Geografika Journal (Geografi Lingkungan Lahan Basah)
Vol. 6, No. 2 - December 2025
Geography Study Program, Lambung Mangkurat University
Journal Of Geografika

IMPLEMENTATION OF SPATIAL MULTI-CRITERIA ANALYSIS METHOD FOR FLOOD VULNERABILITY MAPPING IN BANJARMASIN CITY

Wisnu Putra Danarto[1]*, Selamat Riadi[2], Ghinia Anastasia Muhtar[3]
[1] Geography Department, Lambung Mangkurat University, Banjarmasin, Indonesia

*Correspondent Email: wisnu.danarto@ulm.ac.id

Received 2025-05-27 | **Revision** 2025-07-05 | **Accepted** 2025-12-30
Geography Study Program, Lambung Mangkurat University

Abstract: Flooding is the most prevalent type of natural disaster in terms of both frequency and historical impact in Banjarmasin City. A flood risk assessment is imperative as a foundation for various risk reduction activities (in the pre-disaster stage) and mitigation measures (in the post-disaster stage). This study aims to conduct an analysis of flood hazard risk by presenting its spatial distribution throughout Banjarmasin City. The analysis was conducted utilizing the Spatial Multi-Criteria Analysis (SMCA) method, whereby the spatial distribution of flood hazard risk is determined by the factors (criteria) that influence it, with these factors assigned weights according to their influence on the analysis outcomes. The criteria considered for determining the flood hazard risk in Banjarmasin City include land cover, topography, flow density, distance from rivers, and slope gradient. Prior to processing via the geographic information system platform, these criteria undergo a ranking and weighting process facilitated by the spatial-analytical hierarchy process (spatial-AHP). The results of the analysis indicate that land cover is the most significant factor, with a weight of 0.48. Other criteria, including topography, flow density, distance from the river, and slope, were also considered. The spatial analysis and mapping results have produced a flood risk index, with a distribution of very high and high-risk classes that are dominant in the North Banjarmasin, Central Banjarmasin, and West Banjarmasin Districts. In contrast, South Banjarmasin has a dominant high and moderate class, and East Banjarmasin is a district with a relatively lower hazard risk class compared to other districts. Several key factors contribute to this phenomenon. Firstly, the area's topographic features, located below sea level, trap water, especially during extended periods of heavy rainfall. Second, the city of Banjarmasin is located in the downstream area, which is the confluence of several rivers that carry water from upstream, and this situation is exacerbated by heavy rainfall. Thirdly, the presence of closed land cover, defined by dense vegetation and impermeable soil, intensifies the risk of flooding.

Keywords: Spatial AHP; Multi Criteria Analysis; Flood Hazard Risk; Banjarmasin; Mapping

INTRODUCTION

Floods are one of the most common natural disasters in various regions, both urban and rural, especially in developing countries such as Indonesia and Asian countries in general (Tingsanchali, 2012). Floods, as a disaster with a high frequency of occurrence and a wide area of impact, affect various sectors similarly or even more severely than catastrophic disasters like earthquakes or tsunamis (Chen, Hill, and Urbano, 2009). Areas located in river basins are at higher risk of flooding (Setiawan et al., 2022). Banjarmasin City is a large city located near a large river and a complex network of tributaries.

It has an average ground level of-16 cm below sea level (Central Statistics Agency of South Kalimantan Province, 2022). It has a very long history of flooding with high intensity and frequency (BPBD, 2023). Since 2021, more than 633,000 people have been affected, with tens of thousands of homes submerged and 135,656 residents forced to evacuate due to flooding and tidal flooding. Extremely high rainfall triggered the flooding, causing the Barito River and other rivers in South Kalimantan to overflow. The flooding also disrupted infrastructure, including submerged roads and damaged bridges, impacting mobility and economic activity.

Given the history of flood disasters and the geographic and environmental characteristics that contribute to flood hazards in Banjarmasin City, it is essential to conduct a spatial analysis of flood hazards to inform disaster risk reduction efforts and the development of disaster mitigation policies (Setiawan et al., 2022) (Ikhvan & Mera, 2021) (Nugraha, 2018). Flood vulnerability mapping is the initial stage in the series of flood risk reduction and disaster management efforts with the aim of understanding the spatial distribution of flood hazard risks. This study aims to map the spatial distribution of flood hazard risks using a multi-criteria (factor) analysis approach or Multi-Criteria Decision Making (MCDM) technique.

There are several studies on flood disaster vulnerability analysis in Banjarmasin City that use a spatial approach (Fitriansyah, 2016), but research that explicitly compares the geographical and hydrological variables of Banjarmasin City in a ranking model by applying weighting is still limited. In addition, the method of weighting variables/criteria causing flooding in Banjarmasin City is done by considering expert opinion. This procedure is done because Banjarmasin City has geographical characteristics that are not very diverse (slope gradient, river flow density, and land cover) that characterize the downstream areas of the river.

