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A Fuzzy AHP Approach to Assess Flood Hazard for Area of Bang Rakam Model 60 Project in Yom River Basin, Northern Thailand

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Abstract

The Thai government developed the "Bang Rakam Model 60" to solve flood issues in low-lying areas (Phitsanulok and Sukhothai Provinces). In the project, farmers will have to start planting in early April and harvest in July. This research proposes a methodology for assessing flood hazard using a fuzzy analytic hierarchy process (fuzzy AHP) relied on Chang's extent analysis. It was employed to derive the weight for factor ranking and create a flood hazard map. Eight hazard factors are considered in the methodology: average annual rainfall, drainage density, distance from drainage network, soil water infiltration, land use, elevation, slope, and flow accumulation. The generated flood hazard maps were validated using the repeated flood area from Geo-Informatics and Space Technology Development Agency (GISTDA). Due to the difference of rated opinion on the drainage density factor, the eight experts were divided into two groups of four each. The results of both expert groups indicated that the most pivotal influencing factor to flood hazard is the average annual rainfall. From the first group, it is stated that the highest flood hazard areas are in Phrom Phiram, Mueang Phitsanulok, and Bang Rakam Districts. Whereas, the second group stated that very high flood hazards level occurring mostly in Phrom Phiram District. The flood hazard area was divided into five levels of very low, low, moderate, high, and very high which the first group found that they covered 75.59 km^2, 184.44 km^2, 211.94 km^2, 165.78 km^2, and 57.81 km^2, respectively, while the second group found that they covered 38.93 km^2, 100.22 km^2, 175.58 km^2, 218.90 km^2, and 161.91 km^2, respectively. The obtained flood hazard assessment provides crucial information for future flood preparation, response, prevention, mitigation, and recovery initiatives. Moreover, it will guide the government agencies in supplying water and save the compensation budget to victims' flood-affected farms.

Keywords: Bang Rakam Model 60; Flood hazard assessment; Fuzzy Analytic Hierarchy Process; Geographic Information Systems

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Introduction

Flooding is common and destructive in Thailand that its impact varies by area, and every province in the country deals with flood-related devastation on an annual basis [1]. Spreading wide from Phayao Province to Phrae Province forms the upper part of the Yom River Basin with terraced mountainous topography. The floodplains stretch from Sukhothai, Phichit, and part of Phitsanulok Province areas, and this covers the lower part. Unfortunately, the basin lacks neither a major reservoir nor a major dam to accommodate excess water flow all year long [2]. Bang Rakam District (in Phitsanulok Province) and Sukhothai Province, both are located in the lower Yom River Basin and are inundated every year. The Bang Rakam District is one of the significant districts in the country as a pilot area to mitigate the flood problems for the Thai government, which is known as the Bang Rakam Model 54 Project [3]. Many villages in this area have been inundated, making it the province's worst-affected area [4–5]. The Yom River flows through the Kong Krailat, Mueang Sukhothai, Si Satchanalai, Si Samrong, and Sawankhalok Districts of Sukhothai Province, making them flood-prone [6]. After the implementation of Bang Rakam Model 54, the flood problem over the low-lying area in the Yom River Basin still existed. To resolve the flood in the Phitsanulok and Sukhothai Provinces, the Royal Irrigation Department (RID) and the Ministry of Agriculture and Cooperatives (MOAC) were entrusted with working together. Their responsibility was to change the crop plan in the main target areas so that water allocated for irrigation in low-lying areas. Therefore, in 2017 RID proceed with "Bang Rakam Model 60" at the left bank of the Yom River with a targeted area around 424 km^2 (265,000 rai) [7–9].

Flood hazard maps play important role in flood management because they efficiently depict the distribution of flood hazard and spatial extent [10]. In flood-prone zones, mapping flood hazards is an important aspect of land use planning and mitigation [11]. Flood hazard maps can be used to determine flood hazards to people, probable flood hazard locations, spatial damage extent, flood depth as well as hazard intensity hence mapping and forecasting flood hazards are critical components of assessing flood risks [12–14]. Flood maps are becoming more prominent in government flood-risk management strategies. Maps can assist in designating catchment areas of prone to flood area and providing insight on required measures to control flooding as well as informing conditions beyond human control with reference to weather conditions and environmental conditions [15]. It enables decision-makers, responders, early warning system agencies, design engineers, and flood management agencies with the tools that they need to address and make accurate decisions about flood-related problems, implement best management practices in flood management, and adapt climate decision-making to build resilient infrastructures [16].

There are three principal approaches to creating a flood hazard map: empirical, physically-based, and physical modeling methods. The empirical modeling method includes machine learning, multi-criteria decision-making method (MCDM), and statistical methods. Among these methods, MCDM method is the most often used [12–13, 16]. Flood hazard maps used as a tool for assessing flood risks using GIS-based multi-criteria analysis (MCA) was rare until 2000 [17]. One of the MCA approaches based on the concept of hierarchical partitions using multiple criteria is the analytic hierarchy process (AHP) [18]. Notwithstanding its various implementations, AHP does not usually take into consideration human thoughts. Thus when an AHP is combined with fuzzy set theory, the comparison process becomes more capable of describing the needs of a wider range of experts while also being more flexible [19–20]. In analyzing decisions, a mathematical tool called the "fuzzy analytic hierarchy process (fuzzy AHP)" is used to effectively manage ambiguous information and uncertainties that exist in numerous criteria [21]. The advantage of fuzzy AHP is to minimize the difficulties and error of experts' judgment by using fuzzy numbers because human decision-making is difficult to describe with single numbers [16, 22–24]. The fuzzy AHP is considered particularly suitable for assessing flood hazard. Thereby this research used fuzzy AHP combined with GIS, of which the objective was to create a flood hazard map for assessing flood hazard in the study area of the Bang Rakam Model 60 Project. To our knowledge, the application of the concept of the fuzzy AHP with GIS in this study is the first time of application for Thailand attempting to understand the physical aspects of flood in the most recurring flood area in the country. This study is the extended work done by Yodying et al. [25] with modification of weighting factors derived by experts.

