Flash Flood Hazard Areas Assessment in Bandar Negeri Suoh (BNS) Region using an Index Based Approaches and Analytical Hierarchy Process

RC Wibowo[1], **M Sarkowi**[1], **A F Setiawan**[1], **A Yudamson**[2], **Asrafil**[3], **M Kurniawan**[4], **I Arifianto**[5]

[1] Geophysical Engineering Department, Engineering Faculty, Universitas Lampung, Prof. Soemantri Brodjonegoro Street No.1, Bandar Lampung, Indonesia 35145
[2] Electrical Engineering Department, Engineering Faculty, Universitas Lampung, Prof. Soemantri Brodjonegoro Street No.1, Bandar Lampung, Indonesia 35145
[3] Geological Engineering Department, University of Tadulako, Palu, Indonesia 94148
[4] Physics Department, University of Tadulako, Palu, Indonesia 94148
[5] Geological Engineering Department, Engineering Faculty, Universitas Gadjah Mada, Prof. Grafika Street No.2, Yogyakarta, Indonesia 55281

Corr. Author: rahmat.caturwibowo@eng.unila.ac.id

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 et al. (2016), 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 (2015) 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 flood risk management which are flood risk assessment and mitigation [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].

1.1. The background of literature

Multi-criteria analysis on GIS for flood risk assessment is atypical method until 2000 [3]. A study of state of the art about multi-criteria decision-making in flood risk management has been described Brito and Evers [5]. Tehrany et al. (2013) 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 et al. [6]. Danumah et al. (2016) argued that GIS is a potent analysis tool for many sources of data integration. Flood risk mapping is utilized for various scenarios of urban planning and simulating the consequences of multiple cases [7]. Zerger (2002) introduces relative importance in the input parameter, 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 et al. (2013), in which each parameter is defined by statistical analysis [4].

Zhang et al. (2015) 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 Elkhrachy (2015) [2]. Detailed work step of the multi-criteria analysis to estimate flood vulnerability was presented by Brito and Evers (2016) [5]. Moreover, Elkhrachy (2015) included the distance from river parameters during studying flood hazards in KSA [2].

This article scopes the first element of flood risk management, such as determining flood hazard areas in a particular region. The study aim is to identify flash flood hazard areas that need to mitigate. Therefore, a spatial, multi-criteria index is applied to define such regions. The index was used in the Bandar Negeri Suoh (BNS) region in West Lampung, Indonesia.

2. Material and methods

The study area is the western part of Lampung, comprises the prefectures of Suoh valley, and covers an area 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 pull-apart basin in the West Lampung region with 17.8 Km in length and 7.85 km in width with a critical slope angle of 46^o [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 area 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 mountainous area consisted of impermeable formations, which are volcanic rocks such as 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, an index model is developed in a GIS platform aiming to define flash flood hazard areas in a focus region. The model carries out a multi-criteria analysis integrating a Flood Hazard Index (FHI). The FHI is used to assist flood risk hotspots identification and to allow a comparative study between different basins. To start, we collect and store GIS information from various data sources. Then, the data is processed in a second phase, along with the definition of the parameters weighing, eventually result in the FHI index. In the last stage, we match the historical flood records to verify the accuracy of this methodology.

2.2. Index of flood hazard parameters

There are seven parameters input in FHI, including flow accumulation (F), rainfall intensity (I), geology (G), land use (U), slope (S), elevation (E), and distance to the river (D). Kazakis (2015) named the methodology as: "FIGUSED." Theoretically, the parameters are selected based on their relevancy to flash flood hazards. Moreover, the chosen parameters proved useful when included in relevant research studies and applications [3][2].

Each parameter data input is processed in GIS software, and the seven parameters are visualized in independent thematic maps. The slope, elevation, and flow accumulation thematic maps of are products of the digital elevation model (DEM) 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 zones along with the drainage network data. Then rainfall intensity is calculated from rainfall measurements, using a modified Fournier index [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 final result. Hence, spatial analysis of each grid-point on every parameter of studied areas need to evaluate. The classification of the elevation, flow accumulation, 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 (1983) [29], while the distance from the drainage network classification has been defined by processing records of historical floods in the research area. The land use and geological formation 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 Eq. (1).