Consequently, this study provides a distinctive contribution by utilizing the Spatial-Analytical Hierarchy Process (Spatial AHP) to implement the Spatial Multi-Criteria Analysis (SMCA) method. The Spatial AHP approach enables the integration of expert and local stakeholder considerations to construct pairwise comparisons, which is essential for ensuring that the weighting of the criteria, including land cover, topography, flow density, distance from rivers, and slope gradient, accurately reflects actual field conditions. The weighting results demonstrate the benefits of this methodology. As a result of this contextual application of spatial AHP, this study generates a more representative and pertinent risk mapping for the vulnerable micro-local conditions of Banjarmasin, thereby establishing a more solid foundation for disaster risk reduction and mitigation policies. The Spatial AHP approach enables the incorporation of local stakeholder and expert considerations to create pairwise comparisons.This procedure is essential to guarantee that the weighting of the criteria, which includes land cover, topography, flow density, distance from rivers, and slope gradient, accurately reflects the actual field conditions. The weighting results demonstrate the advantages of this methodology. This study generates a more representative and pertinent risk mapping for the vulnerable micro-local conditions of Banjarmasin by utilizing spatial AHP in a contextual manner. Consequently, it establishes a more robust foundation for disaster risk reduction and mitigation policies.

LITERATURE REVIEW

According to Watrobski et al., (2019), there is an approach that can be implemented for the analysis, evaluation, and assessment of a phenomenon or problem involving geospatial factors with varying levels of influence of each factor, namely Spatial Multi-Criteria Analysis (SMCA). Watrobski also explained that there are several SMCA methods that have been developed, including Simple Additive Weighting (SAW), Technique for Order by Similarity to Ideal Solution (TOPSIS), Analytical Hierarchal Process (AHP), Simple Multi-Attribute Rating Technique (SMART), Multi-Attribute Utility Theory (MAUT), and others. Each method has advantages and disadvantages, so relevant stakeholders need to choose the one that best suits their needs and the problems they face.

Considering the availability of data and the existence of stakeholders involved in flood management in Banjarmasin City, this study uses the Spatial-Analytical Hierarchy Process (AHP Spatial) method. Spatial AHP inherently provides a powerful framework for structuring multi-criteria decision-making problems into a hierarchical structure, breaking down objectives into criteria (factors) and sub-criteria.

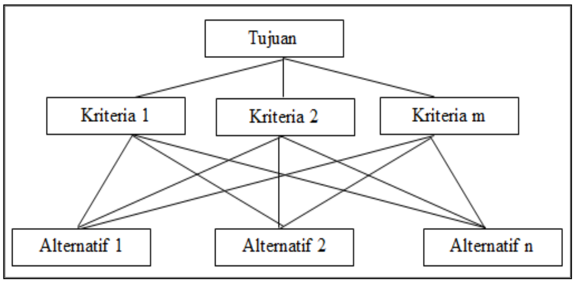


Figure 1. Hierarchical Structure of the AHP Model (Saaty, 1980)

A specific advantage of Spatial AHP in the context of Banjarmasin City is its ability to integrate qualitative and quantitative approaches. This method explicitly involves the opinions of experts, stakeholders, and academics involved in flood mitigation. This involvement ensures that the criteria weighting is not solely based on statistics but also reflects the unique and complex field conditions in Banjarmasin. This integration produces a more representative and contextualized map of the spatial distribution of flood hazard risks for local mitigation policies.

As a concrete example of this advantage, through Spatial AHP, it was found that land cover was the most significant factor with a weight of 0.48. This weighting result validates that, in dense urban areas such as Banjarmasin, the issue of surface runoff due to built-up areas is a major driver of risk, which requires the flexible and contextual weighting approach provided by AHP (Ouma and Tateishi, 2014) (Papaioannou et al., 2015).

Spatial AHP allows the use of multiple criteria (factors) to evaluate the phenomenon under study and represents the spatial distribution and distribution within a defined area. By applying weighting to the factors involved, Spatial AHP can measure the impact of the level of association or similarity between spatial units based on their attribute values (Arthayanti et al., 2017). In flood risk mapping in Banjarmasin City, the alternatives being compared are the factors that determine the level of flood hazard risk. This comparison is carried out to determine the level of influence of each factor on the results of the flood risk assessment. The evaluation then determines the influence value and ranking of these factors in the spatial analysis of flood hazard risk (Setiawan et al., 2022).

RESULTS AND DISCUSSION

Research Location

This research was conducted in Banjarmasin City. Located 20 km from the mouth of the Barito River and bisected by the Martapura River, Banjarmasin appears to be divided into two parts. The land slope is 0.13%, with the geological composition, especially the lower part, dominated by clay with interspersed fine sand and alluvial deposits consisting of soft, grayish-black clay (Central Statistics Agency of South Kalimantan Province, 2022). Banjarmasin City has a tropical climate. Rainfall in Banjarmasin City in 2020 averaged 281.52 mm per month, with the highest rainfall occurring in February 2021, at 532.00 mm.

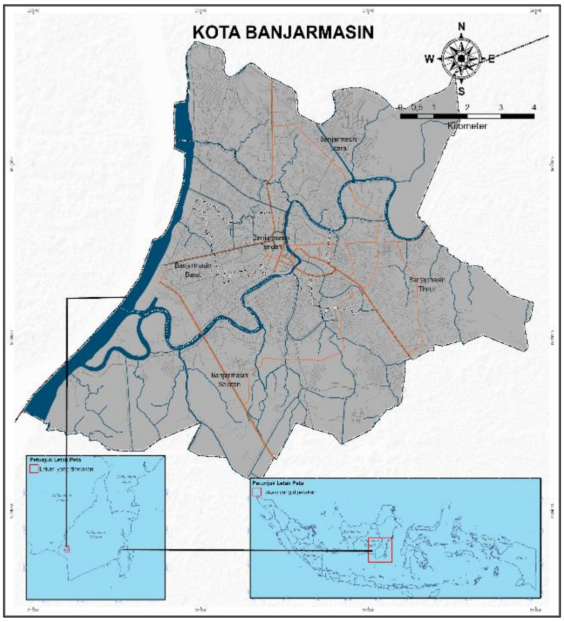


Figure 2. Research Location

Banjarmasin City is traversed by several large rivers, such as the Barito and Martapura Rivers, each with its own tributary network (Central Statistics Agency of South Kalimantan Province, 2022). Given the relatively dense network of rivers and tributaries, the average land surface elevation below sea level, and the predominance of swampy soil types in Banjarmasin City, the area is highly vulnerable to flooding threats. The methodology used in this study is summarized in the diagram in Figure 3. This study aims to determine the spatial distribution of flood hazard risk by utilizing spatial data as a determinant of hazard risk (Forte et al., 2006).