Data and methods

Data were gathered from different sources (Table 1) and were used to generate a flood hazard map as also used in Yodying et al. [25]. As shown in Figure 1, the study area consisted of Phrom Phiram, Wat Bot, Mueang Phitsanulok, and Bang Rakam Districts in Phitsanulok Province, as well as Kong Krailat District in Sukhothai Province (20 sub-districts, 93 villages). To acquire the preference weights of the alternative decisions, the triangular fuzzy numbers (TFNs) based on Chang's extent analysis [26] were used to form pair-wise comparisons. The overall technique shown in Figure 2 that is all about methodologies used in this research.

Table 1 Data and sources used in the research

No.	Data	Year	Sources	Layer produced
1.	Rainfall	1989-2018	Northern Meteorological Center	Average annual rainfall
2.	Repeated floods area	2004-2019	Geo-Informatics and Space Technology Development Agency (GISTDA)	-
3.	Soil group	2016	Land Development Department (LDD)	Soil water infiltration
4.	Land use	2018	Land Development Department (LDD)	Land use
5.	River	-	Yom-Nan Operation and Maintenance Project, and Regional Water Resources (Office 9)	Distance from drainage network and drainage density
6.	SRTM DEM 30 m resolution	-	United States Geological Survey (USGS)	Elevation, flow accumulation, and slope
7.	Boundary data of the study area	-	2nd Office of Agricultural Economics	Boundary of the province, district, sub-district, and village in Sukhothai and Phitsanulok Provinces

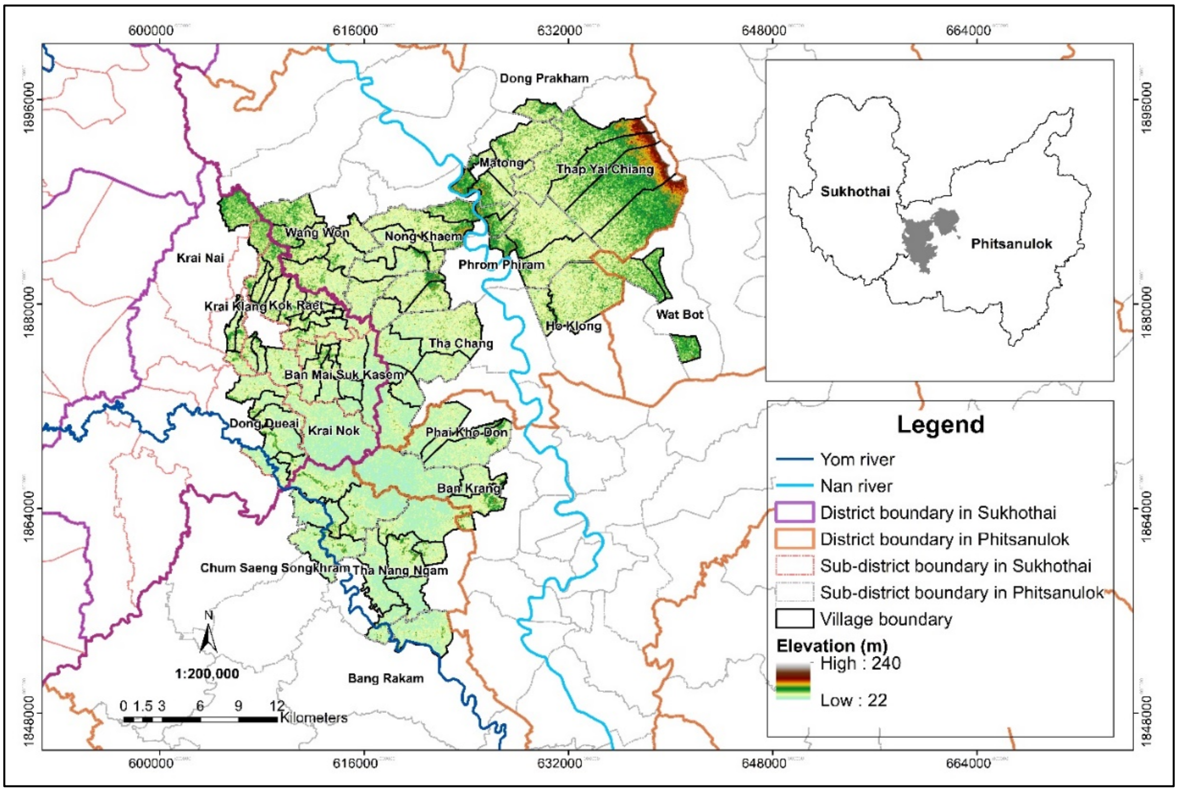

Figure 1 Map of villages in the study location based on Bang Rakam Model 60 Project.

