FLOOD HAZARD ASSESSMENT USING FUZZY ANALYTIC HIERARCHY PROCESS: A CASE STUDY OF BANG RAKAM MODEL IN THAILAND

Aphittha Yodying (1*), Kamonchat Seejata (1), Sasithon Chatsudarat (2), Polpreecha Chidburee (2), Nattapon Mahavik (2), Charatdao Kongmuang (2), Sarintip Tantanee (1)

[1] Department of Civil Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, 65000, Thailand
[2] Department of Natural Resources and Environment, Faculty of Agriculture Natural Resources and Environment, Naresuan University, Phitsanulok, 65000, Thailand

Email: aphityod@gmail.com; nattaponm@nu.ac.th

KEY WORDS: Bang Rakam Model 60, Digital Elevation Model (DEM) Geographic Information System (GIS), Multi-Criteria Analysis (MCA)

ABSTRACT: Flood is a natural hazard with the highest frequency and the widest geographic distribution across the globe that generally affects people's lives and the ecosystem, causing catastrophic disasters. Flood is the most fatal and frequent in Thailand, where people are affected annually. In 2011, Thailand has experienced the worst flood, which makes the floods one of the top five significant natural disaster events in modern history. Therefore, the flood hazard assessment is a fundamental pre-requisite for flood risk assessment. In this study, the combination of Fuzzy Analytic Hierarchy Process (Fuzzy AHP) based on Chang's extent analysis (Chang, 1996) and Geographical Information Systems (GIS) were used to assess flood hazard by comparison the elevation effects between from Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) and Light Detection and Ranging (LiDAR). The study area is "Bang Rakam Model 60" project. Designed as a retention area for the Yom river, this project was launched by the Royal Irrigation Department (RID) as a guideline model to solve flood problems for the central region and Bangkok. Eight factors were considered for flood hazard assessment including 1) distance from drainage network 2) drainage density 3) elevation 4) flow accumulation 5) land use 6) slope 7) soil water infiltration 8) average annual rainfall. Each factor was weighted to obtain the final flood hazard map. The accuracy of the method has been validated with the repeated floods area data, which is the product from the Geo-Informatics and Space Technology Development Agency (GISTDA). The very high flood hazard areas were found near the drainage network. Important supporting factors to flood hazard are flow accumulation, elevation, and soil water infiltration (same weights), distance from drainage network, average annual rainfall, drainage density, land use, and slope, respectively.

1. INTRODUCTION

Flood events are a common global natural disaster. Floods are caused by many processes that in most cases, it is caused by heavy or continuous rainfall, which surpasses the absorption capacity of the soil and the flow capacity of rivers (ICSU-GeoUnions et al., 2013; Queensland Government, 2011). In 2011, the total annual rainfall was the largest rainfall in over 61 years for Thailand. The rainfall increased continuously throughout the six-month from summer monsoon season because four tropical storms, which were Haima, Haitang, Nesat, and Nalgae, moved to the northern part of the country. The water level increased to damage and breached riverbanks causing floods (Gale & Saunders, 2013). In 2011, about 65 out of the 77 provinces in the country was affected by floods resulting in 884 deaths with millions left homeless. The economic losses estimated by the World Bank was THB 1.4 trillion (USD 45.7 billion) (Aon Benfield, 2012).

To counteract the flood event, the Thai government has initiated "Bang Rakam Model 54" in 2011 at Bang Rakam District, Phitsanulok Province as a guideline model to solve flood problems (Promma, 2013). In 2017, a collaborative project named "Bang Rakam Model 60" was commenced on the left bank of the Yom River (Thepsitthar & Boonwanno, 2018) by Royal Irrigation Department (RID) and the agencies in the Ministry of Agriculture and Cooperatives (MOAC) with the aim to solve the flood problems in Sukhothai and Phitsanulok Provinces. The main idea of the project is to use paddy fields as an extension area to relieve flood by applying the Monkey Cheek concept from King Rama IX. Crop calendar has been modified over the main target areas by approximately 424 km^2 (265,000 rai) with the allocation of water for rice cultivation in these areas. Farmers must start to grow their rice fields in April which is earlier than the usual period for one month. As a result, farmers can harvest their crops before the end of July (RID, 2017 & 2018). The main purposes of the adjusted crop calendar are to reduce the government budget for the flood compensation and to generate a job opportunity for the farmer during the flood season (Trakuldit, 2018). However, the flood area is the issue to be monitored in the project area as a tool for analysis and management for government and affected farmer.

Remote sensing data is the key information for many input data layers required for hazard assessment. Hazard assessments can effectively be conducted using tools that can handle spatial information such as Geographic Information Systems (GIS) (Alcántara & Goudie, 2010). GIS is a suitable tool for processing spatial data on flood assessment (Wang et al., 2011). Apart from generating a visual map of a flood, GIS also provides a practical estimation of the possible flood hazard (Sanyal & Lu, 2006). Digital Elevation Models (DEMs) are digital representations of natural topographic and man-made features on the Earth's surface which gives fundamental information of the earth and also used for applying resource management, urban planning, environmental assessments, etc. The Shuttle Radar Topography Mission (SRTM) captures Earth's topography at 1 arc-second (30 m). It has gathered one of the most accurate DEMs of the earth (GISGeography, 2018). However, high-resolution DEMs are not obtainable the whole world. Nowadays, it has a new technology such as Light Detection and Ranging (LiDAR) that offers advantages over traditional methods for displaying a terrain surface. It can provide extremely high vertical accuracy, which allows representing the Earth's surface with high accuracy (Vaze & Teng, 2007).

