and very high (0.63–1.00).

combination of residential and agricultural areas. Ten districts with a moderate flood risk included four districts in Nakhon Sawan and Phra Nakhon Si Ayutthaya, and one district in Lop Buri and Kamphaeng Phet; whereas, the remaining 134 districts with a low flood risk were scattered across the river basin (Fig. 2).

The largest flood devastation in 2011 was observed in the CPRB. The total damage and losses were from flooding in eight provinces, of which more than 50% of the area is located in the river basin, as shown on Table 1 [13]. Unlike other provinces, Bangkok, the crowded capital of Thailand, incurred the largest damages and losses in terms of tourism, water and sanitation, and housing sectors (Table 1), whereas, the f_{flood} and L_{cons} in most of the 50 districts of Bangkok were rather low. These contributed to the low flood risk detected across Bangkok.

Table 1: Estimated damage and losses in major sectors from the 2011 flood in Thailand in the provinces with more than 50% of their area located in the Chao Phraya River Basin, except in Samut Prakan Province where the estimated losses are unavailable [13].

Province	Total damage and losses (million US dollar) by major sector[a]							
	1	2	3	4	5	6	7	8
Ang Thong	11.6	45.7[b]	3.0	22.5	0.3	1.8	5.1	76,475,940.4
Bangkok	28.8	1,959.2	2,291.3	76.6	75.0	69.7	29.9	1,017,111,838.5
Lop Buri	32.2	1,240.9[b]	22.5	59.4	0.2	2.9	2.9	44,700,371.0
Nakhon Sawan	18.6	903.8	22.0	92.4	0.6	7.2	7.7	73,162,641.6
Nonthaburi	13.2	1,033.2[b]	18.2	36.1	2.5	5.0	23.0	290,094,340.9
Pathum Thani	60.7	2,859.9	11.7	59.0	10.4	4.3	24.9	370,763,623.7
Phra Nakhon Si Ayutthaya	147.6	3,643.1	84.5	54.4	204.0	10.4	16.0	327,098,191.8
Sing Buri	4.0	n/a	2.9	33.5	0.0	2.2	2.4	28,818,101.6

[a]1 = Agricultural; 2 = Industrial; 3 = Tourism; 4 = Transport; 5 = Electricity; 6 = Water and sanitary; 7 = Health; 8 = Housing. [b]Ministry of Industry (unpublished data). n/a = unavailable.

Located around the river mouth of the CPR, Samut Prakan Province showed low flood risk (Fig. 2) even during the 2011 mega flood of the country. This might be due to a number of factors. For instance, the floodwaters were not often allowed to flow, as per normal circumstance, through inner Bangkok (where a lot of economic and shopping centers, government offices, academic institutions, important temples, palaces, etc. are located) to Samut Prakan. Accordingly, during the 2011 flood in the CPRB, large amounts of floodwater hitting Bangkok were diverted to the western and eastern areas outside Bangkok [21]. Consequently, many districts located downstream of Bangkok (i.e., in Samut Prakan) were barely flooded or were flooded at a shallow level in 2011.

Land use is another variable that influenced the severity of the flood risk. The agricultural sector covers about 71% of the CPRB. The largest damages and losses in the agricultural sector (147.6 million US dollars) as the result of the 2011 flood were detected in Phra Nakhon Si Ayutthaya (Table 1). Based on the province’s geography and major land use activity (i.e., rice farming), most paddy fields in Phra Nakhon Si Ayutthaya act as flood drainage areas in the wet season each year. That is, after rice harvesting (around after mid-September), farmers will allow the local irrigation offices to drain floodwaters onto their farmlands.

Meanwhile, although it accounted for just about 3% of the total land use (2,270 km^2) in Phra Nakhon Si Ayutthaya, the industrial sector in this province suffered considerable damage in the 2011 flood (Table 1), particularly the five inundated IEs, i.e., Saha Rattana Nakorn, Rojana, Hi-tech, Bang Pa-in, and Factory Land IEs. To reduce the severity of the flood risk in the provinces located in low-lying areas, the residential and industrial sectors should be relocated out of these areas. Land use planning and building zoning in areas with moderate to very high flood risks should be improved; and the relevant flood risk mapping should be considered as one of the key variables in the re-planning/re-zoning process.