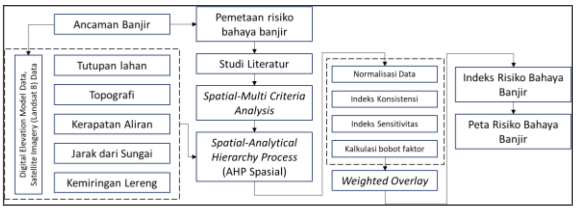
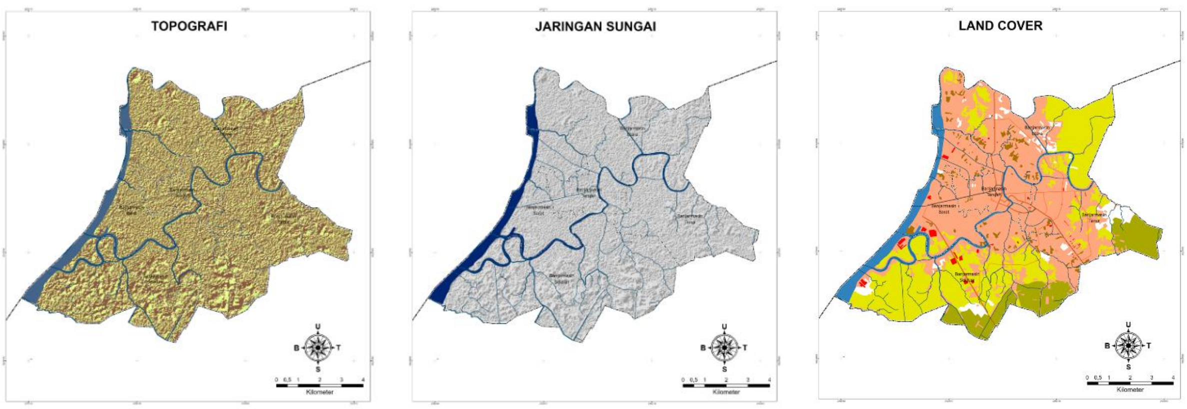


Figure 3. Research Flowchart

The basic data processed and used are SRTM (Shuttle Radar Topography Mission) raster data, river network vector data, and land cover data (Stroppiana et al., 2010). For this reason, this study also calculates the Flood Hazard Risk Index (FHRI) using SMCA analysis with the Spatial AHP approach (Drobne & Lisec, 2009) (Generino et al., 2014).

Selection of Determining Factors of Flood Vulnerability

The determining factors involved in mapping flood hazard risks in Banjarmasin City are determined based on literature studies from scientific journals, books, and disaster data collection document reports, as well as the results of discussions with experts, stakeholders, and academics in the field of disaster risk management and reduction. The factors considered in determining flood hazard risks are (1) topographic variations (topography); (2) river network flow density (drainage density); (3) distance from the river flow (river proximity); (4) type of land cover (land cover); and (5) slope (slope). These factors are generated from topographic spatial data (DEM), river networks, and land cover as presented in Figure 4.



(a) **(b)** **(c)**

Figure. 4 Topographic Map (a); River Network Map (b); and (c) Land Cover Map

The data used for each flood risk determinant factor was obtained from (1) Digital Elevated Model (DEM) Shuttle Radar Topography Mission (SRTM) with a resolution of 30 m/pixel to create a Topographic Map and Slope Gradient obtained from earthexplorer.usgs.gov (accessed February 2024); (2) River flow network vector data from the Geospatial Information Agency (BIG) to create a map of river network flow density and river flow distance (accessed March 2024); and (3) Land Cover Data for 2022 from the Ministry of Environment and Forestry (accessed March 2024). Furthermore, the basic data obtained was processed into data on flood risk determinants.

Pairwise Comparison-Based Factor Weighting

The initial stage in the AHP technique is to identify the phenomenon or problem to be analyzed, then compile a pairwise comparison matrix, as explained by Karagöz & Yaralioğlu (2018).

At this stage, a pairwise comparison matrix with n dimensions for the factors influencing the decision is prepared. This process uses the importance scale introduced by Saaty (1980), which is shown in Table 1. Each factor is rated with a number between 1 and 9, according to its level of importance relative to other factors. A value of 1 indicates that both factors have the same level of significance, while a value of 9 indicates that the factor in the row is much more important than the factor in the column (Saaty, 1980). The comparison of the importance scale levels was collected from interviews with established experts, stakeholders, and academics.

