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Flash flood hazard areas assessment in Bandar Negeri Suoh (BNS) region using an index based approaches and analytical hierarchy process

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Abstract. Flash flood led to high levels of water in the urban areas, causing many problems such as bridge collapse, building damage and the victim died. It is impossible to avoid risks of floods or prevent their occurrence, however, it is plausible to work on the reduction of their effects and to reduce the losses which they may cause. The objective of this paper is to generate a flash flood map in Suoh region, using satellite images, UAVs images and GIS tools. Analytical Hierarchical Process is used to determine the relative impact weight of flood causative factors to get a composite Flood Hazard Index (FHI). The causative factors in this study are flow accumulation (F), rainfall intensity (I), geology (G), land use (U), slope (S), and elevation (E). The presented methodology has been applied to an area in Suoh region, where recurring flood events have appeared. Initially, FIGUSE method resulted in an FHI and a corresponding flood map. A sensitivity analysis on the parameter's values revealed some interesting information on the relative importance of each criterion, presented and commented in the discussion section.

1. Introduction

According to Kourgialas, river, flash, urban, sewer, and coastal flooding are the main flooding type that commonly comes in the urban area. In tiny river basins which has the high inclination and poor permeability rocks are prone to be flooding area, particularly region with high-intensity rainfall [1]. Elkhrachy define flash flood as a short and rapid event of a wave with extremely high water discharge. The flash flood may come about only in an hour of rain, and it also induces other disasters such a landslide and mudflow that can draw damage to buildings, bridge collapses, nay fatalities. [2]. The flood waves have very rapid speed and a massive amount of water, and sometimes it causes terrible damages to buildings and trees. These will impact on economic of the area, especially if happening in the concentrated agriculture area [1]. Thus, a comprehensive flood risk management is essential to surmount geographic site and national borders as well as socio-economic limitations. There is two conventional analysis in management of flood risk which are assessment and mitigation of flood risk [3]. Time is the

essential factor in flood risk management, particularly on the employed model, which must be quick to support early warning systems and prevention action [4].

Multi-criteria analysis on GIS for flood risk assessment is atypical method until 2000 [3]. A study of state of the art about determination of multi-criteria decisions in management of flood risk has been described [5]. Tehrany present spatial prediction applying rule-based decision tree (DT) on the Kelantan River Basin [4]. The study on multi-criteria analysis of flood hazard assessment and flood marks, including duration factors and flood depth, are presented by Luu [6]. Danumah argued that GIS is a potent analysis tool for many sources of data integration. Mapping of flood disaster risk is used for various types of city planning and simulates it in many cases [7]. Zerger introduces relative importance in the parameters entered, which emphasizes the importance of correlating spatial analysis for decision making, thereby aiming at the concrete result rather than just solve technical problems [8]. Ten parameters of the relative importance are included in the study by Tehrany, in which each parameter is defined by statistical analysis [4].

Zhang represent a concept of hydrological distribution model for flood calculation based on the model framework. This model applied a method of geomorphological unit hydrograph [9]. Flash Flood hazard zones have been made for the Najran City (Kingdom of Saudi Arabia), using multi-criteria decision analysis of Elkhrachy [2]. Detailed work step of the multi-criteria analysis to estimate flood vulnerability was presented by Brito and Evers [5]. Moreover, Elkhrachy included the distance from river parameters during studying flood hazards in KSA [2].

This article discusses the basics of flood risk management, such as determining flood-prone zone in certain areas. The purpose of this study is to determine flash flood-prone areas that need to be mitigated. Therefore, multi-criteria spatial indexes are applied to define the area. The index was used in the Bandar Negeri Suoh (BNS) region in West Lampung, Indonesia.

2. Material and methods

The research area is the western part of Lampung, consisting of the Suoh Valley prefecture, and encompass a zone of 149.86 km^2. Suoh valley is best at depicting the overstep basin mechanism with an overlap of the side-stepping fault model in Sumatran Fault. Suoh valley expresses an unusual structure since two basins develop at different times [10]. Suoh valley was found as the biggest wrench-fault system in the West Lampung region with 17.8 Km in length and 7.85 km in width with a critical slope angle of 46° [11]. The drainage pattern is well-developed with a channeling form only one single river on the Suoh valley, such a Way Semangka River. The resident is about 23,466 with primary economic activities in agriculture and livestock. Two prefectures are the majority covered by forest and agriculture land. The average land slope of the zone is 24%, whereas the average elevation is 606 m, with the maximum altitude is 1714 m, and the minimum is 213 m. There several rocks and sediments compose the geology of the research area. The highlands area consisted of impermeable rocks, which are volcanic rocks like an andesitic to basaltic lava, tuff, and volcanic breccia. The climate of the city is hot and dry during summer, and harsh and wet during winter. In the last ten years, major flood events came in 2013 and 2016. The previous flood (February 2016) resulted in 35 hectares of farmland being swapped and had a significant impact on the local economy.