Man-made disturbances (e.g., diverting floodwaters out of their areas and/or flood protection using any type of flood control structures) were unpredictable and therefore excluded from the flood risk assessment in this study. Nevertheless, the results of man-made disturbances were likely to be incurred in either L_{cons} or P_{cons} or both. The obvious example occurred in 2011, during the flood in inner Bangkok, where important areas were protected by the government. Flood dikes and sandbags were installed around these areas; and floodwaters were diverted towards other areas. These caused the affected people to become very upset and some of them destroyed the sandbags or obstructed officials from repairing the flood barriers [21].

The flood control structures installing along the riverbanks of the CPR, which run through urban or economic areas, are apparently another kind of man-made disturbance in the CPRB. These concrete walls not only motivate people to stay in the floodplain, but also create deep areas for retaining water and modifying the patterns of water flow [16]. Additionally, concentrations of people, infrastructure, and assets cause greater risks in urban areas that could subsequently suffer higher fatalities and economic losses from flooding compared to rural areas [22].

5 CONCLUSION

The flood risk index was primarily assessed by district across the CPRB. The districts that showed high and very high flood risks were detected in Lop Buri, Phra Nakhon Si Ayutthaya, and Pathum Thani provinces. Land use activities and man-made disturbances could influence the severity of flood risks in the river basin, particularly in the downstream portion, where Bangkok, the capital of Thailand, is located. Overall, the flood risk assessment in the river basin scale is useful for decision making by local administrations to prepare appropriate plans/measures on flood risk management and mitigation. Although a flood disaster cannot be 100% prevented, its impacts may be managed or mitigated if the relevant flood risks are known. Further flood risk studies at a finer spatial scale across a river basin of interest are recommended by incorporating more important flood-related variables, such as land use activities, seasonal precipitation, flood trace, and so forth. In addition, the current flood risk management plans and measures should be improved by emphasizing both community participation (e.g., community consultation, monitoring, and review) and non-structural measures (such as land use planning, building zoning, and development controls); and these should be based on the severity of the estimated flood risks across the river basin. Community participation can assist in shaping the flood risk management plans more effective in a manner consistent with the severity of flood risks and community support. Meanwhile, proper non-structural measures for managing or mitigating flood risks are, for instance, a regulation that discourages development that may exacerbate impacts of flooding in a certain area, an exclusion of high flood risk areas from the development zone, and preparations of community emergency response plans for the areas with moderate, high, and very high flood risks.

ACKNOWLEDGEMENTS
Special thanks are due to Faculty of Environment and Resource Studies, Mahidol University, for supporting this study and Thai government agencies including Department of Disaster Prevention and Mitigation, Bangkok Metropolitan Administration, Land Development Department, and local administrative organizations in the river basin for supplying the relevant data. This study was supported by Mahidol University (grant TM 94/2557).

