FLOOD HAZARD MAPPING FOR A REPEATED FLOODING AREA IN NORTHERN THAILAND

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ABSTRACT: Bang Rakam district in Phitsanulok is located at the lower Yom River Basin, and holds excess water from upstream districts, resulting in a persistent annual flood. The Thai government has declared flood management a national priority and as a result, this study area was chosen for this pilot project. The Bang Rakam Model 60 was established at the left bank of the Yom River and covered an area of 265,000 rai (424 km^2). This study aims to evaluate the flood hazard posed to the area using geographic information systems (GIS) and the fuzzy analytic hierarchy process (Fuzzy AHP). Parameters were created and classified using GIS, and the preference weights of the alternative decisions were calculated using a Fuzzy AHP based on Chang's Extent Analysis. The findings showed that the most significant predisposing parameter to flood hazard is average annual rainfall. The results of our analysis have shown with levels of very high flood hazard, high hazard, moderate, low, and very low flood hazard accounted for 8.31%, 23.83%, 30.47%, 26.52%, and 10.87% of the total area, respectively. The results of our proposed GIS analysis concept in this study can be applied in real situations to help government agencies to put in mitigation measures for saving lives, properties, and money spent on reliefs and compensation campaigns for suffering people.

1. INTRODUCTION

In 2011, floods caused 95% of Thailand's economic losses (AHA Centre & JICA, 2015). The Thai government attempted to implement flood mitigation measures as a result of this occurrence. As a result, the "Bang Rakam Model 54" was developed to serve as a guideline model (Promma, 2013) that non-structural and structural measures are both available. Afterward in 2017, the new project was evolved and given the name "Bang Rakam Model 60." It is an integrated water management project in the extension area (Trakuldit, 2018). The supply of water for rice crop planning and diversion of water into the three monkey cheeks are the flood problems solving of this project (RID, 2018).

Assessment of flood hazard is essential for assessing flood risk and is important for human lives, the natural environment, and the social economy (Liu et al., 2015). Hazard assessments can be carried out successfully with the help of tools that deal with spatial data, for example, geographic information systems (GIS). GIS was recommended by Wang, Li, Tang and Zeng (2011) for assessing spatial data and has an important role to play in natural hazard management. It not only creates visuals of the flood but also allows for technical estimation of the potential flood hazard (Sanyal & Lu, 2006).

The analytic hierarchy process (AHP) created by Saaty (1987) forms the basis for the use of multi-criteria evaluation. However, subjective expert judgments gained by using crisp numbers (precise values) may produce less accurate results (Ekmekcioğlu et al., 2020). "Fuzzy analytic hierarchy process (Fuzzy AHP)" is able to reflect human thought in that it employs approximate information and uncertainty to make decisions (Kahraman et al., 2004).

The flood hazard map at the Bang Rakam Model 60 project will be assessed utilizing the GIS process in conjunction with fuzzy AHP in this study. This study is based on the improvement of research work proposed by Yodying et al. (2019).

2. MATERIALS AND METHODOLOGIES

The study was carried out at Phitsanulok and Sukhothai provinces in 5 districts, 20 sub-districts, 93 villages based on Bang Rakam Model 60 project as shown in Table 1 and Figure 1. We used the following three-process methodology for the study: (1) collection of data and creation of parameter maps, (2) assessment of flood hazard map, and (3) validation of flood hazard map as shown in Figure 2.

Table 1 Study area of Bang Rakam Model 60.