2.1 Index of flood hazard

In this research, we have done the aforementioned strategy and up-to-date methodologies. Therefore, the index model was expanded in the GIS platform which aims to determine flash flood zone in the specific region. This model performs a multi-criteria analysis that integrates the Flood Hazard Index (FHI). FHI is used to help identify flood risk hotspots and to enable comparative studies between various basins. To begin, we collect and store GIS information from various data sources. Then, in the next step, the data is processed by the weighting method so that it produces the FHI index. At the last stage, matching flood records for previous years to assess the confidence level of the method.

2.2 Index of flood hazard parameters
There are seven parameters input in FHI, including flow accumulation (F), Intensity of rainfall or precipitation (I), geology (G), land use (U), slope (S), elevation (E), and distance to the river (D). Kazakis (2015) named the methodology as: "FIGUSED". Theoretically, all parameters are chosen based on their relationship to the flash flood disaster. In addition, the parameters chosen have proven to be influential when included in an relevant investigation and application [3][2].

All data is inputted and processed in GIS software, and the seven parameters are then displayed in a one single thematic map. The slope, elevation, and accumulation of flow thematic maps are the result of the elevation spatial data from satellite images and UAVs. The geological information gives insight into geological units such as lithology and geology structure, while land use information results in the relevant thematic map. We can get distance from the rivers by calculating buffer areas along with the drainage network data. By applying a modified Fournier index we can calculate the precipitation intensity from the rainfall measurements [12][13][14][15][16][17].

2.3 The criteria weighting
According to Kazakis et al. (2015), the parameter of morphology, hydrogeology, and socio-economic are essential in FIGUSED method, and the importance of each factor assigns its position in the end product. Therefore, the analysis of spatial from each position on every parameter of the study area needs to be evaluated. The classification of the elevation, accumulation of flow, and rainfall intensity are defined by the grading method of natural breaks, which has done by several studies [3]. The slope classification was determined based on Van Zuidam study [29], while the distance from the drainage network classification has been defined by processing records of historical floods in the research zone. The land use and lithological information qualitatively were classified similarly to previously published regional geology studies and land use maps with some minor modifications [4]. Finally, the acquired values are processed to calculate the relative significance of each criterion and the corresponding weighting factor (w). The FHI is computed using equation 1.

$$FHI = \sum_{i=1}^{n} r_i . w_i = F.w_F + I.w_I + G.w_G + U.w_U + S.w_S + E.w_E + D.w_D \tag{1}$$

where:

r_i = each point parameter rating
w_i = each parameter weighting
n   = the criteria number

2.4 Method of AHP
Analytical Hierarchy Process (AHP) is done after weighting each criteria defined [18][19]. We use a structured technique AHP to analyze complicated problems, where are involving a large number of interconnected criteria. These criteria are ranked based on relative importance to define the weight of the requirements. So, after all of the criteria are sorted hierarchically, to enable a significance comparison, we build a pairwise matrix for each criterion. The relative significance for each criterion is evaluated from 1, which is less critical up to 9 the most important rules. Keep in mind that pairwise comparison and variable hierarchization in AHP acquired from a Delphi consensus that had been used in other indexed approaches, which is subjective [20][21]. Nonetheless, AHP weighting applies in many methods and is recommended for use in regional studies [22][23].

This methodology pairwise is using a 7 x 7 matrice, where element diagonal is equal to 1, and the FIGUSED criteria are sorted in a hierarchical manner (table 1). The score of the row shows the importance of the two variables. The second row shows the importance of intensity of precipitation compared to other criteria that are placed in the columns. For example, precipitation intensity is significantly more essential than geology. Thus, the score is seven. Row describes the weightiness of geology. Therefore, the row is the pairwise comparison inverse values of the variable (e.g., 1/7 for rainfall intensity) for detail information about how the Analytical Hierarchy Process refers to Saaty [19].

Based on the previous study, precipitation intensity is considered as the most critical variable in this method. While the distance from the river and flow accumulation have the same weight because generally, flood happens in the adjacent river area, the third place is land use. However, in this research, the land use parameter is the most prioritize [1]. Rainfall intensity will associate with elevation indirectly with diverse terrains, like the study area. The slope, for some reason, is included in the elevation parameter, which shows it less importance. Geological condition, lithology, and permeability can be main elements for the water runoff and flood. Pairwise comparisons of the significance criteria produce the main eigenvectors from table 1. In the other hand, table 2 shows normalized values of the parameters from table 1, their average, and, eventually, the corresponding weight (w) of each criterion.

Table 1. Food hazard parameters used in AHP.