REFERENCES

[1] Samuels, P.G., Risk and uncertainty in flood management. *River Basin Modeling for Flood Risk Mitigation*, eds D.W. Knight & A.Y. Shamseldin, Taylor and Francis: London, pp. 481–517, 2006.
[2] Schanze, J., Flood risk management – A basic framework. *Flood Risk Management – Hazards, Vulnerability and Mitigation Measures*, eds J. Schanze, E. Zeman, & J. Marsalek, Springer: Berlin, pp. 149–167, 2006.
[3] AEMI (Australian Emergency Management Institute), *Managing the Floodplain: A Guide to Best Practise in Flood Risk Management in Australia*, 2nd ed., Biotext: Canberra, Australia, 2013.
[4] Freire, P., Tavares, A.O., Sá, L., Oliveira, A., Fortunato, A.B., Santos, P.P.D., Rilo, A., Gomes, J.L., Rogeiro, J., Pablo, R. & Pinto, P.J., A local-scale approach to estuarine flood risk management. *Natural Hazards*, **84**, pp. 1705–1739, 2016.
[5] Frolova, N.L., Kireeva, M.B., Magrickiy, D.V., Bologov, M.B., Kopylov, V.N., Hall, J., Semenov, V.A., Kosolapov, A.E., Dorozhkin, E.V., Korobkina, E.A., Rets, E.P., Akutina, Y., Djamalov, R.G., Efremova, N.A., Sazonov, A.A., Agafonova, S.A. & Belyakova, P.A., Hydrological hazards in Russia: origin, classification, changes and risk assessment. *Natural Hazards*, **88**(1), pp. 103–131, 2017.
[6] Glas, H., Jonckheere, M., Mandal, A., James-Williamson, S., De Maeyer, P. & Deruyter, G., A GIS-based tool for flood damage assessment and delineation of a methodology for future risk assessment: Case study for Annotto Bay, Jamaica. *Natural Hazards*, **88**, pp. 1867–1891, 2017.
[7] Kabenge, M., Elaru, J., Wang, H. & Li, F., Characterizing flood hazard risk in data-scarce areas, using a remote sensing and GIS-based flood hazard index. *Natural Hazards*, **89**, pp. 1369–1387, 2017.
[8] Guha-Sapir, D., Vos, F., Below, R. & Ponserre, S., *Annual Disaster Statistical Review 2011 – The Numbers and Trends*, Centre for Research on the Epidemiology of Disasters (CRED): Brussels, 2012.
[9] Gale, E.L. & Saunders, M.A., The 2011 Thailand flood: Climate causes and return period. *Weather*, **68**(9), pp. 233–237, 2013.
[10] EM-DAT: The Emergency Events Database, Universite catholique de Louvain (UCL). http://emdat.be/emdat_db/. Accessed on: 20 Jul. 2019.
[11] Marks, D. & Thomalla, F., Responses to the 2011 floods in Central Thailand: Perpetuating the vulnerability of small and medium enterprises? *Natural Hazards*, **87**, pp. 1147–1165, 2017.
[12] Hydro and Agro Informatics Institute, The 2011 mega flood record. (In Thai.) www.thaiwater.net/current/flood54.html. Accessed on: 2 Jul. 2019.
[13] Ministry of Finance and World Bank, *Thailand Flooding 2554: Rapid Assessment for Resilient Recovery and Reconstruction Planning*, Royal Thai Government: Bangkok, 2012.
[14] Montz, B.E., Tobin, G.A. & Hagelman III, R.R. (eds), *Natural Hazards: Explanation and Integration*, 2nd ed., The Guilford Press: New York and London, 2017.

[15] Haraguchi, M. & Lall, U., Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction*, **14**, pp. 256–272, 2015.
[16] Singkran, N., Flood risk management in Thailand: Shifting from a passive to a progressive paradigm. *International Journal of Disaster Risk Reduction*, **25**, pp. 92–100, 2017.
[17] Cooper, R.T., Open data flood mapping of Chao Phraya River Basin and Bangkok Metropolitan Region. *British Journal of Environment and Climate Change*, **4**(2), pp. 186–216, 2014.
[18] Liew, S.C., Gupta, A., Chia, A.S. & Ang, W.C., The flood of 2011 in the lower Chao Phraya valley, Thailand: Study of a long-duration flood through satellite images. *Geomorphology*, **262**, pp. 112–122, 2016.
[19] Sayama, T., Tatebe, Y. & Tanaka, S., An emergency response-type rainfall-runoff-inundation simulation for 2011 Thailand floods. *Journal of Flood Risk Management*, **10**, pp. 65–78, 2017.
[20] DDPM (Department of Disaster Prevention and Mitigation), Disaster statistics 2006–2016. (In Thai.) http://122.155.1.141/inner.directing-6.191/cms/menu_4469/2015.1/. Accessed on: 11 Nov. 2019.
[21] Singkran, N. & Kandasamy, J., Developing a strategic flood risk management framework for Bangkok, Thailand. *Natural Hazards*, **84**(2), pp. 933–957, 2016.
[22] Dickson, E., Baker, J.L., Hoornweg, D. & Tiwari, A., *Urban Risk Assessments: Understanding Disaster and Climate Risk in Cities*, The World Bank: Washington, DC, 2012.