The application of GIS-based Multi-Criteria Analysis (MCA) in flood risk assessment was hardly used until 2000 (Kazakis et al., 2015). The background of the multi-criteria evaluation is based on the Analytic Hierarchy Process (AHP) developed by Saaty (1987). The AHP is one of the MCA methods that structures the various factors into a hierarchical framework (Papaioannou et al., 2014). However, AHP may not generally reflect the human way of thinking, notwithstanding the variety of applications. The fuzzy Analytic Hierarchy Process (fuzzy AHP) is an effective mathematical tool in decision analysis, used for tackling uncertainty and ambiguous information in multiple criteria (Nguyen et al., 2008). Though the fuzzy AHP requires monotonous calculations when analyzing complex decision-making problems, it can capture the judgment of human uncertainties (Erensal et al., 2006).

This study focuses on flood hazard assessment using fuzzy AHP combined with GIS based on the Bang Rakam Model 60 project. To demonstrate the flood hazard assessment, two different DEMs, namely SRTM and LiDAR are used. Flood hazard assessment can provide essential information that links disaster risk reduction with social, economic and environmental policies. Furthermore, this research can help to create a baseline for disaster, risk management and help people to understand the level of damages and losses in the future.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The study area is located on main target areas of the irrigated land in Bang Rakam Model 60 project. The study is conducted in two provinces (Phitsanulok and Sukhothai) within four districts (Phrom Phiram, Mueang Phitsanulok, Bang Rakam, and Kong Krailat excluding Wat Bot district) as shown in Figure 1. The project is implemented in the left bank of the Yom River observing the changes in cropping pattern, in order to use the land as a retention area during the flood season and to mitigate flood impacts (Thepsitthar & Boonwanno, 2018).

The Yom River serves as the main river of the Yom River Basin supporting 1,900,000 people, of which 612,000 belongs to the agricultural sector (RID, 2011). The upper part topography of Yom River is mostly terraced mountainous, which ranges from Phayao to Phrae Province, and floodplains areas are in the lower part of the basin consisting of Sukhothai, Phichit, and part of Phitsanulok Provinces. Unfortunately, the Yom River Basin has neither major dam nor a reservoir that can control water flow during the whole year (Koontanakulvong et al., 2014). The Bang Rakam District, Phitsanulok is located in the lower Yom River Basin. As flooded every year, it covers 26.9% of Yom River Basin and has been. The Mueang Sukhothai district is the capital of Sukhothai province; hence the flood occurrence usually causes a lot of damages to government properties, houses, crops, and humans. About 602,813 of the farmers in Sukhothai, nearly half of them have an annual income less than US$ 500 that is the lowest income among northern region provinces (Sriariyawat et al., 2013).

2.2 Data Collection

Table 1 presents the data and sources are used for creating a data layer of each factor, the following data were collected from different sources to create a flood hazard map and to validate these maps using GIS.

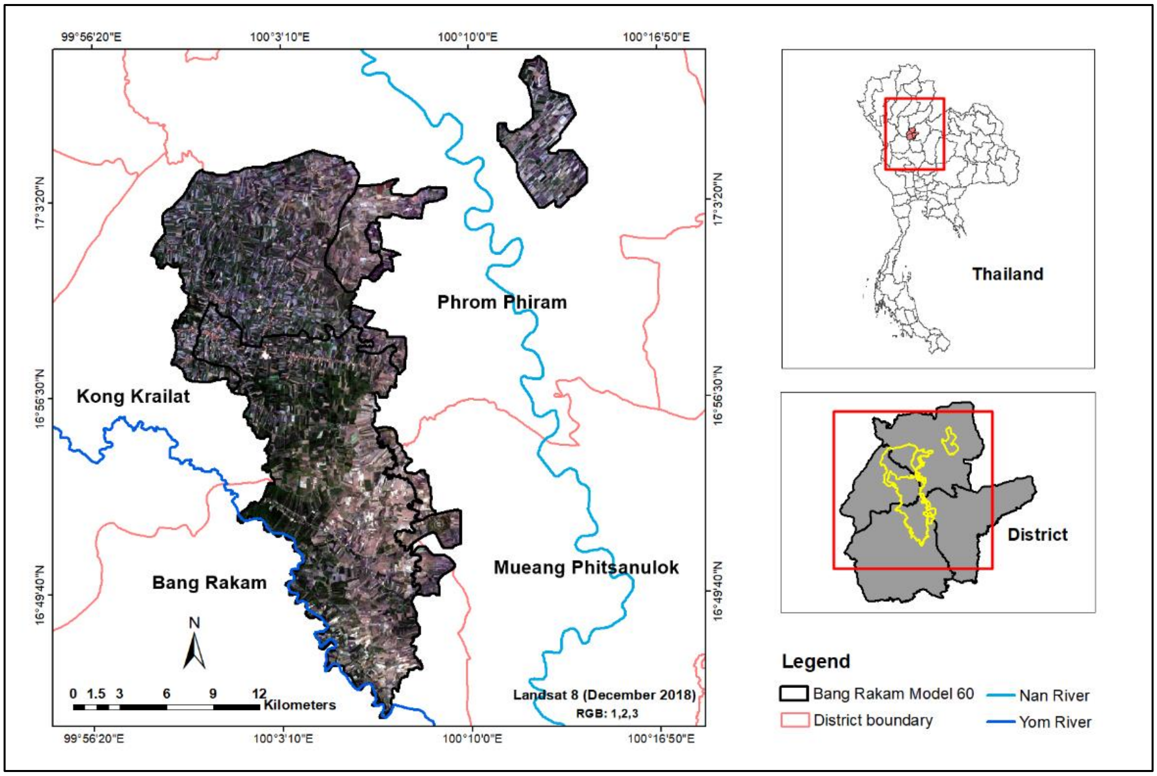

Figure 1 Study area based on Bang Rakam Model 60 project in Thailand.

Table 1 Data and sources used in the study.