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

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 the weight of each parameter is defined [18][19]. We use a structured technique AHP to analyze complex problems, where are involving a large number of interconnected criteria or objectives. 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, weighting by AHP is applicable in many methods and recommended to be used 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 parameters. The second row shows the importance of rainfall intensity compared to other parameters that are placed in the columns. For instance, rainfall intensity is significantly more essential than geology. Thus, the score is seven. Row describes the importance of geology. Therefore, the row has the inverse values of the pairwise comparison (e.g., 1/7 for rainfall intensity) for detail information about how the Analytical Hierarchy Process refers to Saaty (1990a) [19].

Based on previous study, rainfall intensity is considered as the most critical parameter 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. Condition of geology, lithology, and permeability can be critical for the water runoff and the flood occurrence. The pairwise comparison of the criteria significance resulted in the principal eigenvector of Table 1. 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

2.4.1. 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:

$$CR = \frac{CI}{RI} \qquad (2)$$

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. CI is calculated using Equation (3), with λmax as the maximum eigenvalue from the comparison matrix and the number of criteria. RI values are given in specific tables.

$$CI = \frac{\lambda \max - n}{n-1} \qquad (3)$$

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 lower 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, the impermeable geological formations in the western region have also been analyzed. Thematic maps showed in Figure. 1 illustrates the spatial distribution of each parameter value by the FIGUSED method in the study area.

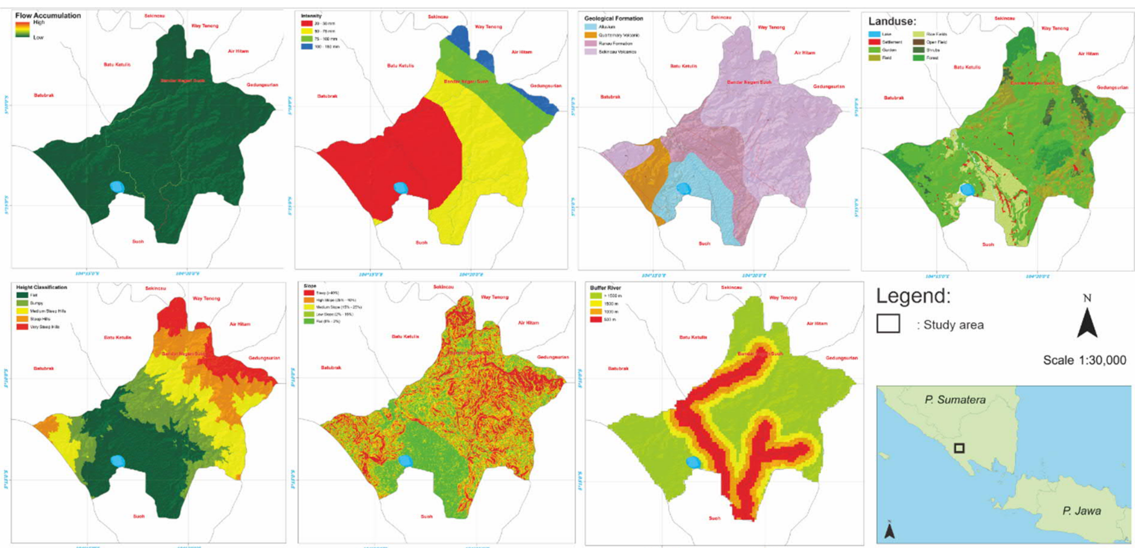

Figure 1. FIGUSED parameters map in BNS region

3.1. Parameters of FIGUSED

3.1.1. Accumulation of flow

Based on the early hypothesis and the values of the parameter in Table 1, flow accumulation is the second important parameter in defining flood hazards. flow accumulation sums the water flowing down-slope into cells of the output raster. High values of accumulated flow indicate areas of concentrated flow and consequently lower flood hazard.

3.1.2. Intensity of rainfall

Modified Fournier Index (MFI) is stated as the rainfall intensity. MFI is the summation of the mean monthly intensity of the rainfall in a particular area. The distribution of the rainfall intensity is accommodated by the placement of stations in the studied area. Because the stations are relatively sparse set-up, we choose the spline interpolation method, taking into account that a geostatistical approach is more appropriate than ordinary kriging/co-kriging [24]. MFI values from 20 to 150, with higher intensity, are located in the north-east part of the study area (Fig. 1).