Table 1. Inter-Factor Rating Scale

Score	Scale of importance
1	Equally important
2	Less important
3	Quite important
4	Enough is more important
5	The importance is high
6	The importance is higher

Score	Scale of importance
7	Very important
8	Very very important
9	The most important

Source: (Saaty, 1980)

After the pairwise comparison matrix is generated, it is necessary to calculate the consistency ratio (CR) to assess the level of consistency in the comparison between factors. A CR value exceeding 0.1 indicates potential inconsistency in the assessment, while a value of 0 indicates absolute consistency (Elkhrachy, 2015). The consistency ratio (CR) is calculated by dividing the consistency index by the random inconsistency index, as illustrated in Equation (1). The RI value depends on the number of criteria involved (Kazakis et al., 2015).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} < 0{,}1$$

where CI is the Consistency Index, and RI is the Random Inconsistency Index

$$\mathrm{CI} = \frac{\lambda - n}{n - 1}$$

In this context, n represents the number of factors, and the average value refers to the consistency vector $\lambda - \mathrm{n}$

Next, each factor is divided into several classes, with weights assigned to each class. The maximum and minimum weights assigned to each class's factor range from 1 to 10. Next, the weights of the various classes of each criterion are calculated, along with the normalized weights.

Mapping and Spatial Analysis of Flood Hazard Risk

Spatial analysis is conducted by overlaying digital maps of each classified factor and adding weights to each factor. The results of this spatial analysis will be used to generate zoning for areas at risk of flooding. The flood hazard will then be classified based on its severity.

The weight value per class reflects the degree of influence each class has on the flood risk value and its spatial distribution. After going through a series of weighting stages for each factor, the next step is to calculate the final score by multiplying the weight of each factor by the previously classified parameter value.

The result of multiplying the weight of each factor by the classification value within that factor is then used to calculate the hazard risk value (FHR = Flood Hazard Index) based on the factors involved by adding them up using the formula:

$$\begin{aligned}\mathrm{FHR} = (\mathrm{W_{ele}}.\mathrm{R_{ele}}) + (\mathrm{W_{slo}}.\mathrm{R_{slo}}) \\ + (\mathrm{W_{dens}}.\mathrm{R_{dens}}) \\ + (\mathrm{W_{prox}}.\mathrm{R_{prox}}) \\ + (\mathrm{W_{LC}}.\mathrm{R_{LC}})\end{aligned}$$

where W is the weight value per factor, and R is the sum of the class score values per factor.

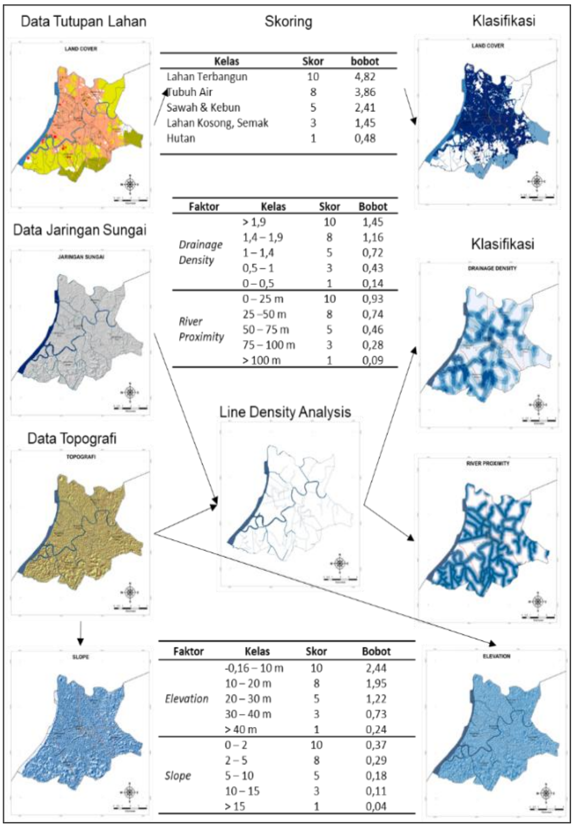


Figure 5. Deep spatial data processing for flood hazard risk factor classification

The FHR is automatically represented in a thematic spatial distribution map (Arissaldi et al., 2023) within the Banjarmasin City analysis unit. To generate this map, the weighted overlay method used in GIS software is used. The spatial data processing and execution process in GIS software is illustrated in the work process framework schematic in Figure 4.

RESULTS AND DISCUSSION

Weighting and Scoring of Flood-Determining Factors Classification

The collected pairwise comparison data from informants was then input into a factor comparison matrix containing all involved factors along with the calculated comparison scores and their normalization. In Table 2, the factors are arranged hierarchically, indicating the relative importance of each factor. The top row represents land cover, which can be interpreted as emphasizing that land cover (LC) plays a critical role in flood risk in a location, compared to other parameters mentioned in the following columns.

As an illustration, LC is considered much more important than topography (Ele), as evidenced by the value of 9. The LC factor has a high priority value because flood-prone areas are usually located in areas with high land cover density (residential or central business areas). The assigned weights are normalized using the AHP method, which is then used as input in further spatial data processing in the GIS platform to create a flood hazard risk map (Hammami et. al., 2019).