No.	Data	Year	Sources	Create data layers
1	SRTM DEM 30 m resolution	-	https://earthexplorer.usgs.gov/	Elevation, slope, and flow accumulation
2	LiDAR DEM 5 m resolution	-	Regional Irrigation Office 3, Phitsanulok	Elevation, slope, and flow accumulation
3	Land use	2018	Land Development Department (LDD)	Land use
4	Rainfall	1989-2018	Northern Meteorological Center	Average annual rainfall
5	Soil group	2016	Land Development Department (LDD)	Soil water infiltration
6	River	-	Regional Irrigation Office 3, Phitsanulok	Distance from drainage network and drainage density
7	Repeated floods area	2004-2018	https://floodv2.gistda.or.th/ (GISTDA)	Repeated floods area
8	Bang Rakam Model 60 area	-	Yom-Nan Operation and Maintenance Project	Study area

2.3 Methodology

Fuzzy AHP is used to prioritize factors influencing flood hazard to create a flood hazard map. The overall methodology is shown in Figure 2.

2.3.1 Factors influencing flood hazard

The resolution sizes are at 30 m for SRTM DEM and 5 m for LiDAR DEM. Natural Breaks (Jenks) classification method is used to determine values to separate classes as shown in Figure 3. Then, those classed are reclassified into five classes as follows: very low (1), low (2), moderate (3), high (4), and very high (5).

Distance from drainage network: Areas affected by river-overflows are important for considering at the beginning of flood events. The role of riverbed decreases while distance increases, consequently areas located far away from the drainage network are generally less likely to suffer flooding than areas that are nearby (Kazakis et al., 2015; Liu et al., 2015; Mahmoud & Gan, 2018a). To create this factor, drainage network data was collected from Regional Irrigation Office 3, and the multiple ring buffer operation in GIS was used to analyze the intensity of distance away from the drainage network.

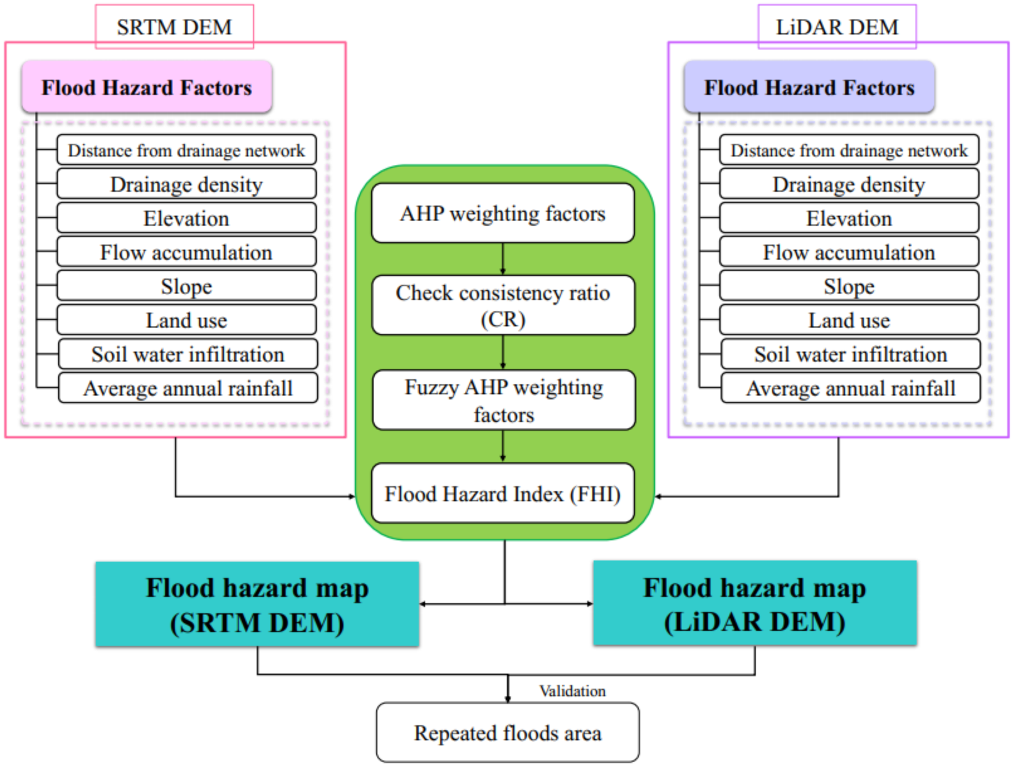

Figure 2 Overall methodology in the research.

Drainage density: It refers to the length of water channels per unit area to delineate flooding from individual water channel and multiple water channels. Generally, high drainage density means greater surface runoff generation than areas with low drainage density, therefore, it has a higher probability of flooding. (Liu et al., 2015; Mahmoud & Gan, 2018a). Drainage density is computed from equation (1).

$$Drainage\ density = \frac{Drainage\ length\ (km)}{Area\ (km^2)} \tag{1}$$

Elevation: Naturally, water flows from high to lower elevations, thereby flat areas in low elevation tend to flood faster than areas in higher elevation forasmuch it is easier to be inundated by flood (Kazakis et al., 2015; Liu et al., 2015). SRTM DEM and LiDAR DEM are used to investigate the effect of flood extent from elevation data.

Flow accumulation: All cells flowing into each down-slope cell are summed up into the output raster leading to increased flow in a specific cell. Areas with more flow accumulations tend to have a flood, therefore, high values of accumulated flow show areas of concentrated flow and as a result for higher flood hazard (Kazakis et al., 2015; Mahmoud & Gan, 2018a). This factor is created from SRTM DEM and LiDAR DEM by using the Flow Accumulation function in GIS.

Land use: Forest and vegetation have a main effect on infiltration, on the other hand, urbanization can generate more surface runoff than bare soil and vegetation cover (Kazakis et al., 2015; Mahmoud & Gan, 2018a). We created according to LDD into five classes as follows: 1) urban and built-up land 2) agricultural land 3) forest land 4) water body and 5) miscellaneous land.

Slope: It influences the quantity of surface runoff and infiltration hence flat areas may have flood faster than steep slope areas since the surface with a steeper slope can be easily drained toward the downslope (Kazakis et al., 2015; Liu et al., 2015; Mahmoud & Gan, 2018a). This factor is created from SRTM DEM and LiDAR DEM by using the slope function on GIS.