Parameters	F	I	G	U	S	E	D
F	1.0	1.0	7.0	3.0	5.0	4.0	2.0
I	2.0	1.0	7.0	3.0	5.0	4.0	2.0
G	0.3	0.1	1.0	0.4	0.7	0.6	0.3
U	0.7	0.3	2.3	1.0	1.7	1.3	0.7
S	0.4	0.2	1.4	0.6	1.0	0.8	0.4
E	0.5	0.3	1.8	0.8	1.3	1.0	0.5
D	1.0	0.5	3.5	1.5	2.5	2.0	1.0

Table 2. Food hazard parameters normalization in AHP.

Parameters	F	I	G	U	S	E	D	W_i
F	0.21	0.34	0.34	0.34	0.34	0.34	0.34	0.27
I	0.41	0.34	0.34	0.34	0.34	0.34	0.34	0.30
G	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.04
U	0.14	0.11	0.11	0.11	0.11	0.11	0.11	0.10
S	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.06
E	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.08
D	0.21	0.17	1.14	0.17	0.17	0.17	0.17	0.15

2.5 Consistency ratio analysis.

After determining the eigenvector matrix of AHP, we need to check their consistency. The level of consistency can be assessed using the following equation:

$$CR = \frac{CI}{RI} \tag{2}$$

where:

CR   = ratio of consistency
CI   = index of consistency
RI   = random index

Table 3 shows the tabulation of the values of RI. The acquired values are depending on how many criteria used in this study RI value 1.32 from seven criteria. While AHP's theory suggests, the consistency ratio (CR) must be less than 0.1. Equation (3) is used to calculate CI based on the number of criteria and the comparison matrix with λmax as the maximum eigenvalue.

$$CI = \frac{\lambda\max - n}{n-1} \tag{3}$$

Based on the values of table 2, CI was calculated by: λmax = 7.11, n = 7 and RI = 1.32. Finally, the consistency ratio (CR) value is 0.01. From the calculation of consistency ratio value is less than the threshold (0.1), the weights' consistency is accepted.

Table 3. RI values adjusted with N (amount) of parameter

N	1	2	3	4	5	6	7	8	9
Random Index (RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3. Application-result

In this study, all of the regions has been analysed by considering geological condition including rock permeability qualitatively based on rock type. Thematic maps showed in figure 1 to figure 7 illustrates the spatial distribution of each parameter value by the FIGUSED method in the study area.

3.1 Parameters of FIGUSED

3.1.1 Accumulation of flow. An accumulation flow map is one of the essential parameters in determining flood hazards maps (see table 1). This parameter is the summation of downslope water movement into cells of the output map. The values of accumulated flow show concentrated water flow area and flood hazard probability. Thus the high score shows that the area has lower flood hazards because of its less concentrated water in that area.
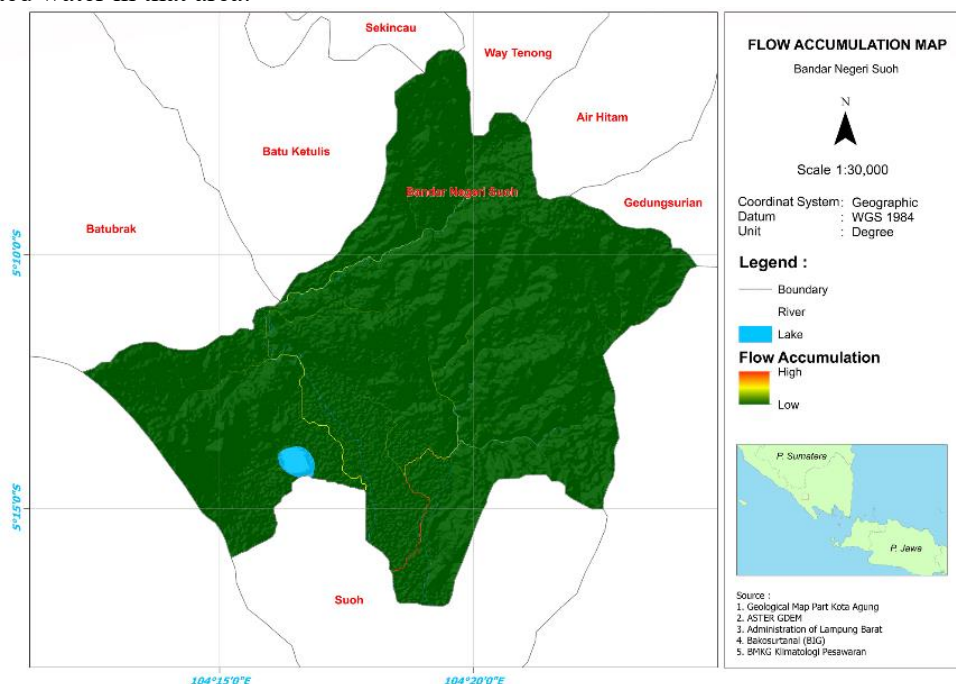

Figure 1. Accumulation of flow map

3.1.2 Intensity of rainfall. Modified Fournier Index (MFI) is stated as rainfall intensity. MFI is the summation of the mean intensity of the precipitation during a month in a particular area. The distribution of the rainfall intensity is accommodated by the placement of points in the zone of interest. Because the stations are relatively sparse set-up, we choose the spline interpolation method, taking into account that a geostatistical approach has a better result than ordinary kriging/co-kriging [24]. MFI values from 20 to 150, with higher intensity, are placed in the north-east part of the BNS region (figure 2).