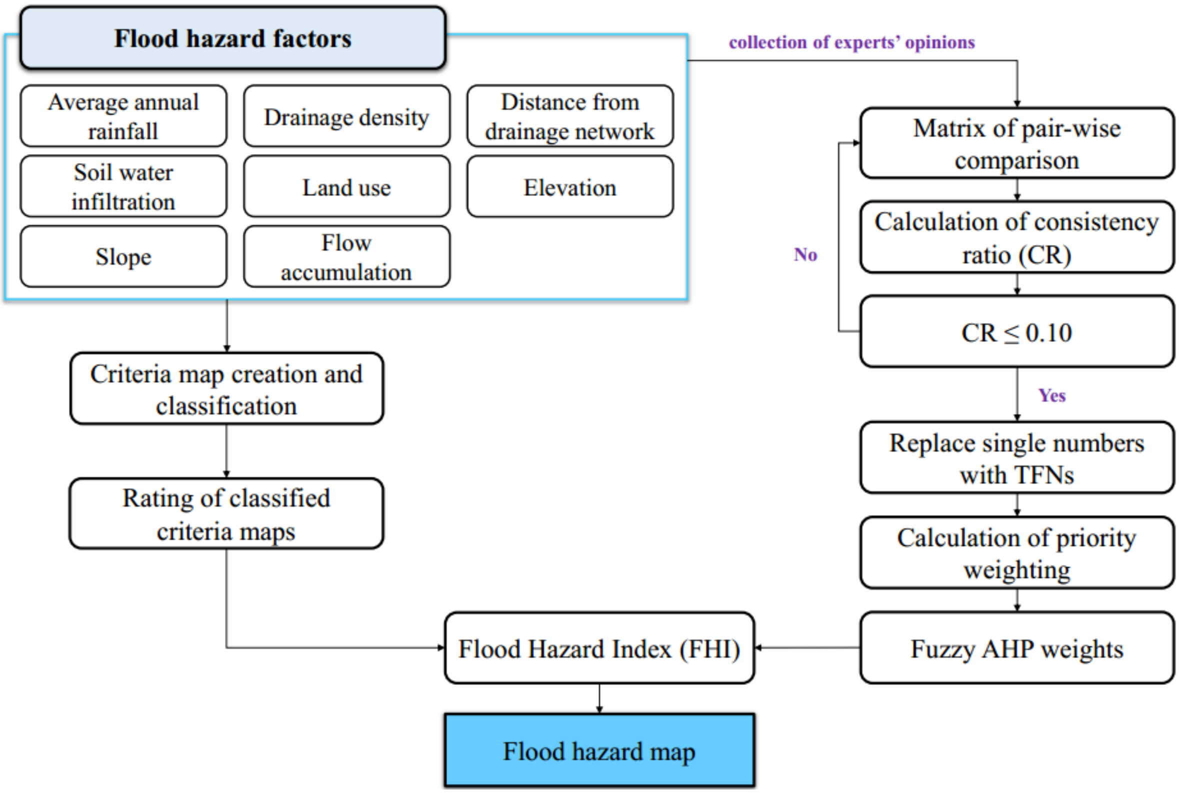

Figure 2 Flowchart of overall techniques.

1) Flood hazard factors

Eight factors were considered based on literature reviews [17, 27–30] i.e. 1) average annual rainfall 2) drainage density 3) distance from drainage network 4) soil water infiltration 5) land use 6) elevation 7) slope, and 8) flow accumulation. These factors were processed in ArcMap10.2 as shown in Figure 3. All factors were in raster data by converting from polygon at a resolution of 30 m. To define values and characterized them, the Natural Breaks (Jenks) classification method were used [29].

Average annual rainfall (mm): The key natural factor that causes floods, according to Lyu et al. [28] is rainfall. Surface runoff and flood hazards are increased as rainfall depth and occurrences rise [29–30]. The data recorded were collected for 30 years from the rain gauges located at the study areas and neighboring locations, and was created using inverse distance weighted (IDW) in Spatial Analyst Tools (Figure 3(a)).

Drainage density (km km^{-2}): In general, high drainage density areas generate more surface runoff than low drainage density areas, increasing the likelihood of floods [27, 29]. The data was computed in Spatial Analyst Tools using line density that calculated following drainage density = drainage length (km) / Area (km^2) as shown in Figure 3(b).

Distance from drainage network (m): It was created with the Multiple Ring Buffer (Figure 3(c)). It is essential to consider the areas that will be impacted by river overflows at the start of a flood event. Several studies [17, 27, 29] described that as the distance increases, the riverbed's influence diminishes, thus areas closer to the drain-age network experience more flooding than those farther away.

Soil water infiltration: According to Liu et al. [27], substantial rain is required for the flooded events to occur because water is stored in the soil during a flood, and as such localized heavy rainfall may influence flooding. This factor was generated using soil group data of LDD and it was grouped according to water infiltration, which was classified into six classes (Figure (d)).

Land use: The factor was created according to LDD into five classes (Figure 3(e)). Land use pattern influences the infiltration rate. Infiltration is greatly influenced by vegetation cover and forest. Unfortunately, urban areas encourage the overland flow of water [17, 29].

Elevation: It is a major factor and has greater intensive influences on the hazard of floods. Flat areas at lower elevations flood more quickly and are easier to flood than areas at higher elevations [17, 27]. This factor, a digital elevation model (DEM) from https://earthexplorer.usgs.gov was used to assess the extent of the flood effect (Figure 3(f)).

Slope: It was created by using the Slope function (Figure 3(g)). The slope is one of the important factors that has an impact on the hazard of flooding in any area. Because water from surfaces with steeper slopes can easily flow to the downslope, thus areas with steeper slopes may cause the flood more slowly than over the relatively flat areas [17, 27, 29].

Flow accumulation: It was created using the Flow Accumulation function in Spatial Analyst Tools (Figure 3(h)). It is the sum of water flowing into the output raster from all down-slope cells, leading to an accelerated flow in a specific cell. Therefore, high values of cumulative flow indicate areas of concentrated flow and consequent higher flood hazard [17, 29].