Soil water infiltration: Water is stored in the soil from previous flood and local rainfall influence flooding which indicates that larger flows are then required for flood inundation to occur (Liu et al., 2015). Soil group data are classified into three classes according to LDD consisting of low, slightly low, and slightly high.

Average annual rainfall: Rainfall is the main natural factor that can lead to flood (Lyu et al., 2016). More rainfall events lead to more surface runoff, hence the flood hazard increases with higher rainfall depth (Mahmoud & Gan, 2018a, 2018b). This study using average annual rainfall during 30 years at each rain gauge station in the study area and neighbor rain gauge station using Kriging interpolation.

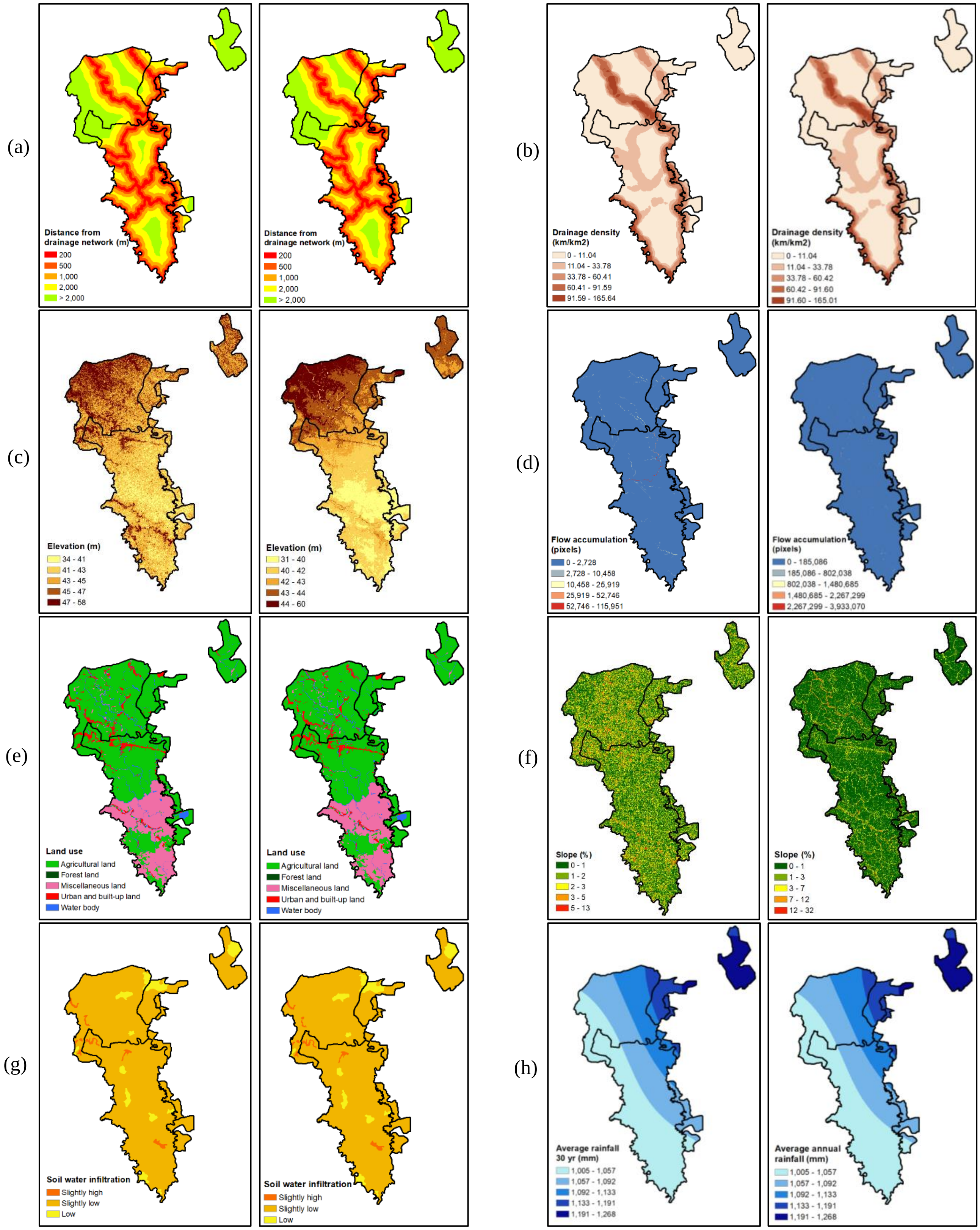

Figure 3 Factors influencing flood hazard used in this study (the left-hand side part is SRTM DEM and the right-hand side part is LiDAR DEM): (a) distance from drainage network, (b) drainage density, (c) elevation, (d) flow accumulation, (e) land use, (f) slope, (g) soil water infiltration, and (h) average annual rainfall.

2.3.2 Analytic Hierarchy Process (AHP)

Pair-wise comparisons matrix is created according to the AHP method. A scale is used to justify the priority important factor as into five levels consisting of equally important (1), moderately more important (3), strongly more important (5), very strongly more important (7), and extremely more important (9). The hierarchical manner 8×8 matrix of pair-wise comparison (Table 2) obtained from the literature review. Each factor is matched one on one with each of the other factors (each row is compared with each column). Diagonal elements are equal to 1 and lower of diagonal is the inverse values.

Table 2 Hierarchical manner of pair-wise comparison: Factors influencing flood hazard.