3.1.3 Geology of study area. The geological condition of the area is a crucial criterion that can aggravate the effect of flood events. An area that consists of high permeability rocks will have better water

infiltration, lowering run-off, and better groundwater flow. Viceversa, Area with impermeable rocks domination, such as volcanic area, leads to a high volume of run-off water. The lower value indicates a lithology of alluvial and alluvial deposits due to their higher infiltration capacity (figure 3).
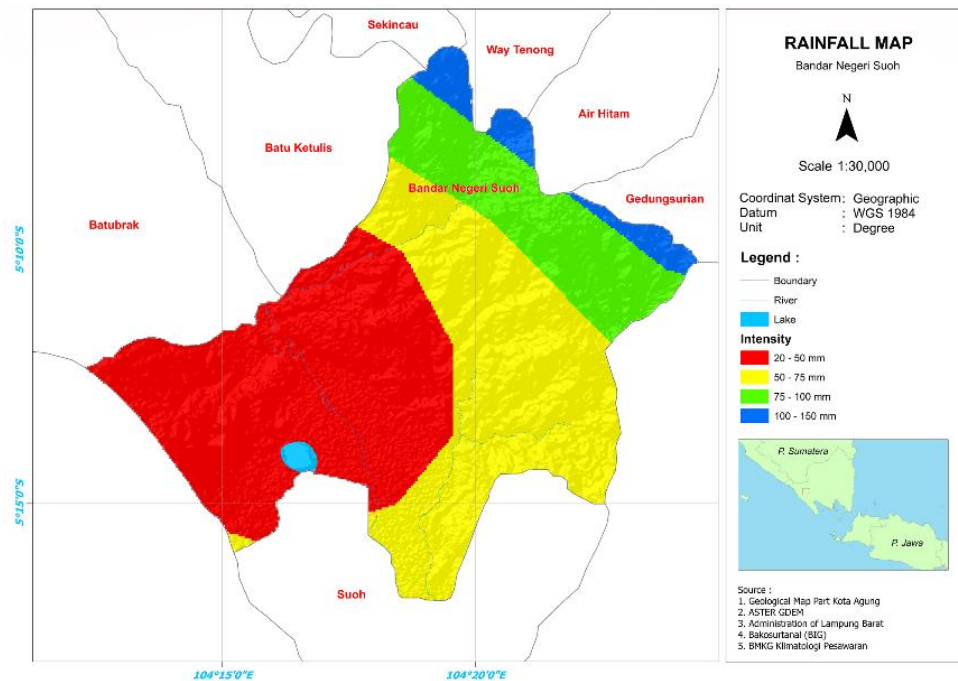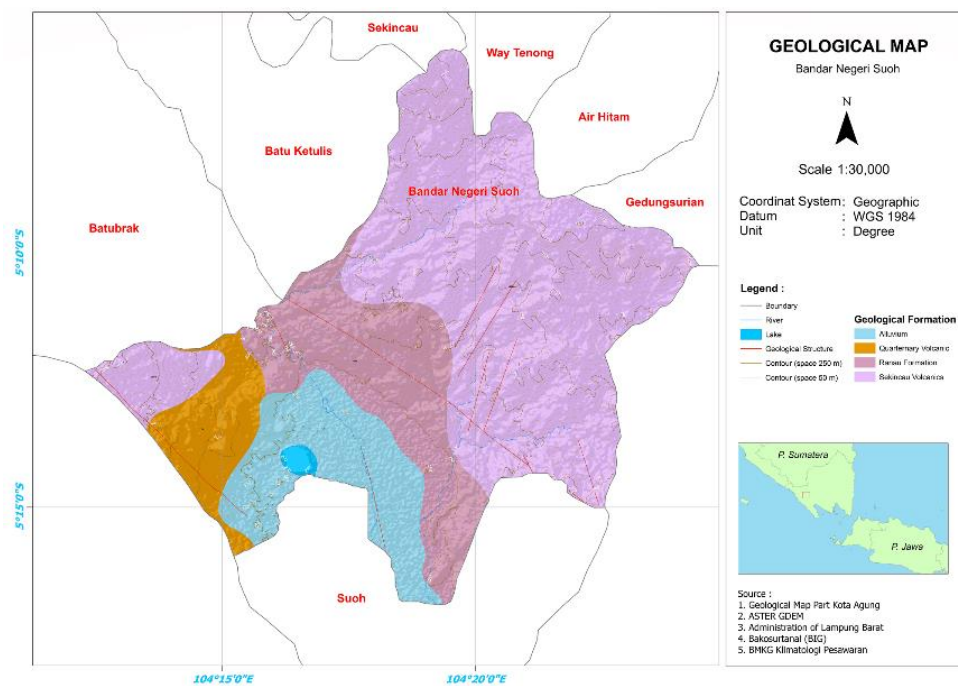