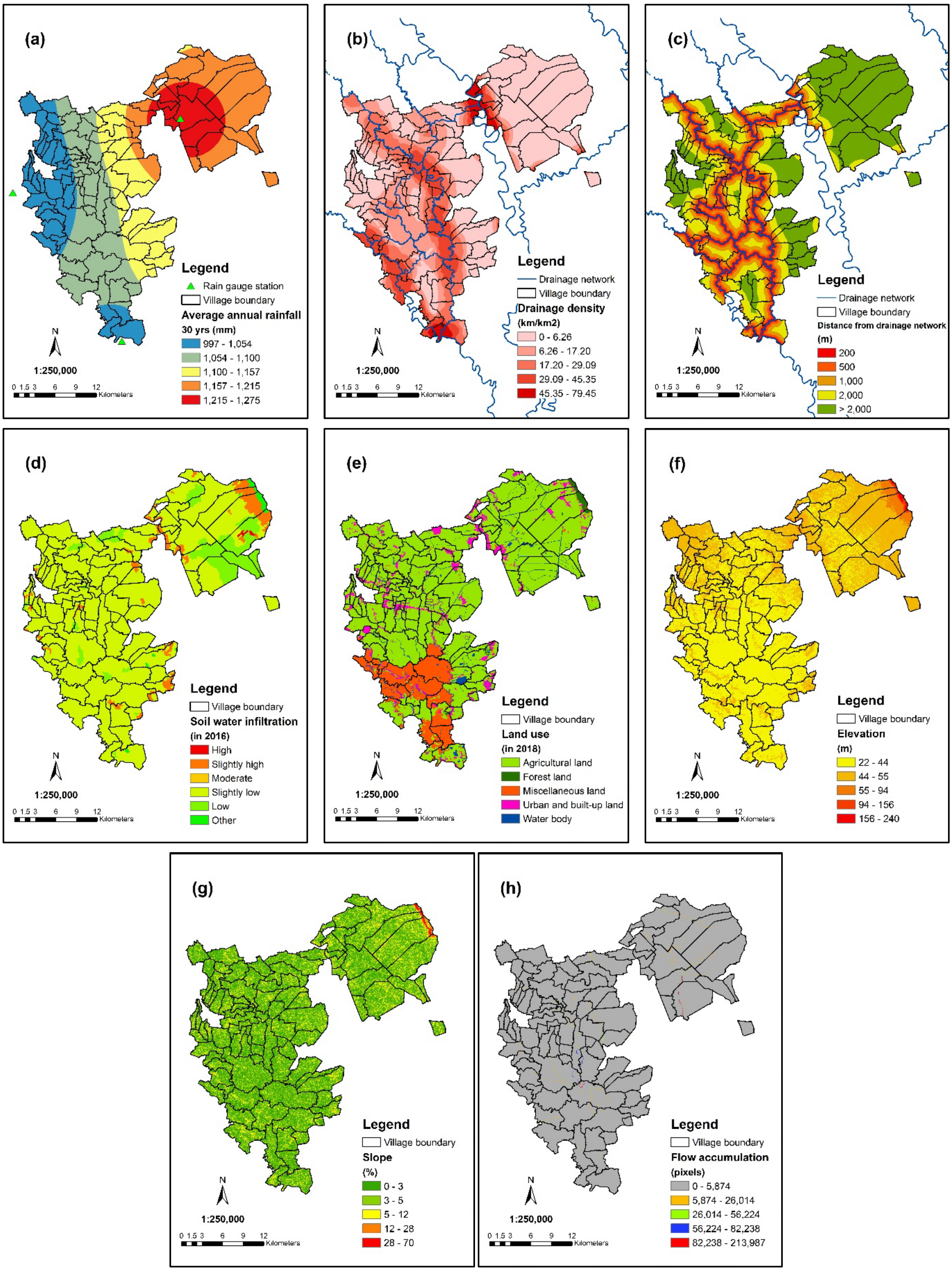

Figure 3 Factors contributing to flood hazard map: (a) average annual rainfall, (b) drainage density, (c) distance from drainage network, (d) soil water infiltration, (e) land use, (f) elevation, (g) slope, and (h) flow accumulation.

In here, the researchers reclassified the results into five classes [11, 29, 31] namely, (1) very low, (2) low, (3) moderate, (4) high, and (5) very high by Reclassify in Spatial Analyst Tools. It was determined with a rating (Table 2) from the eight experts through questionnaires. The selecting criteria for the experts have included many factors namely the experience and knowledge about the Bang Rakam Model 60 project, hydrology, flood hazard, and physical factors. Moreover, the position, workplace, and work experiences (years) of each expert were also considered. In this research, there were experts from several organizations both operational government and university sectors. Lists of expert are provided as follows:

(1) Director of Meteorological Station in Phitsanulok Meteorological Station with 36 years of work experiences

(2) Chief of Strategy and Management in Disaster Prevention and Mitigation Office (Phitsanulok) with 30 years of work experiences

(3) Director of Naresuan Dam Operation and Maintenance Project in Naresuan Dam Operation and Maintenance Project with 33 years of work experiences

(4) Director of Phlai Chumphon Operation and Maintenance Project in Phlai Chumphon Operation and Maintenance Project with 30 years of work experiences

(5) Irrigation Engineer in Yom-Nan Operation and Maintenance Project with 19 years of work experiences

(6) Lecturer in Faculty of Engineering, Naresuan University with 42 years of work experiences

(7) Lecturer in Faculty of Agriculture, Natural Resource and Environment, Naresuan University with 22 years of work experiences

(8) Irrigation Engineer in Engineering Division, Regional Irrigation Office 3 with 29 years of work experiences

The majority of experts have shown the consistency with the literature reviews on assigning the rating scores in all factors (seven factors), except for the drainage density factor. In this point, we considered that there was a major difference on their conceptual background. Therefore, we decided to divide the experts into two groups. Experts No. 1, 2, 7, and 8 were in the first group, while experts No. 3, 4, 5, and 6 were in the second group.

2) Matrix of pair-wise comparison

An 8×8 matrix was used to build a matrix of pair-wise comparisons according to the AHP method. To determine the priority level, each factor on the vertical axis was compared to a factor on the horizontal axis. (1) equally important, (3) moderately important, (5) strongly important, (7) very strongly important, and (9) extremely important were the five levels of pair-wise comparison [32]. Diagonal elements were equal to one. The values from the questionnaires were on the upper of the diagonal, while the inverse values of the pair-wise comparison were on the lower of the diagonal. This step was evaluated (Table 3) by the eight experts.

The data obtained from the pair-wise comparison was checked for consistency ratio (CR). CR was calculated as follows $CR = CI/RI$ where; CI stands for consistency index and *RI* stands for the mean random index for varied size matrix, it was 1.41 in this research. CI was worked out as follows $CI = \frac{\lambda_{max} - n}{n-1}$ where; λ_{max} is eigenvalues and n represents the number of factors. It was acceptable when CR ≤ 0.10. The result of comparison was re-checked if the CR is over the specified level. If so, the process of pair-wise comparison will be repeated until the CR falls within the specified level by asking the expert to re-evaluate.

3) Process of fuzzy analytic hierarchy (Fuzzy AHP)

The steps for calculating and analyzing were taken from the fuzzy AHP, which combines the AHP method and fuzzy theory. There are still employing the AHP method's pair-wise comparison, but single numbers of the AHP method were replaced by TFNs (Table 4).