Table 2. Pairwise Comparison Matrix Between Factors

Factor	Land Cover	Elevation	Drainage Density	River Proximity	Slope	Σ
LC	1	2.40	4.80	6.00	8.00	22.20
Ele	0.42	1	2.00	4.00	6.00	13.42
Dens	0.21	0.50	1	3.00	4.00	8.21
Prox	0.17	0.25	0.33	1	5.00	6.75
Slo	0.13	0.14	0.25	0.20	1	1.72
Σ	1.92	3.79	8.38	14.20	24.00	52.29

LC = Land Cover, Ele = Elevation, Dens = Drainage Density, Prox = River Proximity, Slo = Slope

The Pairwise Comparison Matrix between factors (Table 2) reflects the relative importance of each factor relative to the others based on input from experts, stakeholders, and academics. For example, a value of 9 given to the comparison between Land Cover (LC) and Topography (Ele) confirms that LC is considered the most important in determining flood hazard risk compared to Ele in Banjarmasin City, according to the Saaty scale. A value of 1/9 (not visible in the source excerpt) will then be applied to the reverse comparison (e.g., Ele compared to LC). Once all pairwise comparison values (Table 2) are filled in, the next step is to calculate the factor weights through a normalization process to produce the Normalization Matrix (Table 3).

Table 3. Normalization Matrix of Pairwise Comparisons Between Factors

Factor	Land Cover	Elevation	Drainage Density	River Proximity	Slope	Σ	Weight
LC	0.52	0.56	0.57	0.42	0.33	2.41	0.48
Ele	0.22	0.23	0.24	0.28	0.25	1.22	0.24
Dens	0.11	0.12	0.12	0.21	0.17	0.72	0.14
Prox	0.09	0.06	0.04	0.07	0.21	0.46	0.09
Slo	0.07	0.03	0.03	0.01	0.04	0.18	0.04

LC = Land Cover, Ele = Elevation, Dens = Drainage Density, Prox = River Proximity, Slo = Slope

The results of the AHP process show that Land Cover (LC) has the highest priority vector (weight) of 0.48, which consistently proves that in dense urban areas (43.5% is built-up land) and lowlands such as Banjarmasin, Land Cover is the most dominant determinant of flood risk. After the factor weights are obtained (LC = 0.48; Ele = 0.24; Dens = 0.14; Prox = 0.09; Slo = 0.04). Pairwise comparisons are presented in Table 2, using a 6 × 6 matrix with diagonal elements equal to 1. The first row of the table shows the importance of land cover compared to other factors in the matrix. The research location analyzed is an urban area, so land cover has a dominant influence on flood risk compared to other factors. Land cover is considered significantly more important than topography, so it is given a weight of 9. Meanwhile, river flow density and distance from the river are considered less important than land cover. However, these two factors are considered more important than slope gradient. Nevertheless, all of these are the main factors considered in this study.

After obtaining the weight values for all factors listed in Table 3, the next step is to calculate the matrix that compares the weight assessment results with the class scores for each factor in order to determine the weights for each class.

Table 4. Classification and Scoring of Parameters for Each Factor

Factor	Factor Weight	Class	Score	Score. Weight
Land Cover	0.48	Built-up Land	10	4.82
		Water Body	8	3.86
		Rice Fields & Gardens	5	2.41
		Vacant Land & Bushes	3	1.45
		Forest	1	0.48
Elevation	0.24	-0.16 – 10 m	10	2.44
		10 – 20 m	8	1.95
		20 – 30 m	5	1.22
		30 – 40 m	3	0.73
		> 40 m	1	0.24
Drainage Density	0.14	> 1.9	10	1.45
		1.4 – 1.9	8	1.16
		1 – 1.4	5	0.72
		0.5 – 1	3	0.43
		0 – 0.5	1	0.14
River Proximity	0.09	0 – 25 m	10	0.93
		25 –50 m	8	0.74
		50 – 75 m	5	0.46
		75 – 100 m	3	0.28
		> 100 m	1	0.09
Slope	0.04	0 – 2	10	0.37
		2 – 5	8	0.29
		5 – 10	5	0.18
		10 – 15	3	0.11
		> 15	1	0.04

Adaptation and modification scoring value intervals from Hamammi et. al., (2019)

Once the factor weights and final (weighted) scores for each class for each factor are known, the next process is consistency testing, with the following stages:

1) Calculation of matrix multiplication between factor weights and pairwise comparison scores between factors:

$$0{,}48\begin{bmatrix}1\\0{,}42\\0{,}21\\0{,}17\\0{,}13\end{bmatrix}+0{,}24\begin{bmatrix}2{,}40\\1\\0{,}50\\0{,}25\\0{,}14\end{bmatrix}+$$

$$0{,}14\begin{bmatrix}4{,}8\\2\\1\\0{,}33\\0{,}25\end{bmatrix}+0{,}09\begin{bmatrix}6\\4\\3\\1\\0{,}20\end{bmatrix}+$$

$$0{,}04\begin{bmatrix}8\\6\\4\\5\\1\end{bmatrix}=\begin{bmatrix}2{,}61\\1{,}32\\0{,}79\\0{,}46\\0{,}18\end{bmatrix}$$

2) Division of the results of matrix multiplication by the weight of each factor:

$$\frac{2{,}61}{0{,}48}+\frac{1{,}32}{0{,}24}+\frac{0{,}79}{0{,}14}+\frac{0{,}46}{0{,}09}+\frac{0{,}18}{0{,}04}$$
$$=26{,}4$$

3) Calculation of valueλmax:

$$\lambda\text{max}=\frac{26{,}4}{5}=5{,}28$$

4) Calculation of consistency index (CI) value

$$CI = \frac{\lambda max - n}{n - 1} = \frac{5{,}28 - 5}{5 - 1} = 0{,}07$$

5) Calculation of consistency ratio (CR) value

$$CR = \frac{CI}{RI} < 0{,}1 = \frac{0{,}07}{1{,}12} = 0{,}06$$

Table 5. Random Inconsistency Value RI (Random Inconsistency)

Number of Factors:	3	4	5	6	7
RI:	0.58	0.9	1.12	1.24	1.32

Source: Saaty (1980)

Consistency testing (CR) was conducted to ensure that expert assessments were logical and reliable. The λ max calculation yielded a value of 5.28, which was then used to calculate the Consistency Index (CI) of 0.07. The resulting Consistency Ratio (CR) was 0.06. Because the CR value (0.06) is less than 0.1, the factor weightings are considered consistent, and the resulting weights can be used in spatial analysis.