Figure 2. Intensity of rainfall map

Figure 3. Geological map

3.1.4 Land use of study area. Land use will affect the rate of infiltration, showing a correlation between surface condition and subsurface groundwater flow. Based on the early hypothesis, land use is one of

the critical parameters to define flood hazards area. As an example, Forest or lush vegetation will have good infiltration and catch the rainwater in soil, while urban or commercial spaces tend to overland flow of water. Most of the studied area cover-up with forest vegetation and the agricultural regions, which have been assigned values 2 and 4, respectively (figure 4).
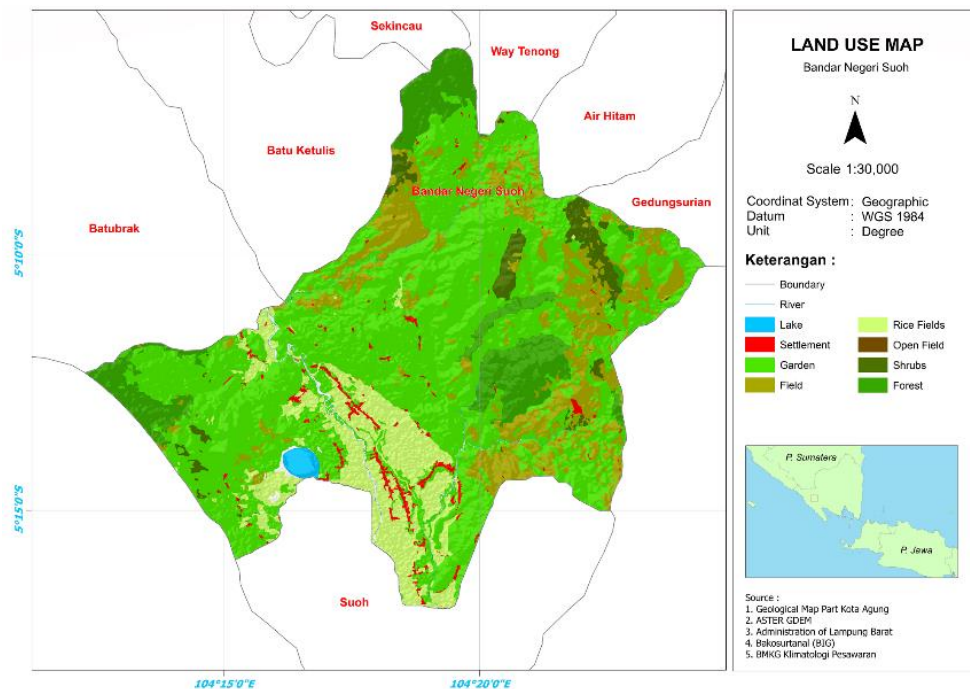

Figure 4. Land use map

3.1.5 Slope and elevation. Water is flowing from high place to the low area, where the flow velocity depends on the slope of the hill. The angle of the slope will affect surface runoff and percolation volume due to the water velocity versus water infiltration. Flat areas at low altitudes shall flood faster compare to the elevated area with abrupt slopes. In the area studied, the western and eastern parts have high-elevations where the slope is also steeper. Absolutely, the sloping lowland area has been given the highest value, as vulnerable areas (figure 5 and figure 6).

3.1.6 River network. Apart from the concentrated surface water area, excess river flow is very important for the initiation of flood events. Often puddles originate from the riverbed and expand around it. The role of the riverbed decreases with increasing distance. That explains why the weight of the river network has been set high in methodology. This class of criteria has been established by looking at historical flood records in the area of interest. It appears that the area not far from the drainage network (<500 m) is very dangerous to flooding, while the effect of this parameter decreases within a distance >1500 m (figure 7).

