Agromet 36 (2): 101-111, 2022

PERHIMPI

Agromet

journal.ipb.ac.id/index.php/agromet

ISSN : 0126 - 3633

Evaluation of Flood Hazard Potency in Jakarta based on Multi-criteria Analysis

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ARTICLE INFO

Received
9 December 2022

Revised
26 December 2022

Accepted for Publication
27 December 2022

Published
30 December 2022

doi: 10.29244/j.agromet.36.2.101-111

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ABSTRACT

The frequency of flood events in Indonesia has increased since 1990, especially in the capital city of Jakarta. Flood events have affected socio-economic activities, and have threaten community health in flood prone areas. Although many efforts have been performed to reduced flood impacts, research on flood hazard remains a research challenge. This study aims to map level of flood hazard in Jakarta and to determine the most affected factors that cause flood. First, we defined factors that influence flood, and combined an analytical hierarchy process (AHP) to determine their weighted values and GIS approach to determine their score values. The combination of weight and score value determined the flood hazard index (FHI). The sensitivity analysis and validation then were applied to determine the robustness of the approaches. Our results show that the most influenced factors determining flood hazard were rainfall intensity, land use, and slope, whereas geology is the less factor. Based on the sensitivity analysis and FHI validation, our approaches were able to represent 59% flood disaster in Jakarta. The pattern of FHI value was high in north areas and low in south areas. The findings indicated that north areas are more flood prone than south areas. Further, this research contributes to the improved approach of flood mitigation in Jakarta

KEYWORDS

analytical hierarchy process, precipitation concentration index, resample, sensitivity, single-parameter analysis

INTRODUCTION

Floods are one of the most destructive and frequent natural disasters in the world (Estiningtyas et al., 2009; Rejekiningrum and Kartiwa, 2002; Surmaini et al., 2018), and tend to increase since 1990. According to the National Disaster Management Agency-BNPB (BNPB, 2020), the total number of flood disasters in Indonesia (2011-2020) was including up to 7.545 cases. Floods have caused some losses causalities and damage for public infrastructure (Basuki et al., 2009; Fatemi et al., 2020; Sholihah et al., 2020a).

Several previous studies have used flood hazard index (FHI) based multi-criteria decision-making analysis for flood hazard estimation (Echogdali et al., 2018; Kabenge et al., 2017; Stefanidis and Stathis, 2013). The analysis combines geographic information system (GIS) and analytical hierarchy process (AHP) techniques to determine the flood hazard potency in specific area. The FHI approach has been widely used in various countries such as Asia, Africa, and Australia (Dou et al., 2018; El Morjani et al., 2016; Kabenge et al., 2017; Kelly and Kuleshov, 2022) but has not been widely used in Indonesia. FHI output shows potential locations to be affected by the flood. Most studies related to FHI usually do not validate the research results, and only a few studies validate FHI output with historical data of flood events. In this study, estimation of the flood hazard potential in Jakarta was carried out using the FHI, then validated using the inundation map produced by BNPB.

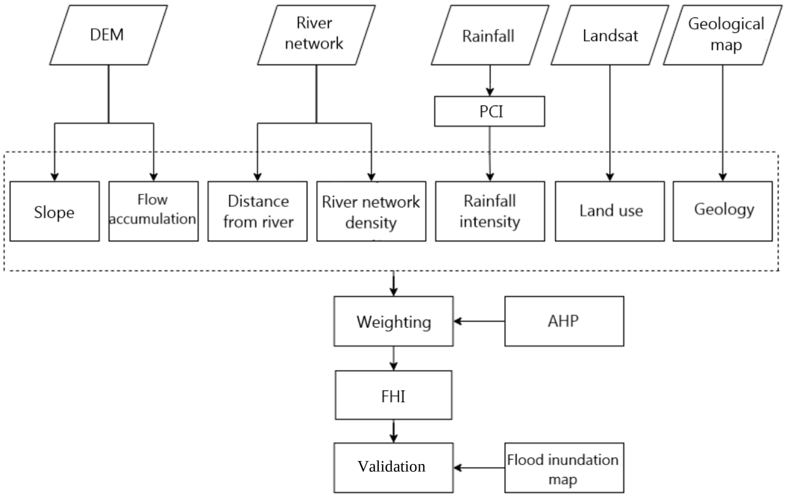

Figure 1. Flowchart of flood hazard index calculation procedure based on multi-criteria and satellite analysis

As the capital city of Indonesia, Jakarta is the downstream for 13 rivers making it vulnerable to flooding. Flood disasters in Jakarta are generally caused by rainfall (Boer et al., 2007; Lestari et al., 2019), land use changes (Januriyadi et al., 2018), and river network density (Marfai et al., 2015). In the past decade, the major flood events in Jakarta occurred in 2010, 2013, 2015 (DISPUSIP, 2019), and most recently in 2020. The flood on January 1st, 2020 caused various losses, such as 67 people died and economic losses reached Rp 1M (Ginting, 2020). Thus, this research focuses on flood disaster management and mitigation using the FHI method to aim at reducing the negative impacts of floods.