Factors	Flow accumulation	Distance from drainage network	Elevation	Land use	Average annual rainfall	Slope	Soil water infiltration	Drainage density
Flow accumulation	1	3	3	5	3	7	3	5
Distance from drainage network	1/3	1	1/3	3	3	3	1/3	3
Elevation	1/3	3	1	3	3	5	1/3	3
Land use	1/5	1/3	1/3	1	1/3	3	1/5	1/3
Average annual rainfall	1/3	1/3	1/3	3	1	3	1/3	3
Slope	1/7	1/3	1/5	1/3	1/3	1	1/7	1/3
Soil water infiltration	1/3	3	3	5	3	7	1	5
Drainage density	1/5	1/3	1/3	3	1/3	3	1/5	1

Data obtained from the pair-wise comparison need to be checked for the Consistency Ratio (CR). It can be calculated following $CR = \frac{CI}{RI}$ *where CI* is consistency index and *RI* is the average random index for different size matrix as shown in Table 3. CI is calculated using equation $CI = \frac{\lambda_{max}-n}{n-1}$ *where* λ_{max} is a summation from the total of each column multiply the average of each row and *n* is the number of factors.

Table 3 Randomly consistency index for different size of matrix.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.3.3 Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

This process is computed when CR ≤ 0.10. Calculation and analysis are done by combining the AHP method and fuzzy together using the pair-wise comparison method of AHP with triangular fuzzy numbers (TFNs) in Table 4 according to Chang's extent analysis (Chang, 1996). The characteristic of TFNs is shown in Figure 4.

Table 4 Triangular fuzzy numbers of pair-wise comparison

Linguistic scale	Intensity of importance on an absolute scale (AHP method)	Triangular fuzzy numbers (l,m,u)
Equally important	1	(1,1,3)
Moderately more important	3	(1,3,5)
Strongly more important	5	(3,5,7)
Very strongly more important	7	(5,7,9)
Extremely more important	9	(7,9,9)

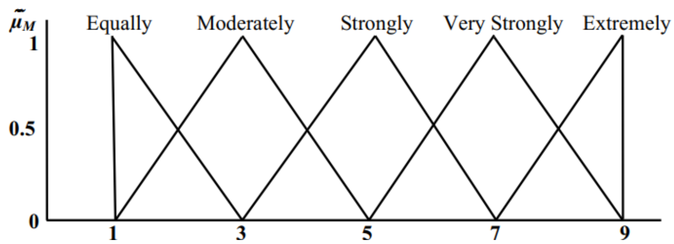

Figure 4 Linguistic variables for the important weight of each criterion

Source: Kabir, G., & Hasin, M. A. A., 2011

Priority weighting for each factor was calculated in the following Jongpaiboon (2015):

Calculation of the fuzzified pair-wise comparison matrix: Let $X = \{x_1, x_2, \ldots, x_n\}$ is an object set and $U = \{u_1, u_2, \ldots, u_m\}$ is a goal set. Each object is taken and the analysis of the extent for each goal, g_i is executed, respectively. Thereby, *m* extent analysis values for each object can be acquired as follows $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m;\ i = 1, 2, \ldots, n$ *where* all the $M_{g_i}^j$ $(j = 1, 2, \ldots, m)$ are TFNs. Pair-wise comparison matrix based on the fuzzy process can be created following equation (2).

$$\left(M_{g_i}^j\right)_{n\times m} = \begin{bmatrix} M_{g_1}^1 & M_{g_1}^2 & \dots & M_{g_1}^m \\ M_{g_2}^1 & M_{g_2}^2 & \dots & M_{g_2}^m \\ \vdots & \vdots & & \vdots \\ M_{g_n}^1 & M_{g_n}^2 & \dots & M_{g_n}^m \end{bmatrix} = \begin{bmatrix} (1,1,1) & (l_{1_2}, m_{1_2}, u_{1_2}) & \dots & (l_{1_m}, m_{1_m}, u_{1_m}) \\ (l_{2_1}, m_{2_1}, u_{2_1}) & (1,1,1) & \dots & (l_{2_m}, m_{2_m}, u_{2_m}) \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{1}{u_{n_1}}, \frac{1}{m_{n_1}}, \frac{1}{l_{n_1}}\right) & \left(\frac{1}{u_{n_2}}, \frac{1}{m_{n_2}}, \frac{1}{l_{n_2}}\right) & \dots & (1, 1, 1) \end{bmatrix} \quad (2)$$

Calculation of the fuzzy synthetic extent with respect to ith alternative: The calculation can be done by using equation (3).

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \times \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \quad (3)$$

where S_i is the synthetic extent value of the pair-wise comparison and $\sum_{j=1}^{m} M_{g_i}^j$ is a summation of the TFNs which can be expressed as follows: $\sum_{j=1}^{m} M_{g_i}^j = \left[\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right]$ and $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right)$

Calculation of the degree of possibility: $S_i \geq S_j$ when $S_i = (l_i, m_i, u_i)$ and $S_j = (l_j, m_j, u_j)$ *where* $i = 1,2,\dots,n$ and $j = 1,2,\dots,m$ as well as $i \neq j$ can be express as in equation (4).

$$V(S_i \geq S_j) = \begin{cases} 1 & if \; m_i \geq m_j \\ 0 & \quad\; l_i \geq u_i \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & otherwise \end{cases} \quad (4)$$

For S_i greater than S_j can be express as in equation 5.

$$V(S_i \geq S_j | j = 1,2,\dots,m; i \neq j) = min\, V(S_i \geq S_j | j = 1,2,\dots,m; i \neq j) \quad (5)$$

Calculation of the weight vector and normalize the non-fuzzy weight vector: Equation (6)-(8) are used to calculate as:

Assuming that $w_i' = min\, V(S_i \geq S_j | j = 1,2,\dots,m; i \neq j)$ (6)

The weight vector is given by $w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'}$ (7)

Normalized weight vectors $W = (w_1, w_2, \dots, w_n)^T$ (8)

where; w_i is a non-fuzzy number that it is weights of each factor.

2.3.4 Flood Hazard Index (FHI)

Raster overlay analysis is carried out using raster calculator tool on GIS software to create the flood hazard map. The map uses the weights of factors acquiring from fuzzy AHP process. It can be calculated using the FHI as in equation (9). Finally, the output is classified into five categories ranging from very low to very high to create an easily readable map.

$$FHI = \sum_{i=1}^{n} r_i \times w_i \quad (9)$$

where r_i is a rating of the factor in each point, w_i is the weights of each factor, and n is the number of the criteria.

