URBAN FLOOD HAZARD MAP USING GIS OF MUANG SUKHOTHAI DISTRICT, THAILAND

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ABSTRACT:

Urban flood is one of the most challenge tasks for cities that needs the complex decision support system based on the integration among physical, social parameters and technical knowledge. It needs the analysis on flood hazard map to set up the emergency response plan. Most of communities in Thailand originated along the river of which urban flood is caused by both overflowing from river bank and ineffective drainage system. The most severe urban flood in Thailand occurs in Muang district of Sukhothai province. Because the city locates along Yom river basin where is no regulated dam upstream. Since there are the limitations on the technical support of local organizations. The aim of this paper, therefore, is to generate flood hazard map by coupling flood frequency analysis with GIS that the local officer can easily develop by themselves. Flood frequency analysis proves it can be an alternative method for flood hazard map generating. With the case study of Muang Sukhothai district, the accuracy of this method is 88.83%. The obtained flood hazard map will be the basic information for the decision maker not only on flood emergency response plan but also on prioritizing of budget allocation for flood protection system.

Key-words: *Urban flood, Flood emergency response plan, Flood hazard map, Sukhothai flood.*

1. INTRODUCTION

Flood is one of the most threatening and damaging natural disasters globally that impacts negatively upon the activities of human lives, with inundation leading to disastrous consequences including the loss of lives and destruction of property (Dadson et. al, 2017). Flood hazard is expected to increase in frequency and magnitude because of the impacts of climate change (Dinh et al., 2012). Then it requires various responses including construction for downstream flood defences, forecasting (for warning and evacuation), and land-use management for upstream land use changes and runoff characteristics (Kidson and Richards, 2005). Floods occur because of the rapid accumulation and release of runoff waters from upstream to downstream, caused by very heavy rainfall (Ouma and Tateishi, 2014; Şarpe and Haidu, 2017). Urban areas in particular suffer from a relatively high flood risk because of high population number and density, a lot of economic activities, infrastructure and property values (Pelling, 2003; Nusit et al., 2019).

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Impacts of urban floods are significant in terms of economic losses. There is a direct relationship between urbanisation and hydrological characteristics; decreased infiltration, increase in runoff, increase in flood frequency and flood height (Alaghmand et al., 2010; Ouma and Tateishi, 2014, Haidu and Ivan, 2016a). Increasing discharge is directly related to the increase in urbanised areas (Phetprayoon et al., 2010; Haidu and Ivan, 2016b). Urbanisation tends to increase peak flood flows because of reduced infiltration under paved areas and rapid flow over the surface (Dadson et al., 2017, Kumar et al., 2013).

Urban flood due to overflow of the riverbank in cities is not an isolated phenomenon but closely related with overall basin characteristics. The city of Sukhothai, located in lower Yom river basin in lower northern of Thailand, frequently suffers from floods due to the low retention capability of the upstream area (lacking of the regulated dam) and the narrow basin cross section in the downstream area (Sriariyawat et al., 2013; Seejata et. al., 2019). The Yom river, a tributary of the Chao Phraya River, is approximately 736 km long with the average flow capacity of the main channel varies from 220 m^3/s to 2,000 m^3/s. As Sriariyawat et al. (2013) pointed out that the segment from Phrae province to Sukhothai province has a capacity of 1,000-2,000 m^3/s, whereas the segment from Sukhothai province to Phitsanulok province has a capacity of only 220-300 m^3/s. Therefore, when there is heavy rainfall over the upstream area, it causes an overflow of the riverbanks, erosion and severe flooding in Sukhothai urban area.

With urban development, impermeable surface areas decrease infiltration and increase the rate and volume of surface runoff (Fitzpatrick et al., 2005). Klemešová et al. (2014) noted that flood hazard map is one of the preventive instruments for assessment and management of flood risks. The problem is that there are still have limitations on technical support of local organizations in Sukhothai province. Having flood hazard and flood extent maps could help them in terms of dicision support system to prioritise the response plan and budget allocation for the protection system. The aim of this study, therefore, is to generate flood hazard map by coupling frequency analysis with Geographic Information System (GIS) that the local officer can easily develop by themselves as well as can be the information for decision maker on flood preparedness and responses.

2. STUDY AREA AND DATA

2.1 Study area

Sukhothai province is most famous for its historical city, the first capital of Thailand. Sukhothai Historical Park in Muang district is now a UNESCO World Heritage Site. Muang Sukhothai is the capital district that can be seen as an urban area of Sukhothai province. It is located in lower Yom river basin in lower northern of Thailand (**Fig.1**). It is divided into 10 sub-districts, which are further subdivided into 98 villages. Total area of Muang Sukhothai is 553.38 km^2 with the population of 104,328. It has the highest population density of 188.53/ km^2 accounting for 18.82% of the Sukhothai province that covers approximately 6,664.48 km^2 with the population of 597,257 (**Tab. 1**).