3.2 Discussion
The flooding risk produces a map (figure 8), the Bandar Negeri Suoh (BNS) can be classified into five levels of risk area, start from very low risk (green color) to very high (red color). Coverage of very low risk, low risk, and medium risk in the BNS area are 23.8%, 22.6%, and 15.9%, respectively. These areas represent high slope, lush vegetation, and agricultural land, as well as less population in this area. The high and very high-risk regions respectively are 22.1% and 15.6% of the BNS area, which covers more
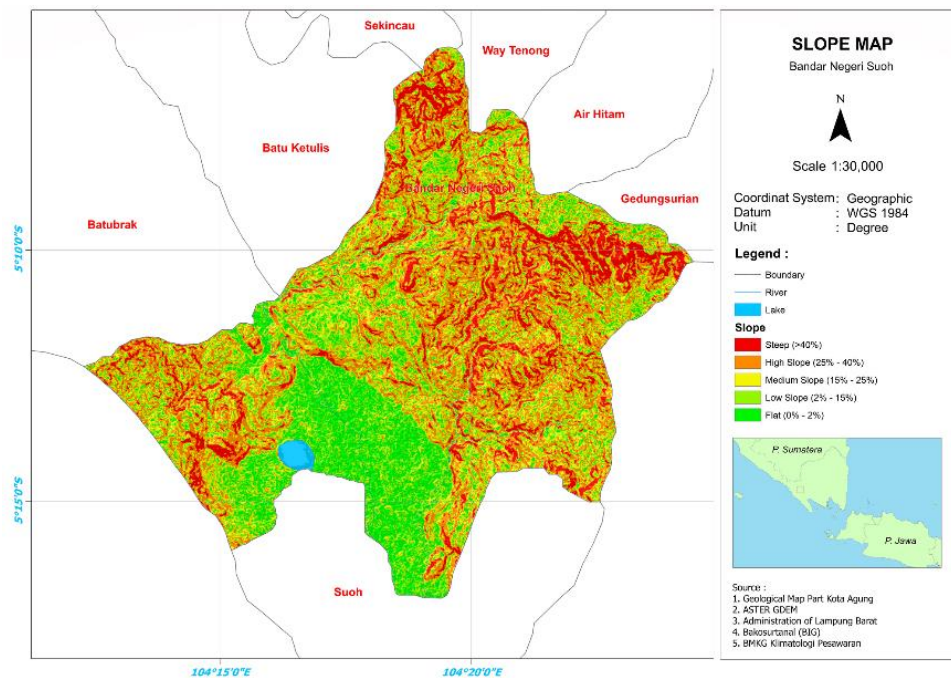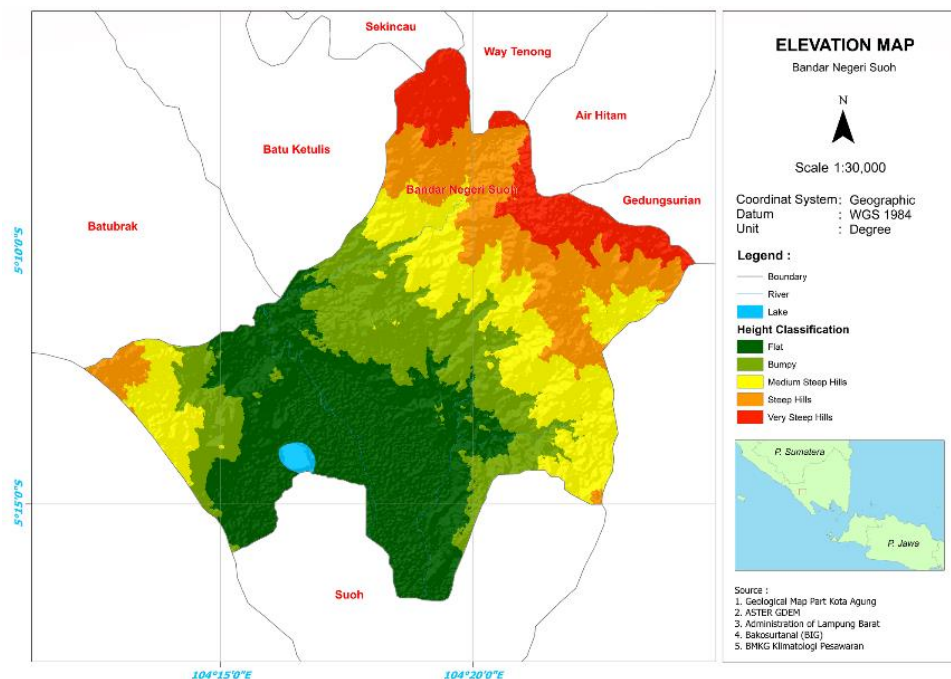
Figure 5. Slope map