RESEARCH METHODS

The research area cover Jakarta Capital City. Where is located at coordinates 6° 12′ S and 106° 48′ E which is a lowland area of 664.01 km^2 with an altitude of ± 7 m.a.s.l. There are 13 rivers that pass-through Jakarta, including Ciliwung, Krukut, Mookervart, Kali Angke, Kali Pesanggrahan, Kali Grogol, Kalibaru Timur, Cipinang, Sunter, Cakung, Buaran, Kalibaru Barat, Cengkareng Drain, Jati Kramat, Cakung Drain, Banjir Kanal Barat, and Banjir Kanal Timur. As the capital city of Indonesia, Jakarta is occupied by with a growth rate of 0,92% per year (BPS, 2021). The combination of Jakarta's geographical and social factors, namely the high density of rivers and the high population growth rate, makes Jakarta vulnerable to flooding.

There were five data used in this study (Figure 1): (i) Digital Elevation Model (DEM) (scale of 8,15 x 8,15 m^2, sourced from the Geospatial Information Agency BIG); (ii) river network (scale of 1:25.000, sourced from BIG); (iii) monthly rainfall for the period 1990-2020 (scale of 0.05 x 0.05°, sourced from Climate Hazards Group InfraRed Precipitation CHIRPS); (iv) Landsat 7 and Landsat 8 (scale of 30 x 30 m, which was acquired on: (a) September 17th, 2001, (b) July 10th, 2005, (c) July 21st, 2009, (d) September 13rd, 2014, and (e) September 11st, 2019); and (v) geological map (scale of 1:100.000 sourced from the Geological Research and Development Center). Data processing and analysis was carried out using several applications, namely ArcMap 10.4.1, Super Decisions 2.8.0, and R programming language.

Data analysis in this study was divided into 4 stages: (a) determining the causes of flooding, (b) compiling and analyzing the Analytical Hierarchy Process (AHP), (c) calculating the Flood Hazard Index (FHI), and (d) sensitivity analysis and validation as shown in Figure 1.

Determination of the Causes of Flooding

Identification of the factors that cause flooding is an essential step in the flood hazard analysis process. The selected factors must represent the existing problems in the study area. This study uses a literature review (Marfai et al., 2015; Asdak et al., 2018; Sholihah et al., 2020) to identify the factors that cause flooding in Jakarta. Based on geographical and meteorological conditions, the factors that influence flood events in Jakarta are (i) flow accumulation, (ii) distance from the river, (iii) river network density, (iv) slope, (v) rainfall intensity, (vi) land use, and (vii) geology. The seven factors that have been determined are then processed using a Geographic Information System (GIS) with a spatial resolution of ~8,15 m.

The first factor that causes flooding is flow accumulation obtained from DEMNAS data. The second factor, the distance from the river, is obtained through the buffering technique on the river network map. The third factor, the density of the river network is determined using river network data and then calculated based on Equation 1.

$$D_d = \frac{L}{A} \quad (1)$$

Table 1. Importance scale for pairwise comparisons (Saaty, 2008).

Importance level	Description
1	Both factors are equally important
3	One factor is slightly more important than the other factor
5	One factor is more important than the other factor
7	One factor is clearly more important than the other factor
9	One factor is absolutely more important than the other factor
2, 4, 6, 8	The value between two adjacent considerations
Reciprocal	If factor i has one of the numbers above when compared to j, then j has the opposite value of factor i

where D_d is the density of the river (m/km^2), L is the total length of the river (m), and A is the watershed area (km^2). Further, the slope was obtained from the DEM data using the spatial analyst tool. The rain intensity factor was obtained by calculating the Precipitation Concentration Index (PCI), which was calculated based on Equation 2.

$$PCI = 100\ x\ \frac{\sum_{i=1}^{12} {p_i}^2}{(\sum_{i=1}^{12} p_i)^2} \quad (2)$$

where p_i is the rainfall of the ith month for each year (mm). Then the land use factor was obtained using Landsat 7 and Landsat 8 data. Landsat data was analyzed using the guided classification method and tested for accuracy using the calculation of the Kappa coefficient value Equation 3.