Table 2 Rating of flood hazard factors

No.	Factors (Criteria)	Classes	Experts No. 1	2	3	4	5	6	7	8
1.	Distance from drainage network (m)	200	5	5	5	5	5	5	5	5
		500	4	4	4	4	4	4	4	4
		1,000	3	3	3	3	3	3	3	3
		2,000	2	2	2	3	2	2	2	2
		> 2,000	1	1	1	3	1	1	1	1
2.	Drainage density ($km\ km^{-2}$)	0 – 6.26	1	1	5	5	5	5	1	1
		6.26 – 17.20	2	2	4	5	4	4	2	2
		17.20 – 29.09	3	3	3	4	3	3	3	3
		29.09 – 45.35	4	4	2	3	2	2	4	4
		45.35 – 79.45	5	5	1	2	1	1	5	5
3.	Elevation (m)	22 – 44	5	5	5	4	5	5	5	5
		44 – 55	4	4	4	4	4	1	4	4
		55 – 94	3	3	3	3	3	1	3	3
		94 – 156	2	2	2	2	2	1	2	2
		156 – 240	1	1	1	1	1	1	1	1
4.	Flow accumulation (pixels)	0 – 5,874	1	1	1	1	1	1	1	1
		5,874 – 26,014	2	2	2	2	2	1	2	2
		26,014 – 56,224	3	3	3	3	3	1	3	3
		56,224 – 82,238	4	4	4	4	4	1	4	4
		82,238 – 213,987	5	5	5	5	5	1	5	5
5.	Land use	Agricultural land	5	4	3	5	3	4	4	3
		Forest land	1	3	2	3	1	1	2	1
		Miscellaneous land	4	3	4	3	4	1	3	4
		Urban and built-up land	4	5	5	5	5	5	4	2
		Water body	5	5	1	1	2	1	5	5
6.	Slope (%)	0 – 3	5	5	5	5	5	4	5	5
		3 – 5	4	4	4	4	4	1	4	4
		5 – 12	3	3	3	3	3	1	3	3
		12 – 28	2	2	2	2	2	1	2	2
		28 – 70	1	1	1	1	1	1	1	1
7.	Soil water infiltration	High	1	1	1	1	1	1	1	1
		Slightly high	2	2	2	2	2	1	2	2
		Moderate	3	3	3	3	3	1	3	3
		Slightly low	4	4	4	4	4	1	4	4
		Low	5	5	5	5	5	2	5	5
		Other	2	2	2	1	5	1	1	1
8.	Average annual rainfall (mm)	997 – 1,054	1	1	1	1	1	1	1	1
		1,054 – 1,100	2	2	2	1	2	1	2	2
		1,100 – 1,157	3	3	3	1	3	1	3	3
		1,157 – 1,215	4	4	4	2	4	1	4	4
		1,215 – 1,275	5	5	5	2	5	2	5	5

Table 3 Pair-wise comparison acquired by experts

No.	Factors		Experts No.							
	Criteria 1	**Criteria 2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Distance from drainage network (m)	Distance from drainage network (m)	1	1	1	1	1	1	1	1
2	Distance from drainage network (m)	Drainage density (km km^{-2})	1/3	1/3	1/7	1/3	1/3	1/3	1/3	1/3
3	Distance from drainage network (m)	Elevation (m)	1/7	3	1/3	1/3	1/3	1/3	3	1/9
4	Distance from drainage network (m)	Flow accumulation (pixels)	1/3	1/3	1/3	1	1/3	1/3	1/3	1/5
5	Distance from drainage network (m)	Land use	1/7	3	1/5	1/3	1/5	1/9	3	3
6	Distance from drainage network (m)	Slope (%)	1/5	3	1/5	3	1/5	1/5	3	1/9
7	Distance from drainage network (m)	Soil water infiltration	1/3	3	3	3	3	1/5	1/3	1/3
8	Distance from drainage network (m)	Average annual rainfall (mm)	1/9	1/5	1/9	1	1/9	1/9	1/3	1/5
9	Drainage density (km km^{-2})	Drainage density (km km^{-2})	1	1	1	1	1	1	1	1
10	Drainage density (km km^{-2})	Elevation (m)	1/7	9	3	5	1/3	1/3	7	1/3
11	Drainage density (km km^{-2})	Flow accumulation (pixels)	1/5	3	3	3	1/3	1/3	1/3	3
12	Drainage density (km km^{-2})	Land use	1/5	9	1/3	3	1/5	1/7	7	3
13	Drainage density (km km^{-2})	Slope (%)	1/3	5	3	5	1/3	1/3	7	1/5
14	Drainage density (km km^{-2})	Soil water infiltration	1/3	7	5	3	3	1/3	3	1
15	Drainage density (km km^{-2})	Average annual rainfall (mm)	1/7	3	1/5	5	1/9	1/9	3	1/3
16	Elevation (m)	Elevation (m)	1	1	1	1	1	1	1	1
17	Elevation (m)	Flow accumulation (pixels)	5	1/5	3	1/3	1/3	1	1/9	5
18	Elevation (m)	Land use	3	1/3	1/3	1/3	1/3	1/5	3	7
19	Elevation (m)	Slope (%)	3	1/3	1/3	1	1/3	1/3	3	1
20	Elevation (m)	Soil water infiltration	3	3	5	1	3	1	1/5	5
21	Elevation (m)	Average annual rainfall (mm)	1/3	1/9	1/3	1	1/7	1/9	1/3	1/3
22	Flow accumulation (pixels)	Flow accumulation (pixels)	1	1	1	1	1	1	1	1
23	Flow accumulation (pixels)	Land use	3	5	1/5	1/3	1/3	1/7	9	3
24	Flow accumulation (pixels)	Slope (%)	3	3	1/5	1/3	1/3	1/3	9	1/5
25	Flow accumulation (pixels)	Soil water infiltration	1	3	3	1	3	1/3	3	3
26	Flow accumulation (pixels)	Average annual rainfall (mm)	1/3	1/3	1/5	1	1/7	1/9	5	1
27	Land use	Land use	1	1	1	1	1	1	1	1
28	Land use	Slope (%)	3	1/3	3	3	3	3	3	1/9
29	Land use	Soil water infiltration	3	1/3	7	3	5	3	1/5	1/3
30	Land use	Average annual rainfall (mm)	1/3	1/9	1/3	3	1/5	1/7	1/3	1/7
31	Slope (%)	Slope (%)	1	1	1	1	1	1	1	1
32	Slope (%)	Soil water infiltration	1/3	3	5	1	5	1/3	1/7	7
33	Slope (%)	Average annual rainfall (mm)	1/3	1/5	1/5	1	1/5	1/7	1/3	1
34	Soil water infiltration	Soil water infiltration	1	1	1	1	1	1	1	1
35	Soil water infiltration	Average annual rainfall (mm)	1/3	1/7	1/7	1	1/7	1/3	1/3	1/5
36	Average annual rainfall (mm)	Average annual rainfall (mm)	1	1	1	1	1	1	1	1