2.2 Data

According to Seejata, et al. (2019) and previous studies, eight conditioning parameters were selected for flood hazard analysis including rainfall, elevation, slope, land use, soil drainage, drainage density, distance from drainage and road density (Anucharn and

Iamchuen, 2017; Cao et al., 2016; Das, 2019; Duangpiboon et al., 2018; Khosravi et al., 2016; Lee et al., 2018; Sahana and Patel, 2019; Samanta et al.,2018; Samanta, 2018; Shafapour et al., 2019; Tehrany et al., 2015; Youssef et al., 2016). **Table 2** and **Fig. 2** give more detailed on data used in this analysis.

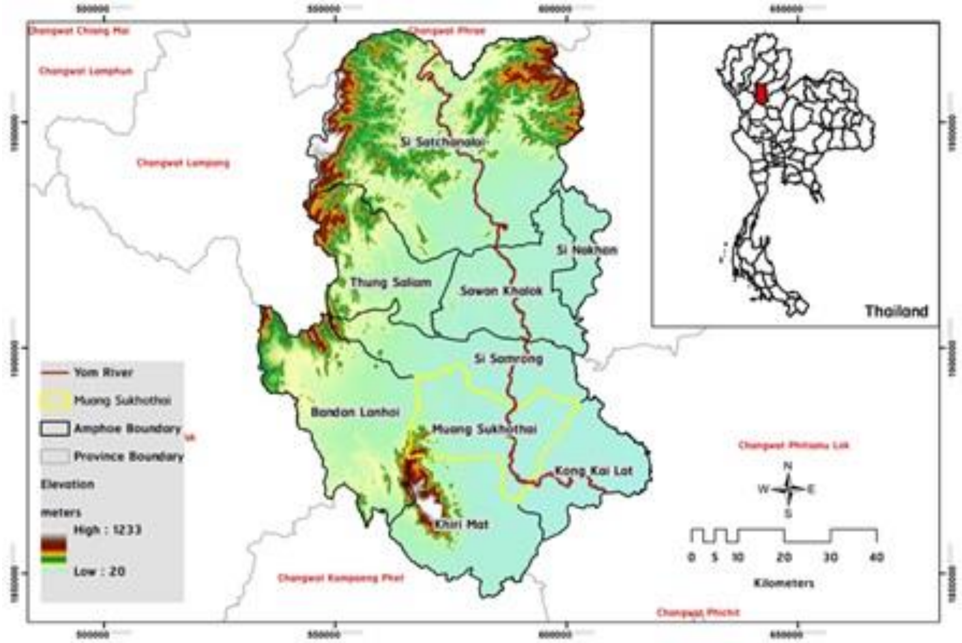

Fig. 1. Study area of Muang Suhkothai district, Thailand.

Table 1.

Area and population of Sukhothai province.

District	Area	Pop	Pop Density (per km^2)	%
Muang Sukhothai	553.38	104,328	188.53	18.82
Kong Krailat	449.10	64,308	143.19	14.30
Si Nakhon	183.25	26,177	142.85	14.26
Sawankhalok	620.06	83,919	135.34	13.51
Si Samrong	558.50	71,110	127.32	12.71
Thung Saliam	583.94	49,492	84.75	8.46
Khiri Mat	679.73	56,864	83.66	8.35
Ban Dan Lan Hoi	923.24	47,960	51.95	5.19
Si Satchanalai	2,113.29	93,099	44.05	4.40
Total	**6,664.48**	**597,257**	**89.62**	**100.00**

Source: National Statistical Office of Thailand

Table 2.

Data and Sources.

Data	Detailed and Sources
Rainfall	Average rainfall (Between1988-2017) obtained from Thai Meteorological Department (TMD)
Elevation	30x30 meter spatial resolution from the Digital Elevation Model of Shuttle Radar Topography Mission
Slope	Derived from the Digital Elevation Model
Land use	(1) Agricultural land (2) Forest land (3) Urban land (4) Water (5) Miscellaneous land (From Land Development Department)
Soil drainage	(1) No survey (2) Poorly to somewhat poorly drained (3) well to moderately well-drained (4) Very well-drained (5) Urban area (6) Miscellaneous area (7) Water (From Land Development Department)
Drainage density	Derived from the Geo-Informatics and Space Technology Development Agency (GISTDA)
Distance from drainage	Five concentric buffers (each of 1,000 meter width).
Road density	Derived from the GISTDA