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+}.x_{+1})}{N^2 - \sum_{i=1}^{r}(x_{i+}.x_{+1})} \quad (3)$$

where K is the Kappa coefficient, N is the total number of observations (pixels), r is the number of rows in the error matrix, x_{ii} is the number of observations in the ith row and ith column, x_{i+} is the total observations in the ith row, and x_{+1} is the total observations in column ith. The last factor that causes flood is the geology which is obtained through the geological distribution map of Jakarta.

Analytical Hierarchy Process (AHP) Preparation and Analysis

The analytical hierarchy process (AHP) is a multi-criteria decision-making method that involves several criteria and alternatives. Each criterion was given a weighted value based on its relative importance, then we input them into a pairwise comparison matrix. In this study, a 7x7 pairwise comparison matrix was created according to the number of factors that cause flooding. Each factor will be compared with other factors and given a weighted value based on the importance scale (Table 1). The number of weights is obtained through expert judgment. There is 6 expert is used in this study from different backgrounds who are classified into academics/researchers, government, and community. Determination of the number of experts refers to the research of Lyu et al. (2020). The questionnaire filling was carried out by each expert to provide an assessment of the weight of each factor causing the flood

The weight of the importance values obtained based on the expert judgment has an element of subjectivity, therefore a consistency test analysis is needed. The consistency test calculation is shown in the Equation 4.

$$CR = \frac{CI}{RI} \quad (4)$$

where CR is the ratio of consistency, CI is the consistency index, and RI is a random index. RI values are shown in Table 2. RI values are determined based on the number of factors used. This study uses 7 factors; therefore, the value of RI is 1.32.

The error tolerance in expert judgment is 0.1. If the CR value<0.1 then it is stated that the hierarchy is consistent and can be used, otherwise if the CR value >0.1 then the judgment value must be corrected. The CI value is calculated based on Equation 5.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

where λ_{max} is the maximum eigen value of the pairwise comparison matrix and n is the number of factors.

Flood Hazard Index (FHI) Calculations

The seven factors causing flooding that have been analyzed are presented spatially with a resolution of 8.15 m and each grid is given a score according to local conditions in Jakarta (Table 3). Quantitative factors such as flow accumulation, river network density, and rainfall intensity are classified based on

Table 2. Random index (RI) value used for consistency test (Saaty, 1977)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

the Natural Jenks classification, where this classification is able to divide classes naturally by reducing variations within classes and maximizing variations between classes. While the qualitative factors are classified based on local conditions.

The weight value of the AHP analysis is combined with each grid score from the factors that cause flooding for the FHI calculation by Equation 6.

$$FHI = \sum_{i=1}^{n} r_i \cdot w_i \quad (6)$$

where r_i is the score of the factors in each grid and w_i is the weight of each factor. FHI values are then grouped based on the probability of flooding using the Natural Jenks distribution. According to FHI, there are five hazard classes viz. very high, high, medium, low, and very low.

Sensitivity Analysis and Validation

The FHI method is quite sensitive to the relative scores and weights of the parameters that cause flooding. Therefore, a sensitivity analysis is used to evaluate the impact of each flood-causing factor on the flood hazard model. The sensitivity analysis used is the single-parameter sensitivity approach proposed by (Napolitano and Fabbri, 1996) (Equation 7).

$$W = \frac{P_r \cdot P_w}{V} \cdot 100 \quad (7)$$

where W is the effective weight of each factor causing flooding, P_r is the score of each factor, P_w is the weight value of each factor, and V is the index aggregated value applied. The weight effectivity of each factor causing flooding in the FHI model is a scale of 0-10. In addition, a map of the flood hazard potential in this study was also carried out using the same weight. There are 3 flood hazard maps made, namely maps (1) FHI, (2) FHI-sensitivity (FHIS), and (3) FHI-same weight (FHIW). The three maps will be validated to find out which map best represents the flood hazard in Jakarta. Map validation was carried out by comparing the model output with the historical flood inundation map of Jakarta for the period January 16th, 2013 issued by the National Disaster Mitigation Agency (BNPB). Map accuracy is assessed based on the total area of flood inundation in different hazard classes.