Table 4 Triangular fuzzy numbers of fuzzy AHP method

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

Source: Jongpaiboon [32]

The method proposed by Jongpaiboon [32] was adopted and the following are the four steps of fuzzy AHP to priority weighting for each factor.

Step 1: Calculate the fuzzified pair-wise comparison matrix. Let $X = \{x_1, x_2, ..., x_n\}$ is an object set and $G = \{g_1, g_2, ..., g_m\}$ is a goal set. g_i was computed for each object, therefore, m extent analysis values for each object was reached as $M_{g_i}^1, M_{g_i}^2, ..., M_{g_i}^m; i = 1, 2, ..., n$ where; all the $M_{g_i}^j$ $(j = 1, 2, ..., m)$ are TFNs. To make a pair-wise comparison matrix, use Eq. 1 as a guide.

Step 2: Calculate the fuzzy synthetic extent with regards to the i[th] alternative. Eq. 2 was used to calculate this step.

Step 3: Calculate 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; $i = 1,2,...,n$ and $j = 1,2,...,m$ as well as $i \neq j$ was expressed as Eq. 3.

Step 4: Calculate the weight vector and normalization of the non-fuzzy weight vector. It was done as in Eq. 4.

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

where; $(l_{ij}, m_{ij}, u_{ij}) = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right)$ for $i = 1, 2, ..., n$, and $j = 1, 2, ..., m$, and $i \neq j$; $(l_{ij}, m_{ij}, u_{ij}) = (1,1,1)$ for $i = j$

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right] \quad \text{(Eq. 2)}$$

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

$$V(S_i \geq S_j) = \begin{cases} 1 & \text{if } m_i \geq m_j \\ 0 & l_j \geq u_i \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & \text{otherwise} \end{cases} \quad \text{(Eq. 3)}$$

For S_i greater than S_j was expressed as follows: $V(S_i \geq S_j | j = 1,2,...,m; i \neq j) = \min V(S_i \geq S_j | j = 1,2,...,m; i \neq j)$

$$w_i' = \min V(S_i \geq S_j | j = 1,2,...,m; i \neq j) \quad \text{(Eq. 4)}$$

The weight vector is defined as follows: $w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'}$ and normalized weight vectors as follows $W = (w_1, w_2, ..., w_n)^T$ where; w_i is a non-fuzzy number. Eventually, the non-fuzzy number representing each factor's weights was obtained.

4) Flood hazard index (FHI)

Flood hazard map was performed in Arc Map10.2 using Raster Calculator with employing the factor weights obtained from fuzzy AHP process. It was calculated using the flood hazard index (FHI) [17, 29] as in Eq. 5.

$$\mathrm{FHI} = \sum_{i=1}^{n} r_i \times w_i \quad \text{(Eq. 5)}$$

where; r_i = rating of the factor in each point, w_i = weights of each factor and n = factor number.

Results and discussion

1) Prioritization of flood hazard factors

The fuzzy AHP is regarded as a more advanced method obtained from traditional AHP. It has the ability to reflect human thought by making decisions based on uncertainty and approximation information [33] and these characteristics make a fuzzy AHP a suitable and useful tool for assisting with complex environmental management decisions [34]. Eight experts were requested to take part in the questionnaire of pair-wise comparison. However, since the experts evaluated drainage density and gave different ratings as shown in Table 2, the flood hazard factor weights were calculated by separating the experts into two groups. The results from the first expert group (experts no. 1, 2, 7, and 8), the highest distance from drain-age network class (>2,000 m) was rated as a very low flood hazard while the lowest distance from drainage network class (200 m) was rated as a very high flood hazard. The highest drainage density class (45.35–79.45 km km^{-2}) was rated as a very high flood hazard while the lowest drainage density class (0–6.26 km km^{-2}) was rated as a very low flood hazard. The highest elevation class (156–240 m) was rated as a very low flood hazard while the lowest elevation class (22–44 m) was rated as a very high flood hazard. The highest flow accumulation class (82,238–213,987 pixels) was rated as a very high flood hazard while the lowest flow accumulation class (0–5,874 pixels) was rated as a very low flood hazard.

Land use was classified into five classes, namely agricultural land, forest land, miscellaneous land, urban and built-up land, and water body which water body class was rated as a very high flood hazard while forest land class was rated as a low flood hazard. The highest slope class (28–70%) was rated as a very low flood hazard while the lowest slope class (0–3%) was rated as a very high flood hazard. The high soil water infiltration class was rated as a very low flood hazard while the low soil water infiltration class was rated as a very high flood hazard. The highest average annual rainfall class (1,215–1,275 mm) was rated as a very high flood hazard while the lowest average annual rainfall class (997–1,054 mm) was rated as a very low flood hazard.

Likewise, the results from the second expert group (experts no. 3, 4, 5, and 6), the highest and lowest classes of drainage density, elevation, slope factors were rated the same as the first expert group. The highest distance from drainage network class was rated as a low flood hazard while the lowest class was rated as a very high flood hazard. The highest flow accumulation class was rated as a high flood hazard while the lowest class was rated as a very low flood hazard. For land use factor, water body class was rated as a very low flood hazard while urban and built-up land class was rated as a very high flood hazard. The high soil water infiltration class was rated as a very low flood hazard while the low class was rated as a high flood hazard. The highest average annual rainfall class was rated as a high flood hazard while the lowest class was rated as a very low flood hazard. It found that ratings derived by fuzzy AHP analysis are defined at the discretion of experts, implying that the methodology heavily relies on expert discretion [35].