Provinces	Districts	Sub-districts	Village No.
Sukhothai	Kong Krailat	Ban Mai Suk Kasem	1-8
		Dong Dueai	2, 4, 6-7, 9-10
		Kok Raet	1-12
		Krai Klang	1-2, 4, 8
		Krai Nai	9
		Krai Nok	2, 5, 7-8
Phitsanulok	Bang Rakam	Bang Rakam	15
		Chum Saeng Songkhram	1-3, 9
		Tha Nang Ngam	3, 5, 8-11
	Mueang Phitsanulok	Ban Krang	6-8, 10
		Phai Kho Don	3, 4, 6
	Phrom Phiram	Dong Prakham	10
		Ho Klong	5, 7
		Matong	2, 5, 8-10
		Nong Khaem	2, 5-10
		Phrom Phiram	1, 10-13, 15
		Tha Chang	7-12
		Thap Yai Chiang	3-6
		Wang Won	3-7, 9
	Wat Bot	Wat Bot	3, 4, 7

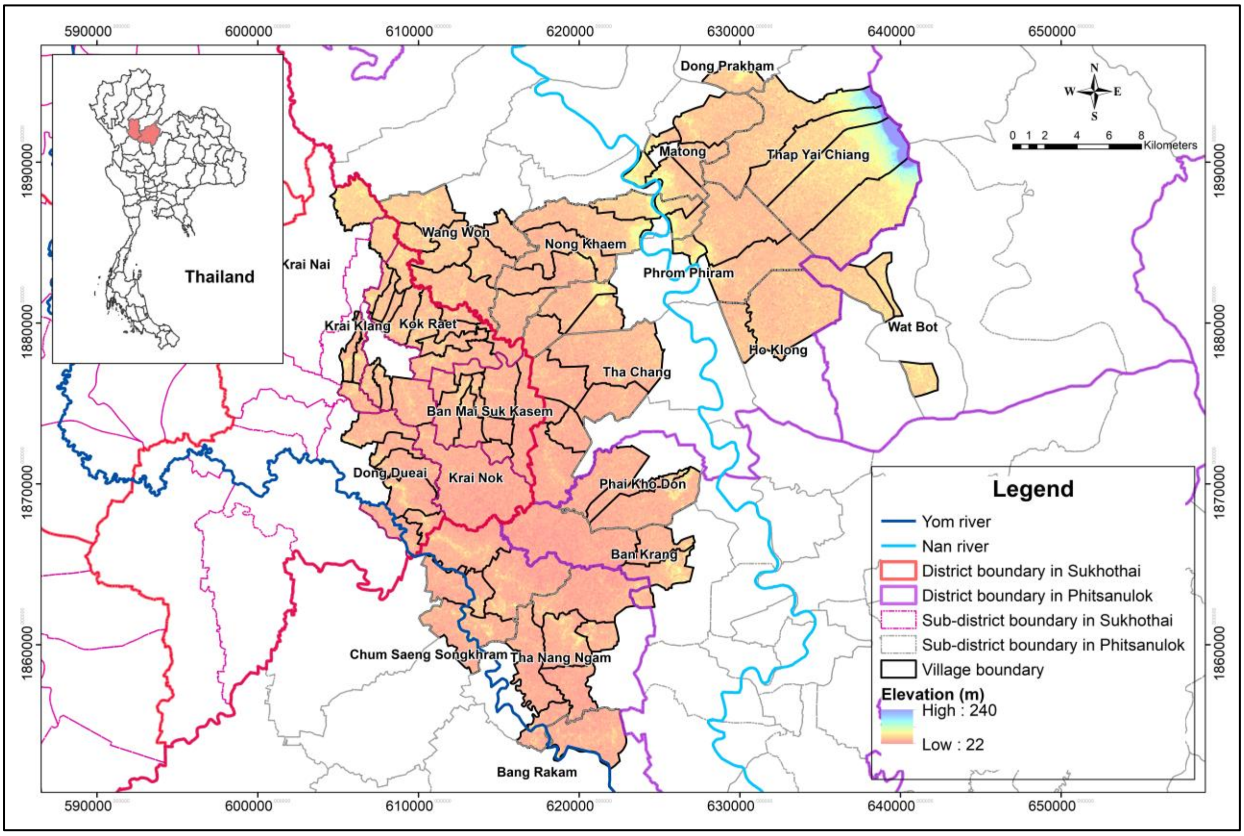

Figure 1 Location of the study area.