RESULTS AND DISCUSSION

Spatial Analysis of the Causes of Flooding in Jakarta

Flow Accumulation

Flow accumulation is obtained from corrected DEMNAS data and flow directions. The direction of the water flow moves topographically. The flow accumulation map is shown in Figure 2. The results of the analysis show that flow accumulation in the Jakarta area varies from 0-3,605,304 pixels, while the dominance of flow accumulation values is 0-84,831 pixels. In general, flow accumulation in Jakarta tends to be homogeneous due to the flat topography of the area (Ng et al., 2012). The higher of accumulation flow in an area will be directly proportional to the potential for the area to experience flooding (Ikirri et al., 2022; Mahmoud and Gan, 2018). On the other hand, areas with low accumulated flow rates have less potential to experience flooding.

Distance from River

The distance of an area from the river was obtained using the river flow buffer method in Jakarta. Making a buffer follows the Regulation of the Minister of Public Works and Public Housing, namely the river border line in urban areas is at least 15 m from the right and left banks of the riverbed. Then combined with the Jakarta Governor's Regulation which states that the occupancy limit of the river border line is at least 4 m from the river borderline. The distance map from the river is shown in Figure 2. The flood hazard potential is lower in the zone far from the river flow. In contrast, zones close to river flows have a high flood hazard (Kazakis et al., 2015; Kabenge et al., 2017).

River Network Density

The river network is an important factor in influencing the river flow. The river network density shows the characteristics of the drainage system which is represented by the length of the river flow per unit area. The results of the analysis of river network density are shown in Figure 2. The density of river networks in Jakarta is quite varied with a value range of 0-4,273 m/km^2. The river network density of an area in the range of <5,000 m/km^2 indicates that the area has gentle slopes, low rainfall, and permeable bedrock (Huggett, 2011).

Based on the results, it is known that several rivers such as the Mookevart, Krukut, Buaran, Banjir Kanal Barat, and Banjir Kanal Timur have a high river network density. The river network density affects the concentration of runoff, therefore becomes a place for the accumulation of water flows and indicates the possibility of flooding. The higher river network density and the lower of infiltration rate and runoff concentration, thereby increasing the potential of flooding (Kabenge et al., 2017; Falah et al., 2019).

Slope

The slope affects the amount of surface runoff and infiltration. It is because the slope of the surface controls the speed and concentration of the water flow. The higher slope, the water will drain faster (Lei et al., 2021; Ullah and Zhang, 2020).

Otherwise, a low slope can cause puddles by the accumulation of high flows. Poor drainage systems, especially in urban areas, lead to higher standing water and flooding (Dash and Sar, 2020). The slopes' slope in the Jakarta area is shown in Figure 2. The location of Jakarta which is downstream of the river makes the slopes tend to be flat. This shows that Jakarta has a high potential to experience flood events.

Rainfall Intensity

The understanding of rainfall variations according to spatial and time scales is important for flood hazard assessment. The Precipitation Concentration Index (PCI) method is able to identify regional rainfall concentration and variability, so it can be used for research related to flood mitigation (Shi et al., 2015; Zhang et al., 2019). A higher concentration of rainfall is represented by a greater percentage of total annual rainfall, so a high PCI value has more potential to cause flooding than a low PCI value. Rainfall intensity in Jakarta is shown in Figure 2.

The PCI value in Jakarta ranges from 9.91-26. The PCI value has a high concentration pattern in the north then the rainfall concentration decreases as it moves to the south. The highest PCI scores are located in North Jakarta and Central Jakarta. This is because the

Table 3. Class value and scores of each factor causing the flood event

Factor (unit)	Class/Range	Score	Source
Flow accumulation (pixels)	1.668.338 - 3.605.304	10	Defined based on natural jenks in ArcGIS
	664.508 - 1.668.337	8	
	311.047 - 664.507	6	
	84.832 - 311.046	4	
	0 - 84.831	2	
Distance from river (m)	0 - 20	10	Ministry Regulation (PUPR 2015);
	21 - 40	8	Government Regulation (Jakarta 2019)
	41 - 60	6	
	61 - 80	4	
	>80	2	
River network density (m/km^2)	1.323 - 4.273	10	Defined based on natural jenks in ArcGIS
	813 - 1.322	8	
	472 - 812	6	
	187 - 471	4	
	0 - 186	2	
Slope (%)	0 - 0.20	10	Trail *et al.* (2017)
	0.21 - 0.40	8	
	0.41 - 0.80	6	
	0.81 - 1.2	4	
	>1.2	2	
Rainfall intensity (mm)	22.404 - 25.999	10	Defined based on natural jenks in ArcGIS
	20.636 - 22.403	8	
	18.301 - 20.635	6	
	13.568 - 18.300	4	
	9.906 - 13.567	2	
Land use	Water body	10	Kabenge *et al.* (2017)
	Built up areas and bare land	8	
	Shrubs	6	
	Agriculture	4	
	Forest	2	
Geology	Floodplain sediments, alluvial fans, and Banten tuff	8	Listyono *et al.* (2016); Morris and Johnson (1967)
	Coastal bund sediments	6	
	Alluvial	4	