3. RESULTS AND DISCUSSIONS

Table 5 shows the weight of the individual influencing factors for the flood hazard. The highest weight for the flood hazard corresponds to the flow accumulation, elevation and soil water infiltration is 0.161. The lowest weight corresponds to slope is weight of 0.012. The distance factor calculated from the drainage network, average annual rainfall, drainage density, and land use corresponds to weight of 0.153, 0.141, 0.121 and 0.090, respectively.

Table 5 Weights of factor influencing flood hazard.

No.	Factors	Fuzzy AHP weight	Fuzzy AHP weight (%)
1	Flow accumulation	0.161	16.1
2	Distance from drainage network	0.153	15.3
3	Elevation	0.161	16.1
4	Land use	0.090	9.0
5	Average annual rainfall	0.141	14.1
6	Slope	0.012	1.2
7	Soil water infiltration	0.161	16.1
8	Drainage density	0.121	12.1

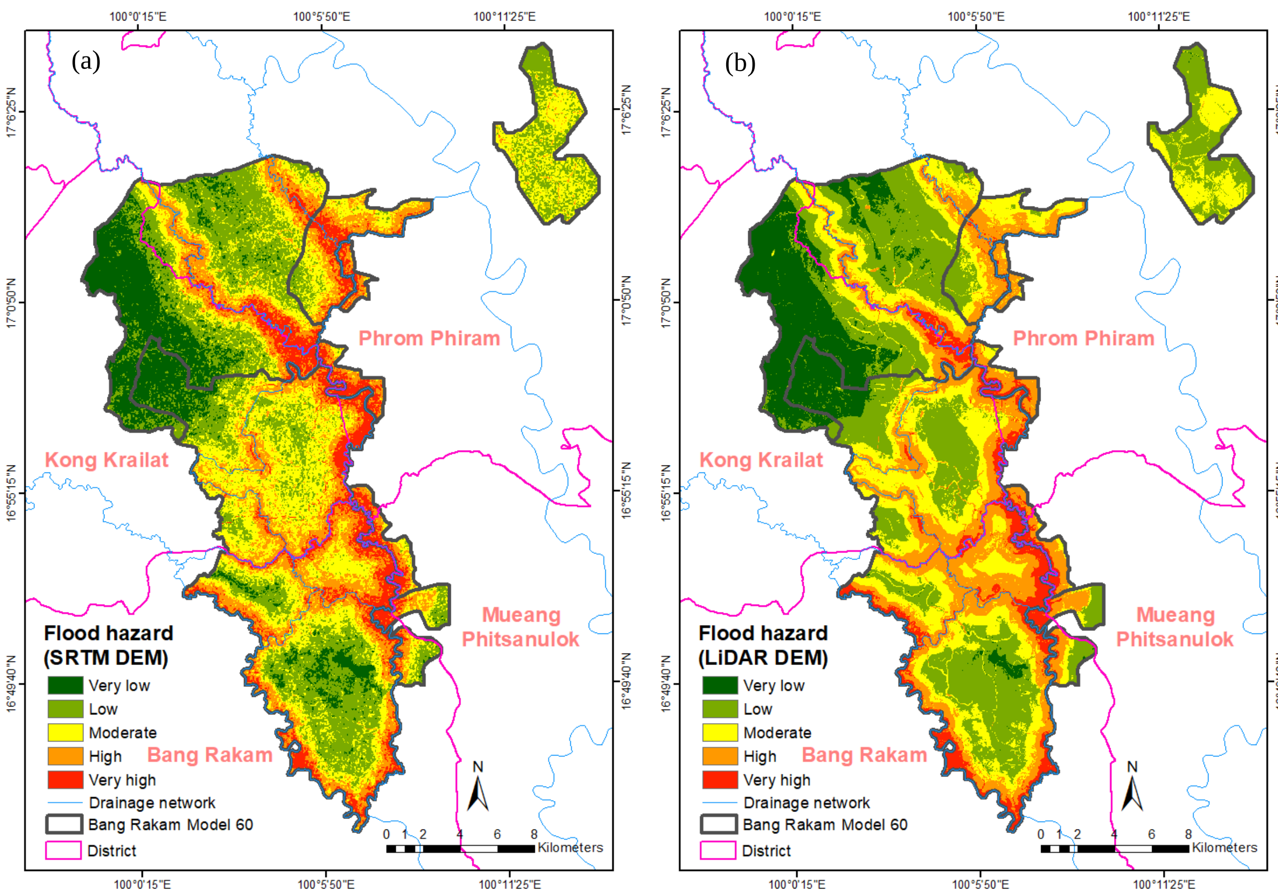

Figure 5 Flood hazard map from different DEMs: (a) SRTM DEM and (b) LiDAR DEM.

The flood hazard map is presented in figure 5 using the SRTM DEM and LiDAR DEM, classified into five classes: very high, high, moderate, low and very low. It was observed that there is a small variation in the area since the spatial resolution size of the SRTM DEM is coarser than that of LiDAR DEM. It was observed that most of the areas derived from two DEM are the low flood hazard. Most of the areas near the drainage network is a very high zone, while the central part in Kong Krailat and Bang Rakam districts show rather a different result between two sources of DEM. Table 6 shows the comparative classes of flood hazard in terms of area. The area percentage of each class of flood hazard from SRTM DEM is 16.7% (64.4 km^2), 26.2% (101.1 km^2), 25.3% (97.4 km^2), 21.1% (81.4 km^2) and 10.6% (41.0 km^2) for the very low, low, moderate, high, and very high, respectively. Similarly, the area percentage for the very low, low, moderate, high, very high using the LiDAR DEM are 14.1% (54.3 km^2), 31.7% (122.6 km^2), 24.2% (93.4 km^2), 21.1% (81.4 km^2) and 8.9% (34.4 km^2), respectively. The profile graph in figure 6 for area 1 and 2 show more altitude variation within a short longitudinal distance for the SRTM DEM compared with the LiDAR DEM because of the coarse resolution of the SRTM DEM.