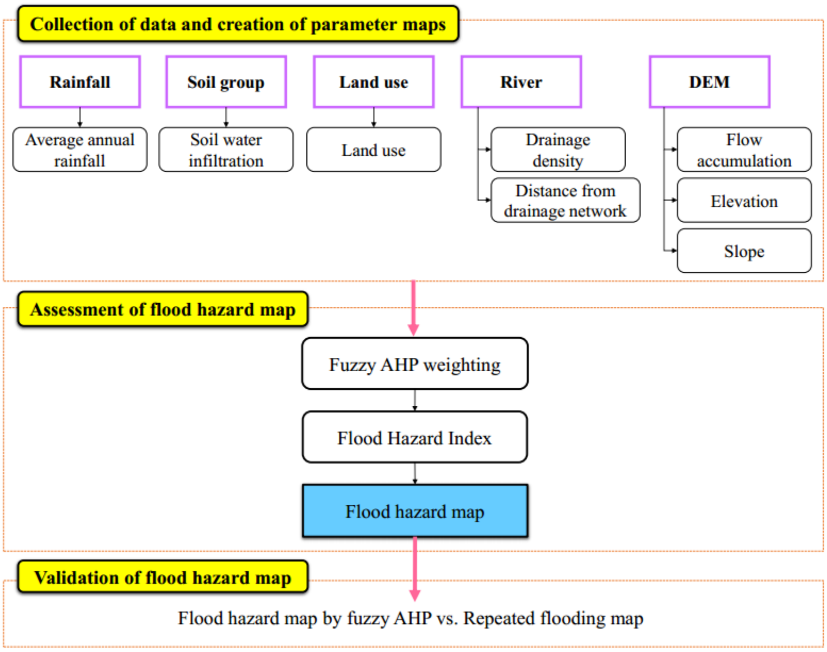

Figure 2 Methodology for the study.

2.1 Collection of data and creation of parameter maps

Eight flood hazard parameters were selected by literature review. Different data were used to create parameter maps and classify for generating a flood hazard map. Rainfall data from Northern Meteorological Center were used to derive average annual rainfall (mm) in 30 years, using interpolation methods in GIS. Soil group and land use data from Land Development Department (LDD) were used to create soil water infiltration and land use parameters, respectively. River data from Regional Water Resources (Office 9), and Yom-Nan Operation and Maintenance Project were used to create drainage density (km/km^2) and distance from drainage network (m) parameters. Digital elevation models (DEMs) were used to derive flow accumulation (pixels), elevation (m), and slope (%) parameters. The resolution sizes of these parameters were at 30 m and were classified using Natural Breaks (Jenks) method in GIS. All of the data preprocessing of the selected flood hazard parameters was performed in GIS software, which is required in the next process to analyze and execute fuzzy AHP.

2.2 Assessment of flood hazard map

Four experts as shown in Table 2, evaluated flood hazard parameters by pair-wise comparison relied on the AHP method as well as considered the class and the rating. The rating was divided into five rates consist of very high (5), high (4), moderate (3), low (2), and very low (1). Consistency Ratio (CR) was checked and calculated as follows: $CR = CI/RI$ where; CI represents consistency index and RI represents the mean random index, which was 1.41 for matrix 8×8. CI was calculated as follows: $CI = \frac{\lambda_{max} - n}{n-1}$ where; λ_{max} represents eigenvalues and n represents the number of parameters. It was acceptable when $CR \leq 0.10$.

Table 2 Expert lists for evaluating pair-wise comparison.