The research was able to identify factor weights based on the merit of the combination between fuzzy AHP and GIS, which was significant in the prioritizing of flood hazard factors.

Prioritization of flood hazard factors showed that the first expert group was average annual rainfall (0.1879), flow accumulation (0.1667), drainage density (0.1611), elevation (0.1423), slope (0.1206), soil water infiltration (0.0988), distance from drainage network (0.0632), and land use (0.0594), respectively. The second expert group was average annual rainfall (0.2556), land use (0.2130), slope (0.1464), drainage density (0.1457), elevation (0.1019), flow accumulation (0.0843), soil water infiltration (0.0306), and distance from a drainage network (0.0224), respectively as shown in Table 5.

According to the findings the average annual rainfall factor is the primary factor to cause showed that areas with higher rainfall are more prone to flooding. Similarly, in the consideration of flooding, rainfall is also recognized as the most influential hazard factor [28, 36]. It is expected to achieve more accurate flooding results when using radar estimated rainfall [37]. However, there is unavailable radar estimated data during the study period. The discrete data of rainfall observed by gauge was used instead. Using satellite rainfall products such as TRMM data [38–39] would also improve the flood modeling in analysis dimension with related rainfall events because high temporal resolution of rainfall estimated will be derived in the ungauged areas.

2) Flood hazard maps

The final maps are heavily influenced and determined by the factor weights and ratings. Several academics have also attempted to create flood maps using a combination of fuzzy AHP methods and GIS [18, 35, 40–41]. Despite of using the same approach, this study we found the difference on expert's opinion. As depicted in Figure 4, two different flood hazard maps were created. The first expert group's map (Figure 4(a)) revealed that flood hazard levels were primarily high in Phrom Phiram, Mueang Phitsanulok, and Bang Rakam Districts, while was very low to moderate in Kong Krailat District. Flood hazard levels were moderate, encompassing 211.94 km^2 (30.47%) of the total area, low level of 184.44 km^2 (26.52%), high level of 165.78 km^2 (23.83%), very low level of 75.59 km^2 (10.87%), and very high level of 57.81 km^2 (8.31%), respectively.

The second expert group's flood hazard map (Figure 4(b)) showed that flood hazard was mainly found on the left side at very low to moderate levels, and on the right side at high to very high levels, with the latter happening mostly in Phrom Phiram District. The areas of high flood hazard level accounted for roughly 218.90 km^2 (31.47%), moderate level for 175.58 km^2 (25.24%), very high level for 161.91 km^2 (23.28%), low level for 100.22 km^2 (14.41%), and very low level for 38.93 km^2 (5.60%), respectively. The findings also revealed that areas with very high flood hazard levels should be given with the first priority in flood management. According to RID [7], this is required to increase the Yom River's retarding water capacity during the flood period and to mitigate the flood impact for potential communities.

Table 5 Fuzzy weights for each factor according to two expert groups

No.	Factors (Criteria)	First group (Experts No. 1, 2, 7, 8)	Second group (Experts No. 3, 4, 5, 6)
1	Distance from drainage network (m)	0.0632	0.0224
2	Drainage density (km km^{-2})	0.1611	0.1457
3	Elevation (m)	0.1423	0.1019
4	Flow accumulation (pixels)	0.1667	0.0843
5	Land use	0.0594	0.2130
6	Slope (%)	0.1206	0.1464
7	Soil water infiltration	0.0988	0.0306
8	Average annual rainfall (mm)	0.1879	0.2556

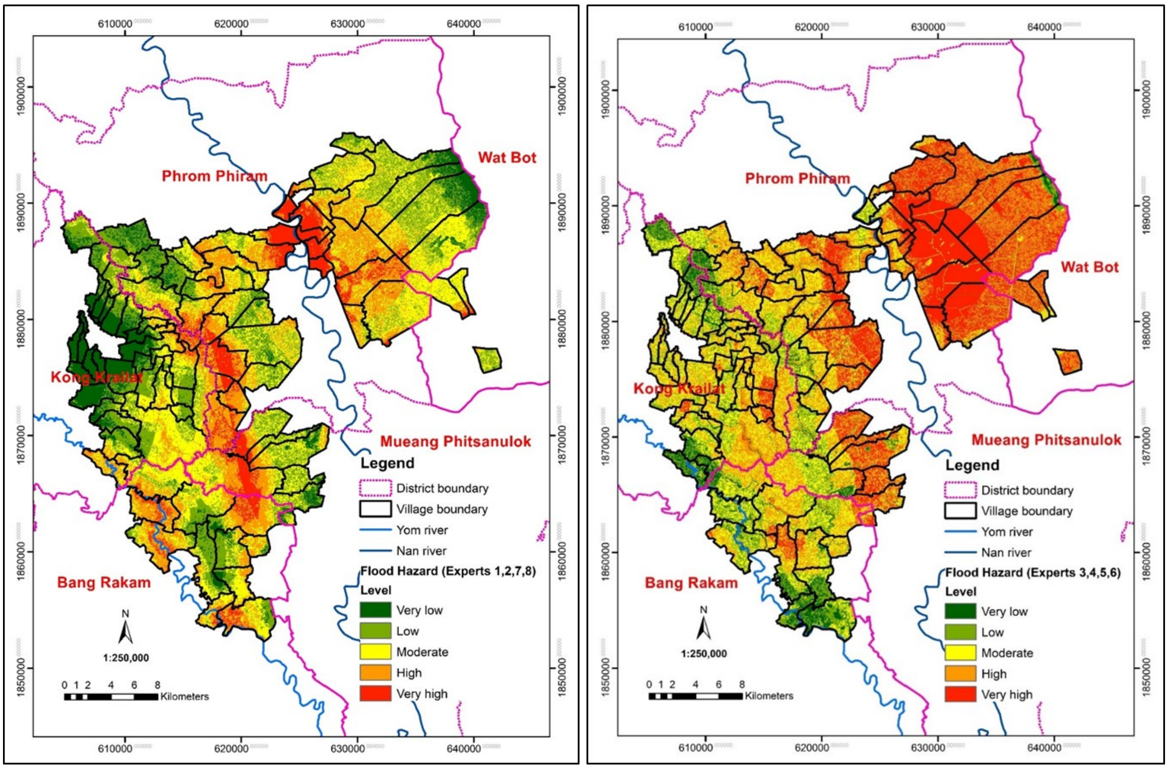

Figure 4 Flood hazard maps: (a) first expert group and (b) second expert group.