Mapping of Each Factor Based on Classification and Weighting

The classification performed in Table 3 was then used as a reference value for the weight of each factor in spatial data processing in ArcGIS spatial data processing software. The classification divided each factor into five classes with score intervals that had been normalized to the respective factor weights. The results of the spatial data processing are shown in Figure 5.

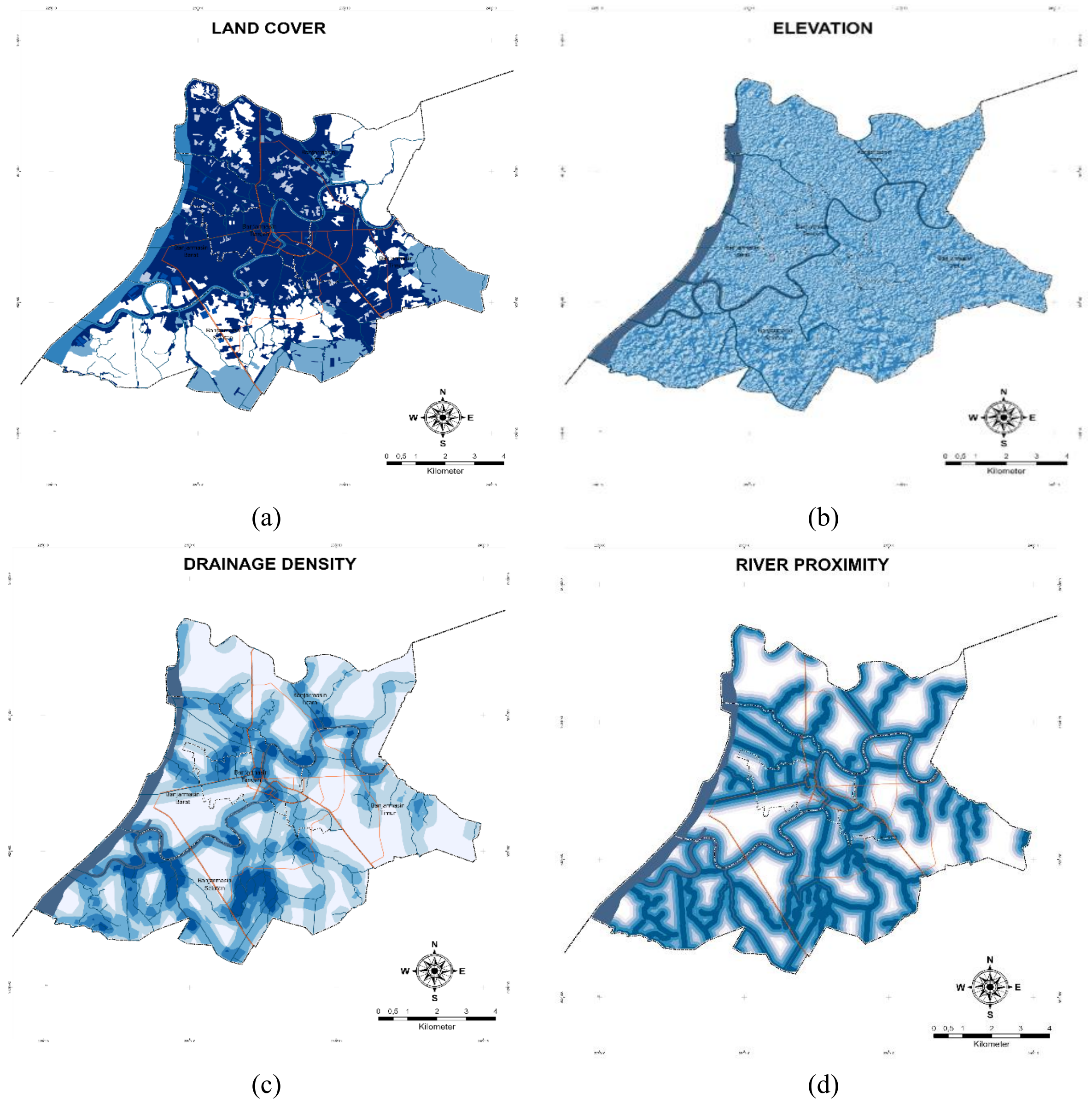


Figure 5. Classification and scoring maps for each factor; LC (a); Ele (b); Dens (c); Prox (d); Slope (e)

The classifications in Table 4 were then used as reference values for the weights of each factor in spatial data processing using ArcGIS spatial data processing software. The results of this spatial data processing, which displays a classification map and scores for each factor, are shown in Figure 5 (ae). In general, the spatial distribution shows a mutually reinforcing pattern in the northern and central regions of Banjarmasin City.