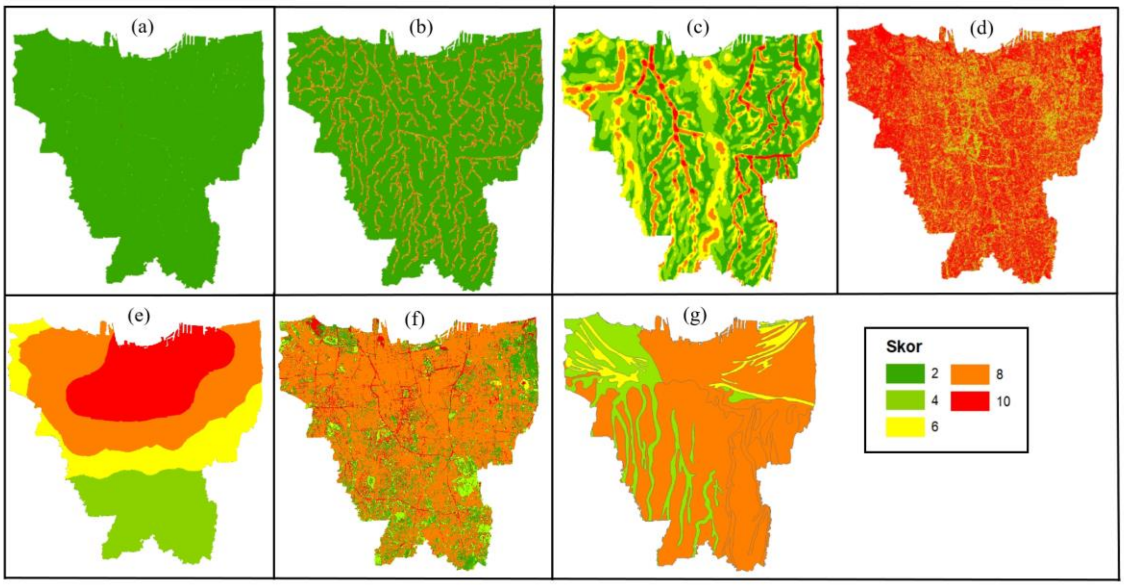

Figure 2. Thematic map of the causes of flooding in Jakarta: (a) flow accumulation, (b) distance from river, (c) river network density, (d) slope, (e) rainfall intensity, (f) land use, and (g) geology.

North Jakarta area is directly adjacent to Jakarta Bay so the water vapor availability is abundant. This causes the total water column to be high so that the frequency of rain also increases (Siswanto et al., 2022). Therefore, the North Jakarta and Central Jakarta areas have a high hazard class for experiencing flooding. In contrast, the lowest PCI values occurred in South Jakarta and East Jakarta.

Previous researchers defined that if the PCI value < 10 indicates low rainfall in the area. PCI values in the range of 11-15 are moderate rainfall, then PCI values of 16-20 represent high rainfall, and PCI values > 20 are very high rainfall (Zhang et al., 2019). Based on this classification, Jakarta belongs to the moderate to very high rainfall class. This indicates that the Jakarta area in general has a high enough potential to experience flooding.

Land Use

Land use influences hydrological processes such as infiltration rates and surface runoff. Lush land use and vegetation increase infiltration, resulting in lower run-off. Meanwhile, built-up land in urban areas and bare land can increase surface runoff, making it more likely to experience flooding (Kazakis et al., 2015). The land use map of Jakarta is shown in Figure 2. The land use map was created based on Landsat 8 imagery acquired on September 11st, 2019. This date was chosen because it indicates the day of the year when satellite imagery has the least cloud cover. Then the guided classification is used to make a land use map in Jakarta. Land use classes are divided into five, namely agriculture, bare land, shrubs, built-up land, and water bodies. The distribution of land use in Jakarta is shown in Table 4.