Table 6 Flood hazard classes between SRTM DEM and LiDAR DEM.

Flood hazard	SRTM DEM		LiDAR DEM	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Very low	64.4	16.7	54.3	14.1
Low	101.1	26.2	122.6	31.7
Moderate	97.4	25.3	93.4	24.2
High	81.4	21.1	81.4	21.1
Very high	41.0	10.6	34.4	8.9

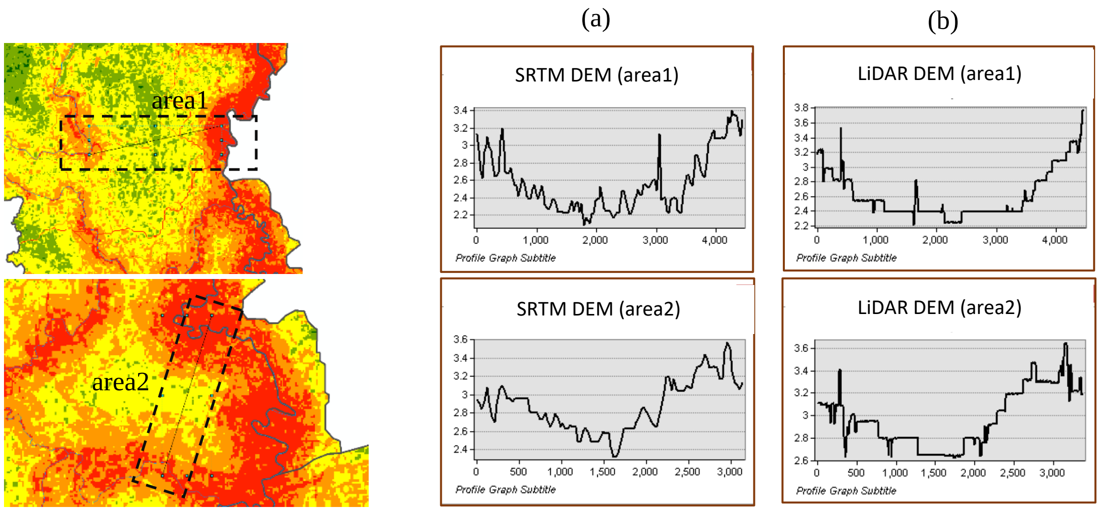

Figure 6 Profile graphs in the same area of flood hazard map: (a) SRTM DEM and (b) LiDAR DEM.

Table 7 Same flood hazard area using fuzzy AHP method and repeated floods area from GISTDA between SRTM DEM and LiDAR DEM.

Flood hazard	Same area (SRTM DEM)		Repeated floods area	Same area (LiDAR DEM)		Repeated floods area
	Area (km^2)	Area (%)	(km^2)	Area (km^2)	Area (%)	(km^2)
Very low	20.2	30.3	66.7	20.5	30.8	66.4
Low	26.7	23.9	111.4	39.6	35.5	111.5
Moderate	17.3	25.4	68.2	18.8	27.5	68.3
High	8.5	25.8	32.9	6.5	19.7	33.1
Very high	5.5	5.4	102.4	12.0	11.7	102.2

Obtained flood hazard map from the fuzzy AHP method was validated with repeated floods area data published by Geo-Informatics and Space Technology Development Agency (GISTDA). This study, we used the repeated floods area during 2004-2018 to calculate the same flood area using the intersect tool in GIS. We found that each class is slightly different between both of DEM, as shown in Table 7. The area percentage for each class of SRTM DEM is 30.3% (20.2 km^2), 23.9% (26.7 km^2), 25.4% (17.3 km^2), 25.8% (8.5 km^2) and 5.4% (5.5 km^2) for the very low, low, moderate, high and very high flood hazard, respectively. For the very low, low, moderate, high, very high flood hazard using the LiDAR DEM are 30.8% (20.5 km^2), 35.5% (39.6 km^2), 27.5% (18.8 km^2), 19.7% (6.5 km^2) and 11.7% (12 km^2), respectively. We considered the percent of the same area rather low accuracy when compared with GISTDA. There are several factors in this study especially the factor weights based on the literature reviews that may not be appropriate for our study area. Thus, experts' opinions are the most important factor for multi-criteria analysis to consider which factor should be used and they should know the geography of the areas.

4. CONCLUSION

The study area of Bang Rakam Model 60 located between Sukhothai and Phitsanulok provinces. The flood hazard assessment was mapped using the fuzzy AHP method based on Chang's extent analysis integrated with GIS by using different DEM is SRTM DEM (30 m) and LiDAR DEM (5 m). Eight factors were considered to assign a weight of the factor influencing flood hazard. The results indicated three factors at same weight namely, flow accumulation, elevation and soil water infiltration (0.161). Both sources of DEM provide the same level of flood hazard in each area, which the areas near the drainage network are the very high flood hazard. However, some areas are not the same, for example, central of the study area in Kong Krailat District. Using the product from the GISTDA to validate the flood hazard map, we found that the obtained map has low accuracy. Factors and weight of the relative factors have an impact on the results, which should be reconsidered in the future. In this study, we used factors and weight from the literature that may not be suitable for our study area. However, in the future, other physical factors should be included by interrogating an expert to obtain suitable factor and weight.

ACKNOWLEDGMENTS

This research was supported by “Advancing Co-design of Integrated Strategies with Adaptation to Climate Change in Thailand (ADAP-T)” (Grant Number: JPMJSA1502) supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS), JST-JICA.” The authors would thank these departments to support the data namely Regional Irrigation Office 3 (Phitsanulok), Yom-Nan Operation and Maintenance Project, Land Development Department, and Northern Meteorological Center.

REFERENCES

Alcántara, I., & Goudie, A. S. (eds.) (2010). GIS for the assessment of risk from geomorphological hazards. Cambridge, UK: Cambridge University Press.