1) Land Cover

Land use and land cover are key factors in determining flood risk in a region (Nuissl et al., 2009), particularly in urban areas. The dominant land cover type, with built-up land and a surface covered by buildings, makes land cover a key determinant of flood risk in urban areas. Covered land surfaces prevent rainwater from infiltrating the soil as it does with non-built-up land. This results in rainwater tending to become almost entirely runoff (Rotzoll & Fletcher, 2013). High runoff contributes to erosion of drainage channels, which can ultimately lead to infrastructure damage and higher maintenance expenses. In the long term, increased runoff can reduce the capacity of urban drainage systems, exacerbating the impact of flooding during heavy rainfall (Rotzoll & Fletcher, 2013).

On the land cover map of Banjarmasin City, the area of land cover classified as having a high risk factor for flooding, namely built-up land in the form of settlements or other buildings, reaches 43.5% of the total area of Banjarmasin City. The spatial distribution of built-up land shows dominance in North Banjarmasin District, which covers 64.4%, and Central Banjarmasin District, at 52.32%. This condition is in line with the historical data of flood events listed in Table 1, where most flood events occurred in these two districts. Dominant factors include high residential density, minimal infiltration areas, and relatively low topography compared to other areas in the city.

2) Topography (Elevation)

A region's topography has a strong correlation with its vulnerability to flooding. Areas with low elevations are more susceptible to flooding because gravity tends to direct water flow to lower areas (Marfai et al., 2008). Furthermore, elevation also affects flood depth and flow velocity, which in turn can exacerbate the impact of flooding. According to a 2022 release from the Central Statistics Agency of South Kalimantan Province, almost all of Banjarmasin is lowland with an average elevation of approximately 0.16 meters below sea level. The variation in topographic classes on the map shows that areas with lower topography are more prone to flooding than areas with higher topography. This indicates a positive correlation: the lower the topography, the higher the risk of flooding.

3) River Flow Density (Drainage Density)

Flow density is calculated using the Line Density function (Yamei et. al., 2011) in Spatial Analyst Tools with ArcGIS software; line density is calculated from the total length of river flow line data per sq km. The results of the flow density assessment show that in general the Banjarmasin City area has a high river flow density, because in addition to the presence of several large rivers (Barito River, Martapura River, Alalak River, etc.) there are many tributaries around these large rivers. The high river flow density in Central and South Banjarmasin Districts is an indication that these districts are at risk of facing a higher flood hazard than other districts.

4) Distance from River (River Proximity)

River proximity is the distance of a specific point or area from the nearest river. Distance from a river is a crucial factor in determining flood risk in areas where flooding is most often caused by outbursts, such as Banjarmasin City. Overall, river proximity across all areas in Banjarmasin City falls into the highest and second-highest classifications, indicating high river flow density and population density in the city.

5) Slope Gradient

Slope gradient is another important factor in determining an area's flood risk (Youssef et al., 2011). Areas with low slope gradients have a higher flood risk because they are more easily inundated. Conversely, areas with high slope gradients have a lower flood risk because water can quickly flow to lower areas (Chen et al., 2015).

Therefore, slope gradient plays an important role in determining the amount of surface runoff and infiltration rate. As a lowland area and a floodplain for several rivers in the Barito Watershed (Banjarmasin City Government, 2020), Banjarmasin City has a low slope gradient that tends to be uniform due to its minimal topographic variation. Based on the results of flood hazard mapping (Figure 6), it can be seen that almost all areas of Banjarmasin City are dominated by the high-to very-high-risk class. This even spatial distribution indicates that flooding is a regional problem, not just a local one. The basic concept in flood hazard mapping is that the risk is a function of physical and geographic factors, including land cover, topography, flow density, distance from rivers, and slope gradient. Through the application of Spatial-AHP, this study aims to examine the relative influence of these factors in the unique geographic context of Banjarmasin.

The analysis results show that land cover is the most significant factor, with a weight of 0.48. This finding strongly reinforces the concept in urban hydrology that in densely populated areas, the condition of the covered land surface (built-up land) is a major determinant of flood risk. In Banjarmasin City, built-up land covers 43.5% of the total area. This dominance of covered land results in very high surface runoff and minimizes infiltration, which ultimately becomes the main driver of high risk in the districts of North Banjarmasin, Central Banjarmasin, and West Banjarmasin areas that also have the highest built-up land density.

DISCUSSION

Based on the mapping results in Figure 4, almost all subdistricts in Banjarmasin City have a low to very high risk of flooding. This fairly even spatial distribution indicates that flooding is not just a localized problem in a small area but a problem throughout Banjarmasin City. Based on literature studies of historical flood data, the cause of recent flooding is river overflows that cannot accommodate rising water levels, particularly during periods of high rainfall intensity over a prolonged period. This research provides a significant contribution and broadens the understanding of the application of Spatial Multi-Criteria Analysis (SMCA) with the Spatial-Analytical Hierarchy Process (AHP Spatial) method in a very specific geographic context: lowland urban areas located below sea level.

Validity of AHP in Complex Urban Context: The findings strongly confirm the effectiveness of AHP as a tool for modeling flood hazard risk in complex urban environments. Although physical factors (topography, slope) are traditionally considered crucial, through AHP weighting involving experts, it is evident that land cover (LC) factor emerges as the most dominant determinant of spatial risk with a weight of 0.48. This highlights that in low-lying and densely populated areas (43.5% built-up land) such as Banjarmasin, hydrological dynamics are controlled by anthropogenic surface responses, namely minimal infiltration and high runoff compared to minimal natural topographic variations.