No.	Workplace	Position	Work experience
1	Disaster Prevention and Mitigation Office (Phitsanulok)	Chief of Strategy and Management	30 years
2	Engineering Division, Regional Irrigation Office 3	Irrigation Engineer	29 years
3	Faculty of Agriculture, Natural Resource and Environment, Naresuan University	Lecturer	22 years
4	Phitsanulok Meteorological Station	Director of Meteorological Station	36 years

Fuzzy AHP analysis based on Chang's extent analysis (Chang, 1996) with triangular fuzzy numbers or TFNs (Table 3) was used in this study.

Table 3 Importance levels in pair-wise comparison.

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

There are four steps to calculate (Jongpaiboon, 2015) as follows: (1) calculate the fuzzified pair-wise comparison matrix. m extent analysis values for each object was reached as $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m;\ i = 1, 2, \ldots, n$ where; all the $M_{g_i}^j$ *(j = 1, 2,…,m)* are TFNs (equation 1).

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

where; $(l_{ij}, m_{ij}, u_{ij}) = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right)$ for $i = 1, 2, \ldots, n$, and j = *1, 2,…,m*, and $i \neq j$; $(l_{ij}, m_{ij}, u_{ij}) = (1,1,1)$ for $i = j$. Next step (2) calculate the fuzzy synthetic extent with regards to the ith alternative (equation 2).

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

where; S_i represents the pair-wise comparison's synthetic extent value and $\sum_{j=1}^{m} M_{g_i}^j$ represents the total of the TFNs. $\sum_{j=1}^{m} M_{g_i}^j = \left[\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right]$, $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right)$, and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right)$. Followed by (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 $i \neq j$ (equation 3).

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

For S_i greater than S_j was expressed as follows: $V(S_i \geq S_j | j = 1,2, \ldots, m; i \neq j) = min\, V(S_i \geq S_j | j = 1,2, \ldots, m; i \neq j)$. Last step (4) calculate the weight vector and normalization of the non-fuzzy weight vector (equation 4).

$$w_i' = \min V(S_i \geq S_j | j = 1,2, \ldots, m; i \neq j) \quad (4)$$

The weight vector is defined as follows: $w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'}$ and normalized weight vectors as follows: $W = (w_1, w_2, \ldots, w_n)^T$ where; w_i represents a non-fuzzy number. Finally, the non-fuzzy number that is the weights of each parameter were obtained.

A combination of the GIS process and fuzzy AHP was calculated using the flood hazard index or FHI (Kazakis et al., 2015) as follows: $FHI = \sum_{i=1}^{n} r_i \times w_i$ where; r_i = rating of the parameter in each point, w_i = weights of each parameter, and n = number of parameters.

2.3 Validation of flood hazard map

The flood hazard map generated was validated using shape factor (f) (Sriariyawat et al., 2013) with repeated flooding area from the Geo-Informatics and Space Technology Development Agency (GISTDA) as follows: $f = \frac{A_{sat} \cap A_{fh}}{A_{sat} \cup A_{fh}}$ where; $A_{sat} \cap A_{fh}$ indicates the intersection of areas by repeated flood areas (A_{sat}) and flood hazard map (A_{fh}). $A_{sat} \cup A_{fh}$ indicates the union area for both repeated flood areas and flood hazard map. The flood hazard map is totally compatible with repeated flood areas when f equals 1. Flood levels were divided into three categories based on LDD (2014) as shown in Table 4.

Table 4 Classification of the repeated flood.

Flood hazard levels	Repeated flood (times in 10 years)
High	> 8
Moderate	4 - 7
Low	1 - 3

3. RESULTS AND DISCUSSIONS

3.1 Flood hazard assessment

Based on fuzzy AHP analysis to obtain parameter weights as shown in Table 5, found in an order of importance, 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). As a result, the most important parameter triggering flood hazard was average annual rainfall. Flood hazard map creation as shown in Figure 3 revealed that Bang Rakam, Phrom Phiram, and Mueang Phitsanulok districts in Phitsanulok province were largely very high flood hazard levels. Likewise, the Kong Krailat district was mostly very low to moderate levels. Flood hazard area at each level showed that moderate level covering the most an area. This was followed by low level, high level, very low level, and very high level, respectively (Figure 4).