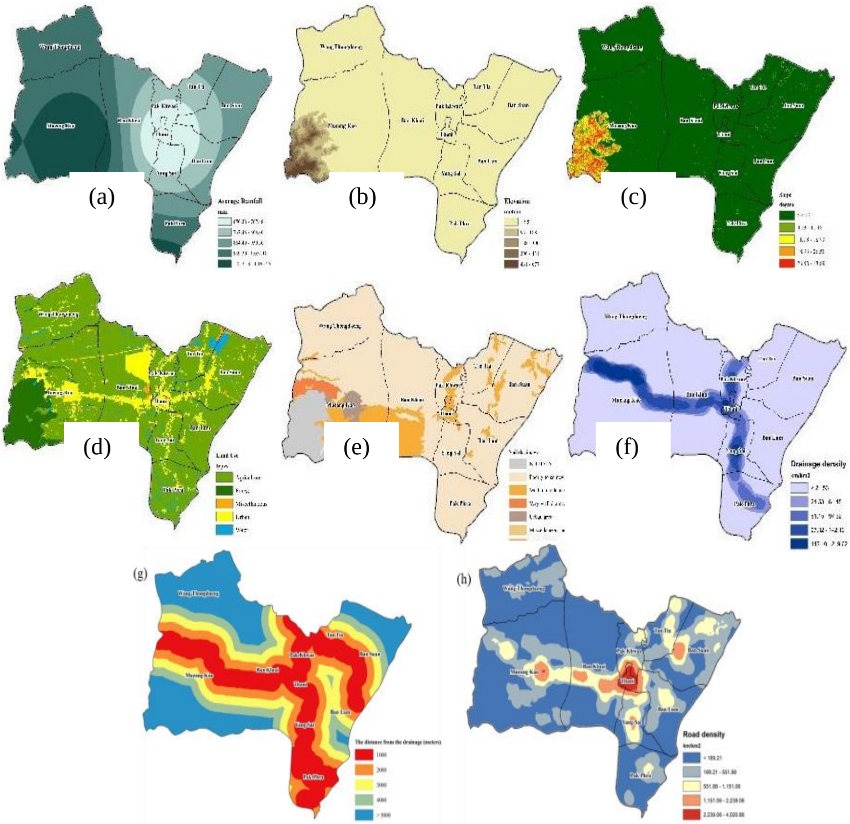

Fig. 2. Eight conditioning parameters: (a) rainfall, (b) elevation, (c) slope, (d) land use, (e) soil drainage, (f) drainage density, (g) distance from drainage and (h) road density.

3. METHODOLOGY

To generate the flood hazard map, this study applied the frequency ratio (FR) method. **Fig. 3** shows the methodology framework.

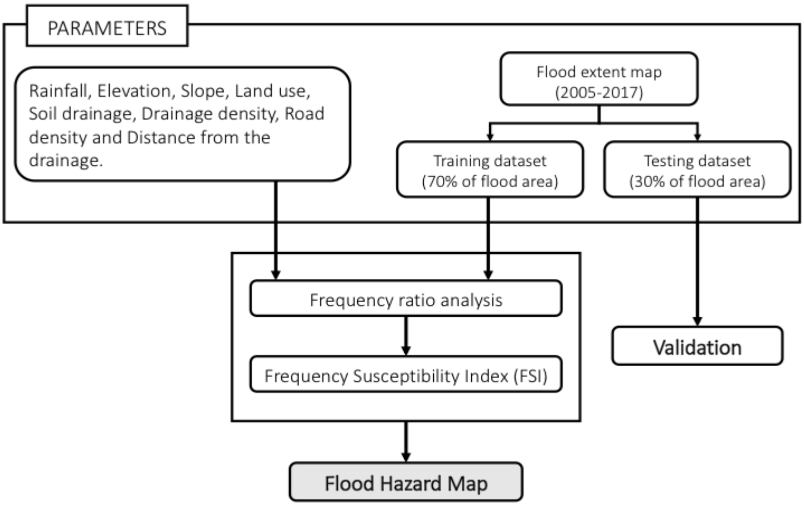

Fig. 3. Flood hazard mapping methodology framework.

3.1 Flood Extent Map

The flood extent map was generated from multi-satellite including RADARSAT-2, THAICHOTE, and COSMO-SkyMed-4 obtained from GISTDA for the period of 2005 to 2019 using Geostatistical analyst tool in GIS environment. Seventy percent of flood area was used to generate the flood hazard map while another thirty percent for validation (Seejata et al., 2019).