Figure 6. Elevation map

than a third of the study area. However, many cities and residential space are included in this flood risk area. Cities that determined as high risk and very high flooding in the BNS area are Bandar Agung, Sri Mulyo, Tri Mekar Jaya, Tanjung Sari, and several regions of the village of Suoh. This map analysis also shows that the type of villages design plays a vital role besides resident density, flat and lowland area, and high rainfall intensity is also risk of flooding at BNS. The risk of flooding may around 53.6% if the study concludes middle, high, and very high classes.
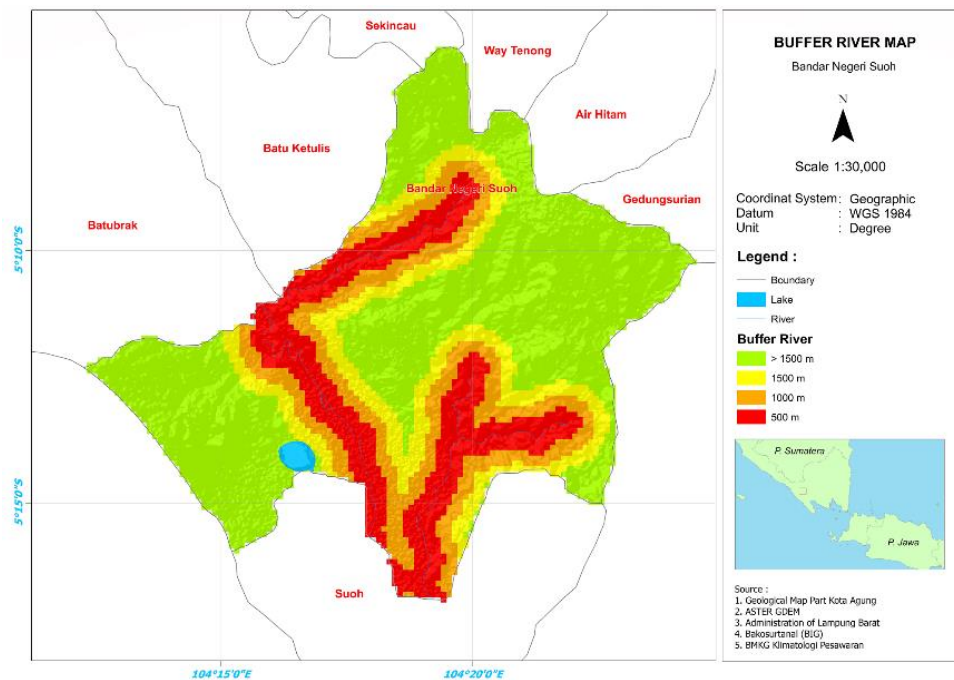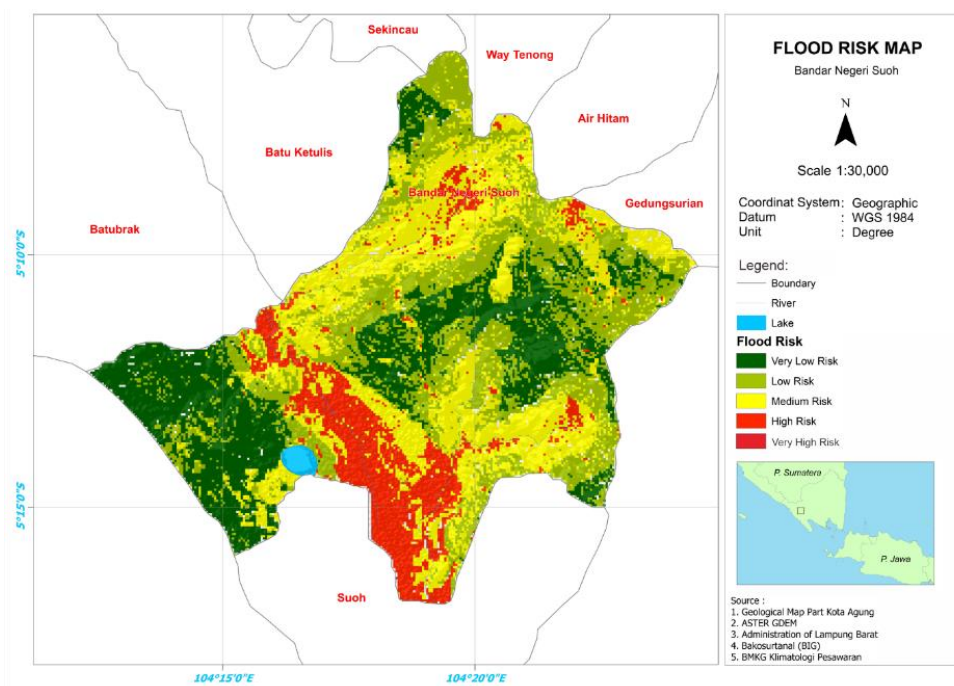
Figure 7. River network map

Figure 8. Flood risk maps with FHI index

The results show that AHP in a GIS environment is an efficient and effective method for assessing and mapping flood risk. The AHP method conveys several failures because this method is very subjective when choosing weight indicator value from random expert judgment [25]. This drawback can be deduced by the assessment of the consistency ratio test. The consistency ratio value should be less than 10% to result in an accurate evaluation [26]. This study does not advise flood risk management

only relying on static visualization produced by index-based approaches. Flooding events can also be influenced by human behavior, especially in urban areas [27]. An elaborate analysis by Birkholz et al. (2014) highlights the need to strengthen flood risk perception study to deliver a more profound understanding of the importance of risk perception impacts on the magnitude, resiliency, and exposure of individuals and society for flooding. [28].