Table 5 Parameter weights from four experts.

No.	Parameters	Fuzzy AHP weights
1	Average annual rainfall (mm)	0.1879
2	Soil water infiltration	0.0988
3	Land use	0.0594
4	Drainage density (km/km^2)	0.1611
5	Distance from drainage network (m)	0.0632
6	Flow accumulation (pixels)	0.1667
7	Elevation (m)	0.1423
8	Slope (%)	0.1206

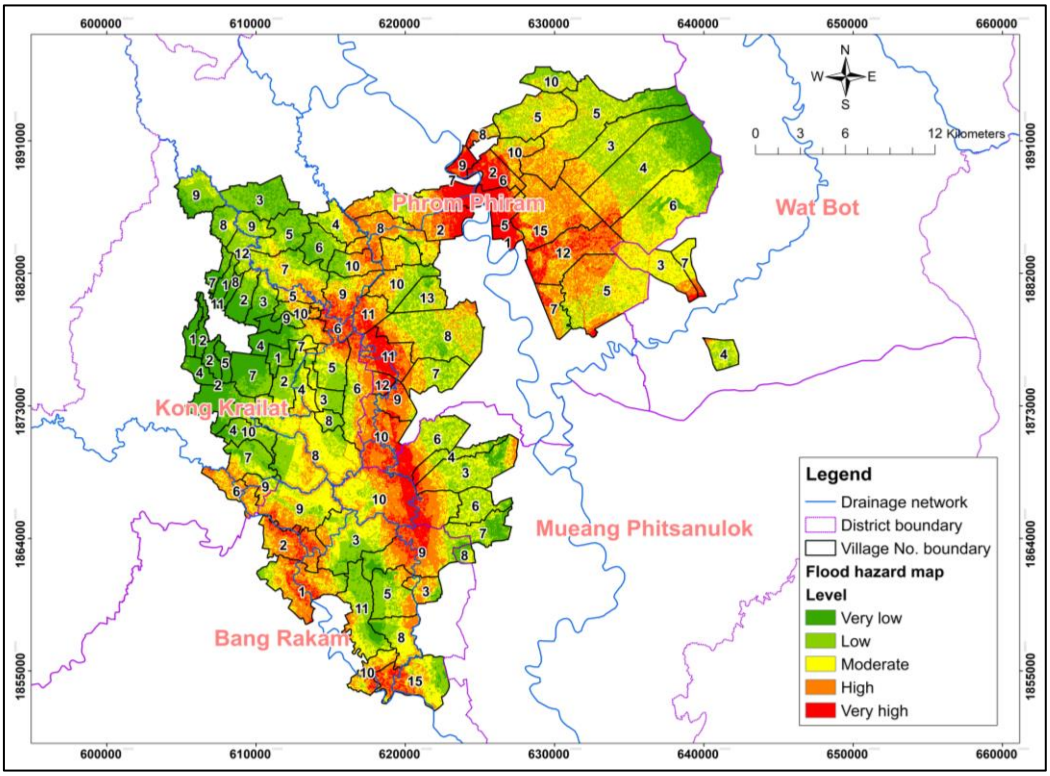

Figure 3 Flood hazard map at the Bang Rakam Model 60 project.

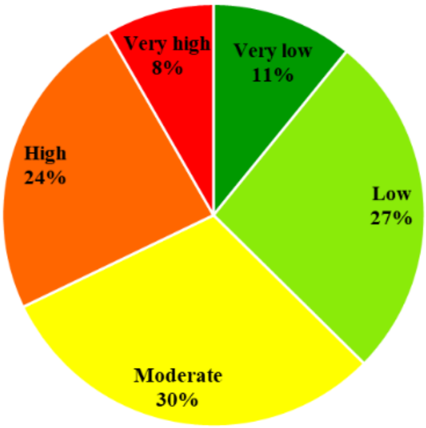

Figure 4 Percent of flood hazard areas at each level.