Table 4. Jakarta land use distribution

Land use	Area (km^2)	Area (%)
Agriculture	124.20	19.3
Bare land	11.20	1.7
Shrubs	43.90	6.8
Built up land	407.08	63.3
Water body	56.44	8.8
Total	642.82	100

Based on Table 4, it is known that built-up land is the largest percentage of land use in Jakarta, reaching ~63% (equivalent to 407 km^2). In contrast, land use with the lowest percentage is bare land, which is 1.7% of Jakarta's area (equivalent to 11.20 km^2). Land use with the second largest area was agriculture (~124.20 km^2) followed by water bodies (~56.44 km^2) and shrubs (~43.90 km^2). The results of the guided classification analysis were tested for accuracy based on overall accuracy and the Kappa value. The results of the accuracy test show that the guided classification has an overall accuracy value of 92% while the Kappa value is 96%. The Kappa accuracy of 0.81-1 has good accuracy (Rwanga and Ndambuki, 2017), therefore land use maps can be used for further analysis

Geology

The geology of an area is an important criterion in determining flood hazard, it is because the geological structure can strengthen or weaken flood events. Permeable geological formations can support the process of water infiltration, whereas impermeable rocks cause surface runoff (Kazakis et al., 2015; Dash and Sar, 2020). The geological analysis of Jakarta is explained in Figure 2. The geological map of Jakarta is grouped into 5 classes, namely alluvial, floodplain sediments, coastal bund sediments, alluvial fans, and Banten tuff.

Floodplain sediments and coastal alluvial sediments are characterized by a brownish gray color. This formation is mostly found in East Jakarta and North Jakarta. Coastal bund sediments are characterized by light brown in color, easily decomposed, and usually contain shell fragments. Coastal bund sediment formations are scattered in parts of North Jakarta, West Jakarta, and East Jakarta. Alluvial formations are river channel sediments, usually brownish gray in color and fine-coarse sand in size. Alluvial is often found in West Jakarta and partly in South Jakarta. While the alluvial fan is volcanic alluvial fan sediment, consisting of tuff and conglomerate. This formation is characterized by reddish brown to blackish brown and is spread over Central Jakarta, East Jakarta, West Jakarta and South Jakarta.

Determination of Weight Based on Analytical Hierarchy Process (AHP)

AHP analysis is used to determine the most influential factors in flooding events of Jakarta. The most influential factor will produce high weight values, otherwise, the less influential factors have low weight values. The determination of weight is based on expert judgment in a pairwise comparison matrix. In this study, there were 6 experts who contributed to providing a weight assessment for the factors that affected Jakarta flooding. Experts provide an assessment using the method of filling out a questionnaire. The results of filling out the questionnaire are then checked for consistency, and after that, the weight values are calculated and validated. Calculation and validation of weight values are done using Super decision software. The recapitulation of the results of the AHP analysis is shown in Table 5.

Table 5. The weight value and ranking of each factor causing flooding in Jakarta

Factor	Weight	Ranking
Flow accumulation	0.84	4
Distance from river	0.73	6
River network density	0.77	5
Slope	1.36	3
Rainfall intensity	3.71	1
Land use	1.94	2
Geology	0.65	7

The results of the AHP analysis in the table above have been validated with the CR value is 0.01357 (<0.1). These conditions indicate that the weight of the AHP value can be used for further analysis. Based on the AHP analysis, it was found that the factor that had the highest influence on flood events in Jakarta was rainfall intensity with a weight of 3.71. Otherwise, the factor that has the lowest influence on flooding is geology with a weighted value of 0.65.

Flood Hazard Index (FHI) Analysis

The combination of the seven parameters (Figure 2) and the weighted value of each factor (Table 5) will produce an FHI map. There are 5 classes in FHI, namely very low, low, medium, high, and very high. The results of the Jakarta FHI analysis are shown in Figure 3a. The dominant flood hazard index is in the high class, which is ~ 166 km^2 (26%), while the least is in the very low class, which is ~ 72.1 km^2 (11%). The hazard indexes in the low, medium, and very high classes are 133.5 km^2, 151.5 km^2, and 133.3 km^2 respectively. The very high flood hazard class consists of the sub-districts of Cilincing, Koja, Tanjung Priok, Pademangan, Tambora, Taman Sari, Kelapa Gading, Pulo Gadung, Grogol Petamburan, Kebon Jeruk, Palmerah, Tanah Abang, Menteng, Senen, Gambir, Kemayoran, Sawah Besar, Johar Baru, and Cempaka Putih. Meanwhile, areas that are classified in the very low flood hazard class are Cipayung, Makasar, Kramatjati, Pasar Rebo, Pasar Minggu, Jagakarsa, Cilandak, and Kebayoran Lama Districts.

FHI-sensitivity (FHIS) and FHI-same weight (FHIW) Analysis

Single-parameter sensitivity analysis was applied to evaluate the factors that most influence the FHI score. The single-parameter analytical method was introduced by Napolitano and Fabbri (1996) to estimate the resistance of aquifers to pollution and since that been used in several related studies, including this study. In the single-parameter analysis, we first calculate the weight of the effective value (W) to obtain the Flood Hazard Index Sensitivity (FHIS). The FHIS index analysis has the same factors and scores as the FHI index, it's just different in the weight values used. The effective value weight used to obtain FHIS is shown in Table 6.