3.1.3. Geology of study area

The geological condition of the area is a crucial criterion because it may amplify the magnitude of flood events. Permeable formations will have better water infiltration, throughflow, and groundwater flow. On the contrary impermeable rocks, such as igneous rock, lead to surface runoff. The lower value indicates a lithology of alluvial and alluvial deposits due to their higher infiltration capacity.

3.1.4. Land use of study area

Land use influences the infiltration rate, the interrelationship between surface and groundwater. Based on the early hypothesis and the values of Table 1, land use is one of the important parameters to define flood hazards area. Thus, Forest and lush vegetation will have infiltration, urban, and pasture areas support the overland flow of water. A large proportion of the studied area is covered by mixed forests and agricultural areas, which have been assigned rates equal to 2 and 4, respectively (Fig. 1).

3.1.5. Slope and elevation

Flows of water from higher to lower elevations and, therefore, slope affects surface runoff amount and infiltration amount. Flat areas at low altitudes may flood faster than areas at higher altitudes with steeper slopes. In the area studied, the western and eastern parts have high-elevations where the slope is also steeper. Absolutely, the area with lower slope and lower elevation have been given the highest rating, as vulnerable areas (Fig. 1).

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. These criteria classes have been defined by processing historical flood records in the study area. It appears that the area near the river network (<500 m) is very dangerous to flooding, while the effect of this parameter decreases within a distance >1500 m (Fig. 1).

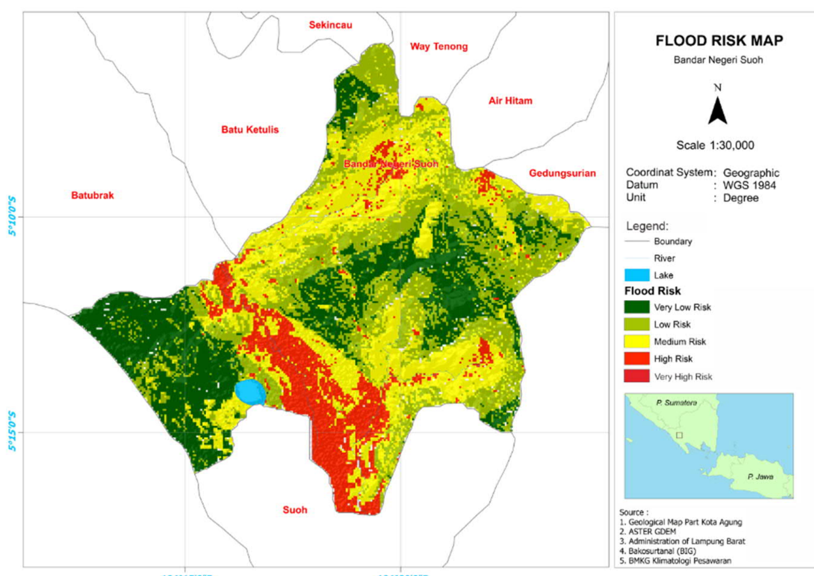

Figure 2. Flood risk maps with FHI index

4. Discussion

The flooding risk produces a map in Figs. 2, defining five levels of risk, ranging from very low to very high. Areas with very low, low, and medium flood risk cover 23.8%, 22.6%, and 15.9% of BNS, respectively. They are not evenly distributed and are characterized by high slope, vegetation, and agricultural land, as well as low population density. High and very high-risk areas cover 22.1% and 15.6%, respectively. Overall areas with high and very high flood risks cover 37.7% of the study area.

Cities identified as being at high risk and very high in flooding in the BNS area are Bandar Agung, Sri Mulyo, Tri Mekar Jaya, Tanjung Sari, and several areas in the village of Suoh. This map analysis also shows that the type of urban structure plays a key role besides population density, flat slope, and heavy rainfall is the risk of flooding at BNS. The risk of flooding is around 53.6% when the study concludes middle, high, and very high classes. The analysis shows that 37.7% of the study area is a flood risk zone, but from the critical analysis, most of the communal areas are high flood risk areas.