3.2 Flood Hazard Map using Frequency Ratio Method

Geographic Information System (GIS) and Frequency Ratio (FR) method have been used to create flood hazard map. The FR method is a bivariate statistics analysis method based on relationships between historical data and conditioning factors (AlThuwaynee, 2018). It is not only simply implemented but also easy to understand (Khosravi, 2016). The FR is calculated using the following equation (1).

$$FR = \frac{PH}{PS} \quad (1)$$

where PH is the percentage number of flood hazard in each class and PS is the percentage number of study area in each class.

If FR value is lower than 1 means weak correlation, on the other hand, if the FR value is more than 1 means strong correlation.

The Frequency Susceptibility Index (FSI) is calculated using the following equation (2).

$$\mathrm{FSI} = \sum_{i=1}^{n} FR_i \quad (2)$$

where FR_i is the value of FR in each factor and *n* is the number of factors.

In conclusion, the FSI value applied for flood hazard mapping and classified by Jenks natural breaks classification method into 5 classes: (1) very high, (2) high, (3) moderate, (4) low, and (5)very low.

3.3 Validation Process

The validation process had been done by the Area Under Curve (AUC). The success rate was calculated using the training flood area of 70% whereas the prediction accuracy was calculated using a testing flood area of 30%. The FSI was classified into 100 categories on the x-axis, with a cumulative of flood occurrence on the y-axis (Tehrany et al., 2019).

4. RESULTS AND DISCUSSIONS

Table 3 shows observed flood extent for the period of 2005-2019. As can be seen that flood occurred in Muang Sukhothai district almost every year with the severe events, especially in 2006, 2010, 2011 and 2017 (**Fig. 4**) Among 13 years records, flood extent in Muang district are severe as 78.94%, 38.83%, 55.10%, 49.68% of the total district area in 2006, 2010, 2011, and 2017, respectively (**Tab. 3**). This shows that it is needed to have the preparedness and response plan to cope with flood over the district.

Table 3.
Flood area during 2005-2019.

Year	Area (km^2)	% of Flooding area
2005	156.683	26.95
2006	458.996	78.94
2007	141.625	24.36
2008	85.227	14.66
2009	88.147	15.16
2010	225.807	38.83
2011	320.403	55.10
2012	170.973	29.40
2013	124.257	21.37
2014	103.867	17.86
2016	123.956	21.32
2017	288.885	49.68
2019	65.890	11.33

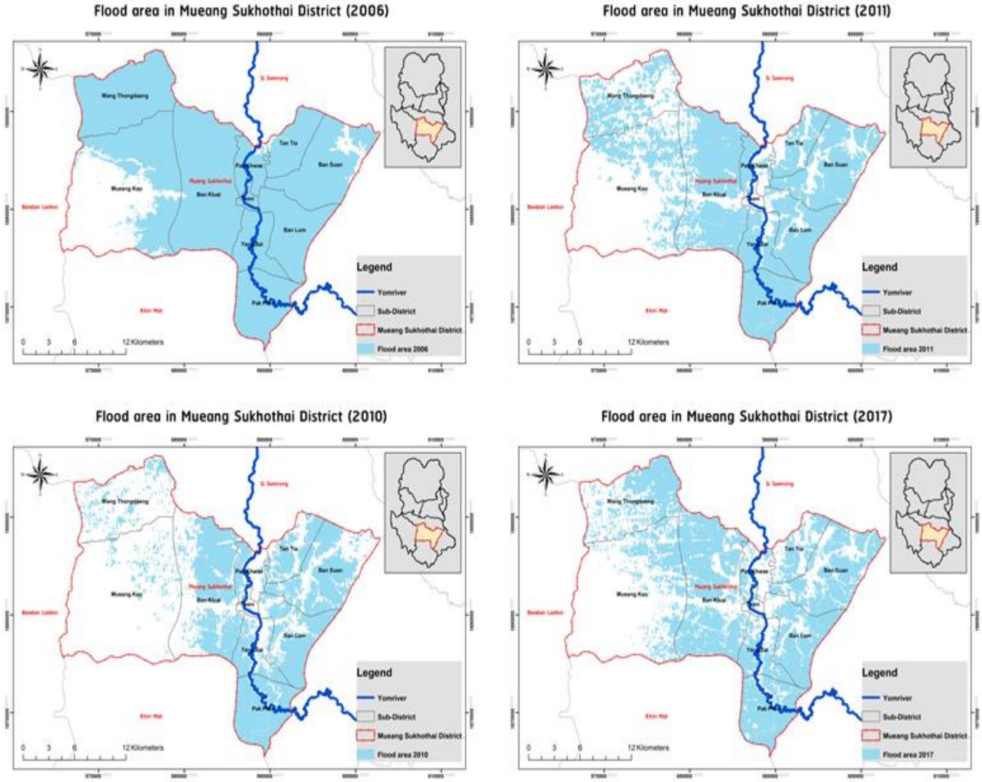

Fig. 4. Observed flood extent for severe events.