4. Conclusions

This research is successful in applying a methodology of identification flood-prone in various areas by using index-based approaches and analytical hierarchy processes. In flood mitigation research, this kind of study plays an important role providing a road map in determining the best strategy and scenario. FIGUSED method as the index-based methodology is proven in assessing the flood risk map in Bandar Negeri Suoh (BNS) region by inputting the appropriate seven parameters of Flood Hazard Index (FHI). In the analysis, the weight assigned to rainfall intensity parameter is higher than geology condition parameters. Then, the effects of each parameter are combined linearly, and resulting in the numerical superimposition for mapping that indicates high vulnerable zones. The methodology in this research has disclosed several areas in the BNS region that have a high vulnerability flooded. Based on the map, the river terrace and surrounding area are determined as high hazard flooding areas that have been confirmed from the historical flood records in this area.

References

[1]   Kourgialas N N and Karatzas G P 2016 *Environ. Sci. Policy* **63** 132–142
[2]   Elkhrachy I 2015 *Egypt. J. Remote Sens. Sp. Sci.* **18** 261–278
[3]   Kazakis N, Kougias I, and Patsialis T 2015 *Sci. Total Environ.* **538** 555–563
[4]   Tehrany M S, Pradhan B, and Jebur M N 2013 *J. Hydrol*. 504 69–79
[5]   De Brito M and Evers M 2016 *Nat. Hazards Earth Syst. Sci.* **16** 9
[6]   Luu C, Von Meding J, and Kanjanabootra S 2017 *Nat. Hazards* (under review version)
[7]   Danumah J H, Odai S N, Saley B M, Szarzynski J, and Thiel M 2016 *Geoenvironmental Disasters* **3** 13
[8]   Zerger A 2002 *Environ. Model. Softw.* **17** 287–294
[9]   Zhang D, Quan J, Zhang H, Wang F, Wang H, and He X 2015 *Water Sci. Eng.* **8** 195–204
[10] Putra A F and Husein S 2016 *Proc. Seminar Nasional Kebumian Ke-9* p. 19
[11] Aribowo S 2018 .*IOP Conf. Ser. Earth Environ. Sci.* **118** 6
[12] Haq M, Akhtar M, Muhammad S, and Paras S 2012 *Egypt. J. Remote Sens. Sp. Sci.* **15** 135–141
[13] Coveney S 2017 *Int. J. Remote Sens.* **38** 3159-3180
[14] Maurato S, Fernandez P, Pereira L, and Moreira M 2017 *IOP Conf. Ser. Earth Environ. Sci.* **95** 10
[15] Schumann G J P, Muhlhausen J, and Andreadis K M 2019 *Remote Sens.* **11** 12
[16] Villanueva J R E, Martinez L I, and Montiel J I P 2019 *Sensors* **19** 20
[17] Yazid A S M *et al.* 2019 *J. Adv. Manuf. Technol.* **13** 1
[18] Saaty T L 1990 *Manage. Sci.* **36** 10
[19] Saaty T L 1990 *Eur. J. Oper. Res.* **48** 18
[20] Aller L, Bennett T, Lehr J H, Petty R J, Hackett G, and Thornhill J 1987 *DRASTIC : A Standardized System for Evaluating Ground ater Pollution Potential Using Hydrogeologic Settings* (Oklahoma, USA)
[21] Pacheco F A L and Sanches L F 2013 *J. Hydrol.* 476 442–459
[22] Romdani R P, Tamamadin T, Susandi A, Pratama A, and Wijaya A R 2018 *IOP Conf. Ser. Earth Environ. Sci.* **166** p. 8
[23] Dottori F, Salamon P, Bianchi A, Alfieri L, and Hirpa F. A 2016 *Adv. Water Resour.* **94** 87–102
[24] Lloyd C D 2005 *J. Hydrol.* **308** 128–150
[25] Papaioannou G, Vasiliades L, and Loukas A 2015 *Water Resour Manag.* **29** 399–418
[26] Saaty T L and Vargas L G, 2012 *Models, Methods, Concepts & Applications of the Analytic*

    Hierarchy Process Second Edition (London: Springer)

[27] Cherqui F, Belmeziti A, Granger D, Sourdril A, and Le P 2015 *Sci. Total Environ.* **514** 418–425

[28] Birkholz S, Muro M, Jeffrey P, and Smith H M 2014 *Sci. Total Environ.* **478** 12–20

[29] van Zuidam, R A 1983 *Guide To Geomorphological Aerial Photographic Interpretation And Mapping*, ITC (Enschede, the Netherlands)