In the FHI analysis, the order of factors that most influence flood events in Jakarta sequentially includes: (i) rainfall intensity, (ii) land use, (iii) slope, (iv) flow accumulation, (v) river network density, (vi) distance from the river, and (vii) geology. However, based on the FHI-sensitivity analysis (FHIS), the factors that affect flooding sequentially are: (i) rainfall intensity, (ii) land use, (iii) slope, (iv) geology, (v) river network density, (vi) distance from the river, and (vii) flow accumulation. The effective weight indicates that there is an overestimation of the flow accumulation weight, an underestimation of geology, and a correct estimation for the factors of rainfall intensity, land use, slope, river network density, and distance from the river.

Table 6. Effective weight statistics for sensitivity analysis

Factor	Min	Max	Mean(μ)	SD(σ)
Flow accumulation	0.18	1.23	0.27	0.48
Distance from river	0.17	1.83	0.32	2.20
River network density	0.17	1.75	0.52	2.66
Slope	0.32	3.26	1.87	4.37
Rainfall intensity	1.41	6.76	4.08	8.07
Land use	0.89	4.18	2.21	5.05
Geology	0.28	1.57	0.74	2.06

In addition to using the effective value weight, this study also uses the same weight value for each factor. This was done as a comparison, therefore the most representative analysis of the FHI index for flood events in Jakarta is known. The FHI index with the same value weight is called the FHIW. The results of the FHIS and FHIW analysis are shown in Figures 3b and 3c.

Visually, the FHIS is similar to the FHI although the weight values used for the analysis are different. In more detail, according to the FHIS index, the dominant hazard class is the high class of ~171.9 km^2 (27%) followed by the moderate hazard class which is an area of ~148.1 km^2 (23%). Meanwhile, the low, very high, and very low hazard classes cover ~128.2 km^2 (20%), ~126.7 km^2 (20%), and ~61.5 km^2 (10%) respectively. Areas included in the high-hazard class are the sub-districts of Kalideres, Penjaringan, Cengkareng, Kembangan, Setia Budi, Tebet, Jatinegara, Pulo Gadung, Kelapa Gading, Cakung and Cilincing. Then for areas that classified into the low hazard class are the southern part of Kebayoran Lama District, Cilandak, Pasar Minggu, Jagakarsa, Pasar Rebo, Ciracas, Cipayung, Kramatjati, Makasar, Pasar Minggu, southern Mampang Prapatan, and a small part of Cakung District.

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FHIW analysis shows that the low hazard class is the dominant class in Jakarta, which is ~274.7 km^2 (43%) followed by the moderate hazard class covering ~183.7 km^2 (29%), and the high hazard class (~84.6 km^2 equivalent to 13%). Meanwhile, the small area is in a very low hazard class (~50.2 km^2 equivalent to 8%) and a very high hazard class of ~43.2 km^2 (7%). The areas belonging to the very low hazard class according to the FHIW index are a small part of the Districts of Cilandak, Pasar Minggu, Jagakarsa, Ciracas, Cipayung, Pancoran, Kembangan, Kalideres, and Cakung. While areas with a very high hazard class are the sub-districts of Cengkareng, Kebon Jeruk, Palmerah, Tambora, Gambir, Tanah Abang, Tebet, Pademangan, Taman Sari, Kemayoran, Tanjung Priok, Koja, and Cilincing.

Flood Hazard Index (FHI), FHI-Sensitivity, and FHI-same Weight Validation

The FHI, FHIS, and FHIW hazard indices were then validated with the Jakarta flood inundation map for the period of 16 January 2013 published by BNPB (Figure 4). Based on the flood inundation map, several sub-districts affected by the flood disaster included Penjaringan, Cengkareng, Grogol, Petamburan, Kebon Jeruk, Kembangan, Pademangan, Sawah Besar, Tanjung Priok, Kelapa Gading, Tebet, Pancoran, Kebayoran Lama, Pesanggrahan, Cilandak, Pasar Minggu, Jagakarsa, Kramatjati, and Makasar. A comparison of flood area with hazard class according to three indices is shown in Table 7.