The results show that AHP can be used as an efficient method for assessing and mapping flood risk in a GIS environment. The AHP method shows several failures due to subjectivity in choosing the value of indicator weights from arbitrary expert judgment [25]. This weakness is reduced by the assessment of the consistency ratio test. Saaty (2012), provides a consistency ratio threshold that must be lower than 10 % to make a coherent assessment [26]. This study does not suggest that flood risk management only relies on static visualization provided from index-based methods. Although this method seems to be reliable, additional tools are needed. Flooding events can also be influenced by human behaviour, especially in urban areas [27]. A detailed review by Birkholz et al. (2014) highlights the need to strengthen flood risk perception research to convey a more integrated understanding of how risk perception influences the capacity, resilience, and vulnerability of individuals and communities for flooding. [28].

5. Conclusions

The main objective of this research is to develop a methodology that identifies flood-prone zones and can be applied in various regions. It is important for decision making because it creates a road map for necessary flood mitigation measures. An index based methodology has thus been developed, named "FIGUSED" and expressed with an appropriate FHI index. This method spatially analyzes seven parameters, combining the information in the Flood Hazard Index (FHI). The higher the weights assigned to rainfall intensity and the lower to geology. After that, the effects of each criterion are combined linearly and the results of their numerical superimposition for mapping that visualizes very vulnerable zones. The application of the methodology and indices mentioned in the BNS region has revealed areas of danger that will be flooded. Tributaries and torrents are designated as high hazard areas for flooding, and therefore, they may significantly contribute to flooding events in the region. Historical flood records confirm the reliability of the application.

6. References

[1] N. N. Kourgialas and G. P. Karatzas, “A flood risk decision making approach for Mediterranean tree crops using GIS ; climate change effects and flood-tolerant species,” *Environ. Sci. Policy*, vol. 63, pp. 132–142, 2016.

[2] I. Elkhrachy, “Flash Flood Hazard Mapping Using Satellite Images and GIS Tools : A case study of Najran City , Kingdom of Saudi Arabia (KSA),” *Egypt. J. Remote Sens. Sp. Sci.*, vol. 18, no. 2, pp. 261–278, 2015.

[3] N. Kazakis, I. Kougias, and T. Patsialis, “Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process : Application in Rhodope – Evros region , Greece,” *Sci. Total Environ.*, vol. 538, pp. 555–563, 2015.

[4] M. S. Tehrany, B. Pradhan, and M. N. Jebur, “Spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS,” *J. Hydrol.*, vol. 504, pp. 69–79, 2013.

[5] M. De Brito and M. Evers, “Multi-criteria decision-making for flood risk management : a survey of the current state of the art,” *Nat. Hazards Earth Syst. Sci.*, vol. 16, p. 9, 2016.

[6] C. Luu, J. Von Meding, and S. Kanjanabootra, “Assessing flood hazard using flood marks and analytic hierarchy process approach : a case study for the 2013,” *Nat. Hazards*, 2017.

[7] J. H. Danumah, S. N. Odai, B. M. Saley, J. Szarzynski, and M. Thiel, “Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques , (cote d’ivoire),” *Geoenvironmental Disasters*, vol. 3, p. 13, 2016.

[8] A. Zerger, “Examining GIS decision utility for natural hazard risk modelling,” *Environ. Model. Softw.*, vol. 17, pp. 287–294, 2002.

[9] D. Zhang, J. Quan, H. Zhang, F. Wang, H. Wang, and X. He, “Flash flood hazard mapping : A pilot case