3.2 Validation of flood hazard map

Flood hazard levels (shown in Figure 3) were divided into three classes. The classes were low (i.e. very low and low group), moderate, and high (i.e. very high and high group). This was validated with the repeated flood as shown in Figure 5. It was revealed that shape factors were 0.21, 0.18, and 0.34 at high, moderate, and low levels, respectively. Despite shape factor values are not close to 1 but flooded areas in Bang Rakam district, as visible on both the flood hazard map and the repeated flood areas are at nearly the same point. It revealed that parameter weights and ratings acquired are determined at the discretion of experts, implying that flood map creation using fuzzy AHP heavily relies on expert discretion. In this study rainfall data is so important as input factor to the method. In this study, rainfall data is so important as an input parameter to the method. However, the rainfall data used here is considered as an insufficient spatial resolution to resolve the study area. It is interesting to investigate the effect of using rainfall estimated by ground-based radar (Mahavik et al., 2021) and also rainfall products estimated by satellite products such as TRMM (Mahavik et al., 2021; Mahavik & Tantanee, 2021; Mahavik & Tantanee, 2018).

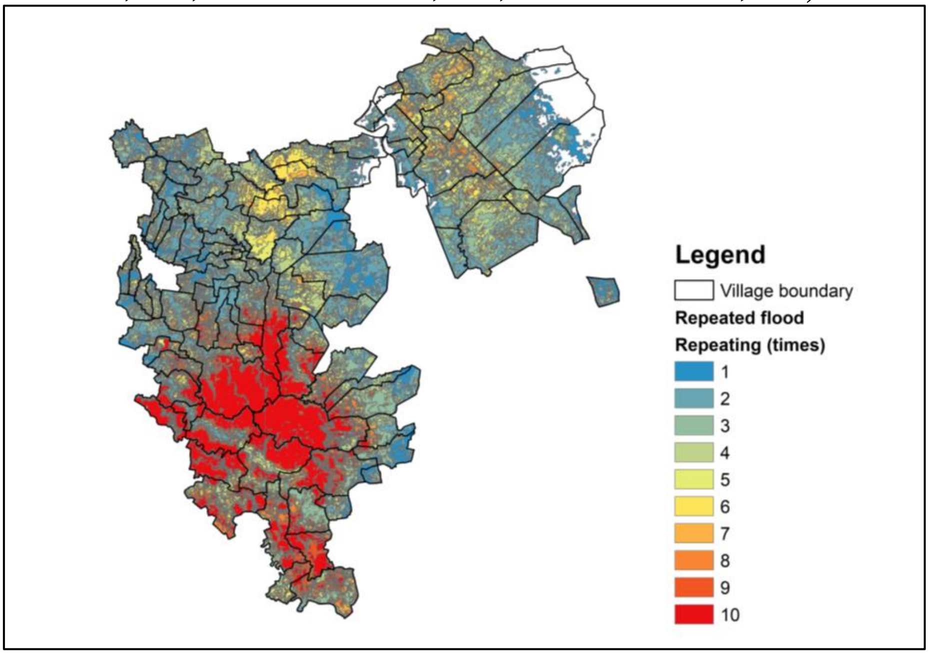

Figure 5 Repeated flooding from GISTDA.

4. CONCLUSIONS

The most influential parameter is average annual rainfall, which has a weight fuzzy of 0.1879. The majority of the areas on the flood hazard map (30.47% of the total area) are at a moderate level and very high flood hazard are along drainage network. We interrogated the experts for evaluating suitable weight parameters, which were used to map the flood hazard zone with the fuzzy AHP concept. The proposed concept of GIS analysis in this study is considered to be useful for the budget allocation and water planning at the Bang Rakam Model 60 project. It can also be applied to other projects in the future.

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