Aon Benfield. (2012). 2011 Thailand Floods Event Recap Report Impact Forecasting: March 2012. Aon Benfield, London.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. EJOR, 95(3), 649-655. doi:10.1016/0377-2217(95)00300-2

Erensal, Y. C., Öncan, T., & Demircan, M. L. (2006). Determining key capabilities in technology management using fuzzy analytic hierarchy process: A case study of Turkey. Inf Sci, 176(18), 2755-2770. doi:10.1016/j.ins.2005.11.004

Gale, E. L., & Saunders, M. A. (2013). The 2011 Thailand flood: climate causes and return periods. Weather, 68(9), 233-237. doi:10.1002/wea.2133

GISGeography. (2018). SRTM Shuttle Radar Topography Mission. Retrieved from https://gisgeography.com/srtm-shuttle-radar-topography-mission/

ICSU-GeoUnions, JBGIS, & UNOOSA. (2013). The Value of Geoinformation for Disaster and Risk Management (VALID): Benefit Analysis and Stakeholder Assessment. UN-SPIDER.

Jongpaiboon, M. (2015). Green supply chain management triple bottom line and organization theory- prioritization with fuzzy and method. (Master dissertation, Thammasat University).

Kabir, G., & Hasin, M. A. A. (2011). Comparative analysis of AHP and fuzzy AHP models for multicriteria inventory classification. IJFLS, 1(1), 1-16.

Kazakis, N., Kougias, I., & Patsialis, T. (2015). Assessment of flood hazard areas at a regional scale using an index based approach and Analytical Hierarchy Process: Application in Rhodope-Evros region, Greece. Sci Total Environ, 538, 555-563. doi:10.1016/j.scitotenv.2015.08.055

Koontanakulvong, S., Hanittinan, P., & Suthidhummajit, C. (2014). Flood Impact and Risk Assessment at the Yom River Basin due to Global Climate Change: Part 2 Impact and Adaptation. In Proceedings of the PAWEES 2014 international conference, Kaohsiung City, Taiwan.

Liu, R., Chen, Y., Wu, J., Gao, L., Barrett, D., Xu, T., . . . Yu, J. (2015). Assessing spatial likelihood of flooding hazard using naïve Bayes and GIS: a case study in Bowen Basin, Australia. SERRA, 30(6), 1575-1590. doi:10.1007/s00477-015-1198-y

Lyu, H.-M., Wang, G.-F., Shen, J., Lu, L.-H., & Wang, G.-Q. (2016). Analysis and GIS Mapping of Flooding Hazards on 10 May 2016, Guangzhou, China. Water, 8(10), 447. doi:10.3390/w8100447

Mahmoud, S. H., & Gan, T. Y. (2018a). Multi-criteria approach to develop flood susceptibility maps in arid regions of Middle East. Journal of Cleaner Production, 196, 216-229. doi:10.1016/j.jclepro.2018.06.047

Mahmoud, S. H., & Gan, T. Y. (2018b). Urbanization and climate change implications in flood risk management: Developing an efficient decision support system for flood susceptibility mapping. Sci Total Environ, 636, 152-167. doi:10.1016/j.scitotenv.2018.04.282

Nguyen, T., Peterson, J., Gordon-Brown, L., & Wheeler, P. (2008). Coastal Changes Predictive Modelling: A Fuzzy Set Approach. WASET, 48,468-473.

Papaioannou, G., Vasiliades, L., & Loukas, A. (2014). Multi-Criteria Analysis Framework for Potential Flood Prone Areas Mapping. Water Resources Management, 29(2), 399-418. doi:10.1007/s11269-014-0817-6

Promma, K. (2013). Elevated Detached House for Handling Repeated Floods Based on Sufficiency Economy: A Case Study of Bang-Rakam Model. Naresuan University Journal, 21(3), 139-147.

Queensland Government. (2011). Understanding Floods: Questions & Answers. Queensland Government.

RID. (2011). Integrated Drought Prevention and Mitigation: Mae Yom Operation and Maintenance Office Phrae Province. Retrieved from http://unpan1.un.org/intradoc/groups/public/documents/un-dpadm/unpan049667.pdf

RID. (2017). Bang Rakam Model 60. [In Thai: บางระกำโมเดล 60] Retrieved from http://ridceo.rid.go.th/pisanulok/yomnan/2014/data/

RID. (2018). Bang Rakam Model 2560 Project and resultant expansion in 2018. [In Thai: โครงการบางระกำโมเดล 2560 และการขยายผลในปี 2561]

Saaty, R. W. (1987). The Analytic Hierarchy Process- What it is and how it is used. Mathematical Modelling, 9(3-5), 161-176. doi:10.1016/0270-0255(87)90473-8

Sanyal, J., & Lu, X. X. (2006). GIS-based flood hazard mapping at different administrative scales: A case study in Gangetic West Bengal, India. Singapore Journal of Tropical Geography, 27(2), 207-220. doi:10.1111/j.1467-9493.2006.00254.x

Sriariyawat, A., Pakoksung, K., Sayama, T., Tanaka, S., & Koontanakulvong, S. (2013). Approach to Estimate the Flood Damage in Sukhothai Province Using Flood Simulation. Journal of Disaster Research, 8(3), 406-414.

Thepsitthar, Y., & Boonwanno, T. (2018). Reconstruction Bang Rakam Model: The Inequality in Public Duty. CMU Journal of Law and Social Sciences, 11(2), 142-167.

Trakuldit, T. (2018). Analysis of Public Participation in the design of Flood Expansion Areas in Nakhon Sawan province and Phitsanulok province, Thailand (Master dissertation, Asian Institute of Technology).

Vaze, J., & Teng, J. (2007). High resolution LIDAR DEM–How good is it. Modelling and Simulation, 692-698.

Wang, Y., Li, Z., Tang, Z., & Zeng, G. (2011). A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China. Water Resources Management, 25(13), 3465-3484. doi:10.1007/s11269-011-9866-2