study in Xiapu River Basin , China," *Water Sci. Eng.*, vol. 8, no. 3, pp. 195–204, 2015.
[10] A. F. Putra and S. Husein, "Pull-Apart Basins Of Sumatran Fault : Previous Works And Current Perspectives Regional Setting Pull-Apart Basin Along," in *Seminar Nasional Kebumian Ke-9*, 2016, p. 19.
[11] S. Aribowo, "The geometry of pull-apart basins in the southern part of Sumatran strike-slip fault zone," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 118, p. 6, 2018.
[12] M. Haq, M. Akhtar, S. Muhammad, and S. Paras, "Techniques of Remote Sensing and GIS for flood monitoring and damage assessment : A case study of Sindh province , Pakistan," *Egypt. J. Remote Sens. Sp. Sci.*, vol. 15, no. 2, pp. 135–141, 2012.
[13] S. Coveney, "Lightweight UAV Digital Elevation Models and Orthoimagery for environmental applications : data accuracy evaluation and potential for river flood risk modelling .," *Int. J. Remote Sens.*, no. February, 2017.
[14] S. Maurato, P. Fernandez, L. Pereira, and M. Moreira, "Improving a DSM Obtained by Unmanned Aerial Vehicles for Flood Modelling Improving a DSM Obtained by Unmanned Aerial Vehicles for Flood Modelling," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 95, p. 10, 2017.
[15] G. J. P. Schumann, J. Muhlhausen, and K. M. Andreadis, "Rapid Mapping of Small-Scale River-Floodplain Environments Using UAV SfM Supports Classical Theory," *Remote Sens.*, vol. 11, p. 12, 2019.
[16] J. R. E. Villanueva, L. I. Martinez, and J. I. P. Montiel, "DEM Generation from Fixed-Wing UAV Imaging and Flood Estimations," *Sensors*, vol. 19, p. 20, 2019.
[17] A. S. M. Yazid *et al.*, "Terrain Mapping From Unmanned Aerial Introduction," *J. Adv. Manuf. Technol.*, vol. 13, no. 1, 2019.
[18] T. L. Saaty, "An Exposition of The AHP in Reply to The Paper 'Remarks on The Analytic Hierarchy Process,'" *Manage. Sci.*, vol. 36, p. 10, 1990.
[19] T. L. Saaty, "How to make a decision : The Analytic Hierarchy Process," *Eur. J. Oper. Res.*, vol. 48, p. 18, 1990.
[20] L. Aller, T. Bennett, J. H. Lehr, R. J. Petty, G. Hackett, and J. Thornhill, "DRASTIC : A Standardized System for Evaluating Ground ater Pollution Potential Using Hydrogeologic Settings," Oklahoma, 1987.
[21] F. A. L. Pacheco and L. F. Sanches, "The multivariate statistical structure of DRASTIC model," *J. Hydrol.*, vol. 476, pp. 442–459, 2013.
[22] R. P. Romdani, T. Tamamadin, A. Susandi, A. Pratama, and A. R. Wijaya, "Development of Flash Flood Hazard Map in Bima City (NTB) using Analytical Hierarchy Process Development of Flash Flood Hazard Map in Bima City (NTB) using Analytical Hierarchy Process," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 166, p. 8, 2018.
[23] F. Dottori, P. Salamon, A. Bianchi, L. Alfieri, and F. A. Hirpa, "Advances in Water Resources Development and evaluation of a framework for global flood hazard mapping," *Adv. Water Resour.*, vol. 94, pp. 87–102, 2016.
[24] C. D. Lloyd, "Assessing the effect of integrating elevation data into the estimation of monthly precipitation in Great Britain," *J. Hydrol.*, vol. 308, pp. 128–150, 2005.
[25] G. Papaioannou, L. Vasiliades, and A. Loukas, "Multi-Criteria Analysis Framework for Potential Flood Prone Areas Mapping," *Water Resour Manag.*, vol. 29, pp. 399–418, 2015.
[26] T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process Second Edition*, vol. 175. London: Springer, 2012.
[27] F. Cherqui, A. Belmeziti, D. Granger, A. Sourdril, and P. Le, "Assessing urban potential flooding risk and identifying effective risk-reduction measures Science of the Total Environment Assessing urban potential fl ooding risk and identifying effective risk-reduction measures," *Sci. Total Environ.*, vol. 514, no. February, pp. 418–425, 2015.
[28] S. Birkholz, M. Muro, P. Jeffrey, and H. M. Smith, "Science of the Total Environment Rethinking the relationship between fl ood risk perception and fl ood management," *Sci. Total Environ.*, vol. 478, pp. 12–20, 2014.
[29] van Zuidam, R. A., *Guide To Geomorphological Aerial Photographic Interpretation And Mapping*, ITC, Enschede, the Netherlands, 1983.