By using the frequency ratio method, the obtained flood hazard map is shown in **Fig. 5** and **Table 4** demonstrates the percentage of each level of flood hazard. It has been found that area with very high flood risk is 88.87% of the whole district.

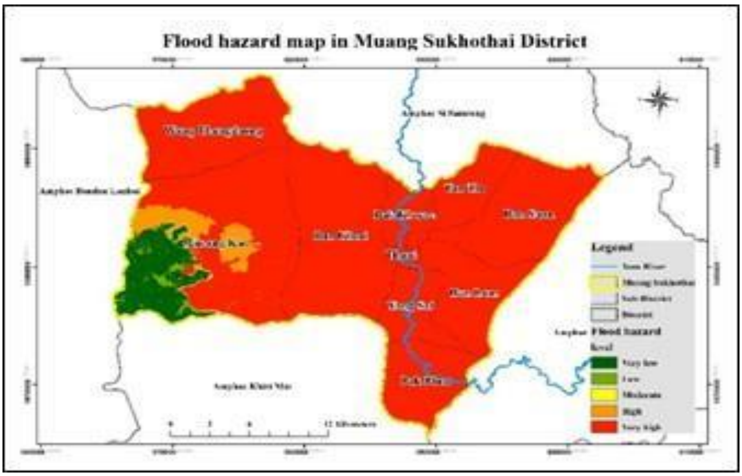

Fig. 5. Flood hazard map in Muang Sukhothai District.

Table 4.
Flood hazard classification in Muang Sukhothai District.

Level	Area (km2)	%
Very Low	34.24	6.19
Low	5.14	0.93
Moderate	0.91	0.16
High	21.23	3.084
Very High	491.37	88.87

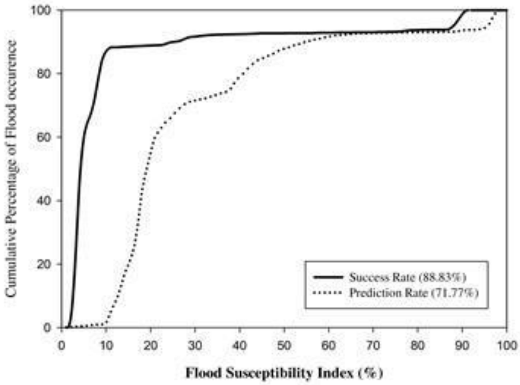

Fig. 6. Success rate and prediction rate curve of the frequency ratio model.

The Area Under Curve (AUC) was used to examine the accuracy of the flood hazard map. Flood Susceptibility Index (FSI) was classified into 100 categories on the x-axis, while a cumulative of flood occurrence was shown on the y-axis. For the frequency ratio model, it has been found that AUC of the training area was 88.83% and the testing area was 71.77% (**Fig. 6**). In order to mitigate flood disaster in Muang Sukhothai district, it is important not only to promote structural measure by constructing flood control facilities such as levee or floodwall but also to prepare non-structural measures by improving ways to communicate disaster information and evacuation as well as by increasing public awareness towards disaster prevention because there is a possibility that a levee or floodwall can breach if the flood exceeds its designed capacity. For these reasons, flood extent map and flood hazard map should be disclosed as a part of flood control measures and flood emergency response plan.

5. CONCLUSIONS

The method of flood frequency analysis can be an alternative for flood hazard map generating. With the case study of Muang Sukhothai district, the obtained accuracy of this method is 88.83%. Although, Muang Sukhothai district has floodwall and sandbags to prevent the overflowing in urban area, sometimes it was at risks of collapsing. Therefore, *"Flood Hazard Mapping Manual"* will be delivered to local officer with the aims of minimizing flood damage by providing residents with inundation-related information in an easy-to-understand way. The manual will describe how to prepare a flood hazard map by coupling frequency analysis with GIS step by step. And that the local officer can easily develop by themselves. As can be seen that flood hazard map proves it can uncover and identify risk areas that exist in the district as the basic information for risk-based decisions. However, further develop should be done as follows: evacuation information, communication system during disaster, disaster tracking system, disaster quantify process, allocate mitigation measures, as well as the effectiveness verification system.

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