3) Validation of flood hazard maps

Repeated floods area from GISTDA obtained from https://floodv2.gistda. or.th was used to validate the obtained flood hazard maps. Flood levels were classified into three classes according to LDD [42] as follows: low level is repeated floods 1–3 times /10 years, moderate (4–7 times/ 10 years), and high (>8 times/10 years). Since flood hazard maps were classified into five levels, so the researchers were regrouped class into three levels as follows: very high and high was the group as high, moderate, while low and very low was the group as low. According to Sriariyawat et al. [43], these maps were validated by shape factor *(f)* as in Eq. 6.

$$f = \frac{A_{sat} \cap A_{fh}}{A_{sat} \cup A_{fh}} \quad \text{(Eq. 6)}$$

where the intersection of areas from GISTDA by satellite (A_{sat}) images and flood hazard map (A_{fh}) represents $A_{sat} \cap A_{fh}$. The union area for both satellite images and flood hazard maps is $A_{sat} \cup A_{fh}$. If f equal to 1, the flood hazard maps are completely consistent with satellite data.

Flood hazard maps from two expert groups were regrouped into three levels as same as the repeated floods area from satellite images were also classified into three levels using GIS software. Then, the intersection and union area were calculated. Intersect tool in GIS software was used to calculate the geometric intersection of the input features for both flood hazard map and repeated floods area. All the input features were projected into the spatial reference and clustering snaps together vertices that are within the XY tolerance. Then features overlapping in all layers will be the output feature class [44]. Union tool was used to calculate the geometric union of the input features for both flood hazard map and repeated floods area. This can only be used with polygon features which all features and their attributes will be written to the output feature class [45]. Therefore, we obtained the results of intersection and union areas at each flood hazard level. Lastly, we can calculate the shape factor of each expert group.

Table 6 indicate that the first expert group's *f* was closer to 1 than the second expert group. Aly and Vrana [46] stated that it is not always true that all experts have equal significance when it comes to the decision due to the fact that those experts' degrees of experiences, knowledge, and relevancy may not be comparable. As a result, the first expert group's flood hazard map is more accurate than the second expert group. Therefore, this research revealed that the areas with higher rainfall are more likely to be flooded. The areas located close to the high cumulative flow of concentrated flow and drainage density have the potential to generate more surface runoff and post higher flood threat. It found that Phrom Phiram, Mueang Phitsanulok, and Bang Rakam Districts in the Phitsanulok Province had very high flood hazards. Many causes contribute to floods, including hydrological phenomena such as the south-west monsoon, intertropical convergence zones, tropical storms, and depressions, and others [47]. These results also concluded that when the level of water in a river exceeding its water retention ability due to high-intensity rainfall or when a big amount of water is incapable to drain downstream towards the river mouths and flows over the river banks or stream are resulting to flooding at Bang Rakam Model 60 areas.

Table 6 Validation of flood hazard maps using shape factors (f)

Flood level	Intersection		Union		Shape factors (f)	
	First group	Second group	First group	Second group	First group	Second group
Low	134.09	49.17	393.92	373.74	0.34	0.13
Moderate	64.22	52.41	356.47	334.22	0.18	0.16
High	63.35	47.49	297.58	452.55	0.21	0.10

Remark: First group of experts included Experts No. 1, 2, 7, 8
Second group of experts included Experts No. 3, 4, 5, 6

Conclusions

In this research, the flood hazard assessment in area of the Bang Rakam Model 60 Project using the fuzzy AHP method. Our findings show that the results from the first expert group (No. 1, 2, 7, and 8) were selected. Average annual rainfall is the most important factor of flood hazards. According to the flood hazard map, very high and high flood hazard are mostly in Phrom Phiram, Mueang Phitsanulok, and Bang Rakam Districts. Usually, at areas along the drainage network, these areas and their environs are prone to flooding. However, the causes of floods in the three areas have shown in different results. Floods in the Phrom Phiram and Mueang Phitsanulok Districts are caused by overflow from the river bank, whilst floods in the Bang Rakam District depends on low drainage flow to downstream.

This approach, which combines the fuzzy AHP and GIS, creates a modern scientific framework for assessing flood hazard as well as making the analysis findings more comprehensive and appropriate. Flood hazard mapping is critical for the Bang Rakam Model 60 Project's water and budget allocation planning. Therefore, flood hazard maps can assess the danger floods pose to people. This will aid risk management decision-making in terms of plans, operations, and investments.

The researchers have relevant recommendations to be considered in future research that are the fuzzy AHP's performance depends on defining extensive criteria and subject experts, as well as appropriately prioritizing and ranking the criteria without subjective bias. This research used the concept of spatial analysis. Engineering knowledge is the background of the second expert group which provides less the accurate results than the first group. Therefore, the qualifications of experts for this type of study should have a good knowledge and understanding of the physical factors, physical characteristics of the study area, and the objectives of the study area. We found that experts from the Meteorological Station, Disaster Prevention and Mitigation Office, Regional Irrigation Office, and lecturers in educational institutions were suitable for weight evaluation. The study should employ a DEM with both high resolution and accuracy, since it would produce more accurate results. Lastly, the physical factors that influence irrigation technology selection, such as water depth, return period, and so on were not examined in this study. If these are studied, it will be possible to have a better understanding of the causes and amount of each year's flood.

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