Table 7. The percentage of flood inundation area according to Flood Hazard Index (FHI), FHI-Sensitivity, and FHI-same Weight

Hazard class	FHI	FHIS	FHIW
	Area (%)	Area (%)	Area (%)
Very low	7	6	7
Low	14	13	41
Medium	25	22	31
High	35	37	14
Very high	19	22	7

Based on Table 7, it is known that the FHIS index has the best ability to represent flooding. This is indicated by the area of flood inundation that occurred in the very high and high hazard classes of 22% and 37%, respectively. While the very high hazard class based on the FHI and FHIW indices is only able to represent as much as 19% and 7%, then the high hazard class according to the FHI and FHIW indices represents flood inundation of 35% and 14%. The low and very low hazard classes are best represented by the FHIS

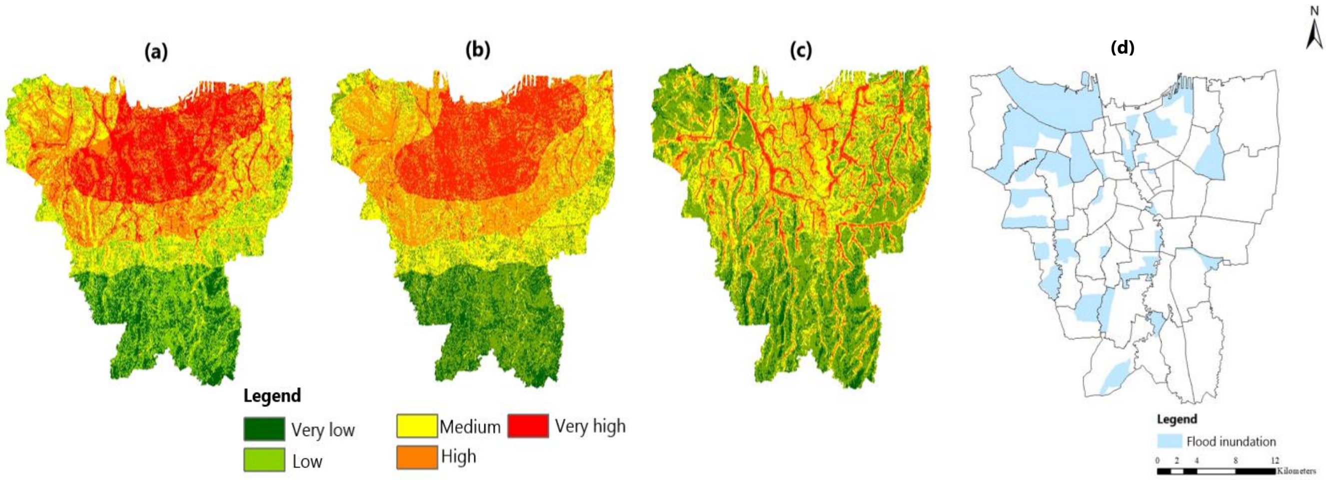

Figure 3. Flood hazard index in Jakarta based on method: (a) flood hazard index (FHI), (b) FHI-Sensitivity, (c) FHI-same Weight, and (d) flood inundation (BNPB 2013)

indices of 13% (1% lower than FHI and 28% lower than FHIW) and 6% (1% lower than FHI and FHIW). Based on this information, the FHIS index is best used for flood hazard analysis in Jakarta. This is in accordance with previous research by Kazakis et al. (2015) and Kabenge et al. (2017) which states that the weight of the results of a single-parameter sensitivity analysis is believed to be more applicable for estimating the potential for flood hazard in an area.

CONCLUSIONS

Jakarta is the capital city of Indonesia which is classified as a metropolitan city. The high population rate coupled with high construction makes Jakarta have many environmental problems, including flooding. Estimation of potential flood hazards can be used as mitigation in dealing with flood disasters. The combination of GIS and AHP methods is used to determine the flood hazard in Jakarta. Determination of scores and weights in making flood hazard maps is a very crucial factor. Sensitivity analysis is used to find the weight of the effective value in flood hazard maps. Validation is used to find the best index for representing flood events. The best index to use is FHIS.

The results of the analysis show that the most influencing factor for flooding in Jakarta is rainfall intensity, followed by land use and slope. The hazard class in Jakarta Province varies from very low to very high hazard class. FHIS values have a pattern of high in the north and low in the south. It indicates that the North Jakarta area has a higher level of hazard than the South Jakarta area. This phenomenon occurs due to the high intensity of rainfall in North Jakarta due to its location close to the Java Sea. In addition, the North Jakarta area is downstream from 13 rivers, so it has a higher potential to experience flooding.

ACKNOWLEDGEMENT

The authors would like to thank the anonymous reviewers for their valuable comments that greatly improved the manuscript.

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