Within the context of regional geography studies, this research contributes to the literature by providing an empirical case study from a downstream area (floodplain) in Indonesia, which serves as the confluence of several major rivers (Barito and Martapura). Specifically, the mapping results provide a contextual and representative picture of the inherent vulnerability of a city with an average elevation of -16 cm below sea level. Through this mapping, it is known that flood risk is a widespread and systemic problem across almost all areas of the city, challenging the assumption that it is only concentrated on certain riverbanks.

The spatial analysis results indicate that areas with relatively low topography, located near rivers in areas with numerous rivers, and typically in areas with residential land cover, are at high risk of flooding. Banjarmasin City's lowland topography, with elevations close to sea level, makes it difficult for water to drain quickly, especially when the water volume reaches its maximum capacity.

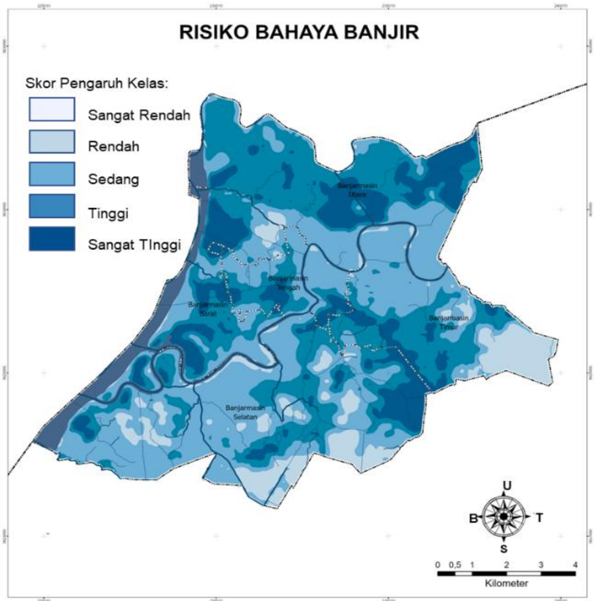


Figure 6. Flood Hazard Risk Map

As a downstream area, Banjarmasin also serves as the confluence of several rivers. These rivers carry water from various upstream areas, further exacerbating the situation when high rainfall occurs simultaneously across the entire river basin. However, unlike other geographic factors, fluctuations in rainfall factors are not considered in the spatial analysis of flood hazard risk due to the relatively small area of Banjarmasin City, resulting in almost no spatial variation in rainfall values throughout the city.

The spatial distribution percentages of very high and high flood hazard risks, in order from highest to lowest, are North Banjarmasin, Central Banjarmasin, West Banjarmasin, South Banjarmasin, and East Banjarmasin. This occurs because the very high-high influence class on the land cover factor, as the factor with the heaviest factor weight, is very dominant in North Banjarmasin, West Banjarmasin, and Central Banjarmasin. Although the dominant percentage of flow density is in South Banjarmasin and Central Banjarmasin. The spatial distribution percentage of flood risk classes is shown in Table 5.

Table 5. Distribution of Class Area (km²) of Flood Hazard Risk in Banjarmasin City

Subdistrict	Very high	Tall	Currently	Low	Very Low	Total
North Banjarmasin	5.60	5.57	4.22	1.40	0.12	16.91
Central Banjarmasin	5.70	7.01	9.15	0.30	1.35	23.51
West Banjarmasin	2.10	2.45	0.71	0.90	0.50	6.66
South Banjarmasin	3.71	5.64	2.32	1.10	0.30	13.07
East Banjarmasin	4.95	5.50	6.56	11.54	9.79	38.33
Total	**22.06**	**26.17**	**22.95**	**15.24**	**12.05**	**98.47**

Source: data processing, 2024

Mitigation efforts should be prioritized in sub-districts with the highest concentration of Very High and High risk classes, such as North Banjarmasin, Central Banjarmasin, and West Banjarmasin. North Banjarmasin has the largest Very High and High risk areas, at 5.60 km² and 5.57 km², respectively. Focus in this area should include improvements to spatial planning and drainage infrastructure. South Banjarmasin and East Banjarmasin should receive continued attention to prevent future increases in risk, particularly in areas exhibiting high and medium risk classes.

CONCLUSION

Flooding is a frequent occurrence in Banjarmasin City, occurring almost evenly across all sub-districts. Flooding is typically caused by river overflows and prolonged, high rainfall. The flood risk index calculation shows that Banjarmasin City is generally dominated by very high and high risk classes. The results of the Spatial Multi-Criteria Analysis (SMCA) using the Spatial AHP approach indicate that land cover is the most significant determinant of flood risk. This factor ranks highest with a weight of 0.48. This dominant weight indicates that in dense urban environments like Banjarmasin, the dominance of high built-up land significantly contributes to high surface water runoff, making it the primary driver of flood risk compared to other physical factors.

The high potential risk of flooding in Banjarmasin City is also driven by other factors, which overall worsen the situation; (1) The physical condition of the area which is a flat area and has a relatively low elevation above sea level (average -16 cm); (2) Banjarmasin City is a downstream area which is the meeting point of several large rivers, such as the Barito River and the Martapura River, which carry water from upstream; (3) The condition of the drainage network infrastructure is inadequate in the type of residential land cover and other built-up land, where the drainage dimensions are not wide enough and are not yet connected as an urban drainage system; (4) The occurrence of sedimentation in the river flow and its tributaries which causes the water capacity to be reduced.

THANK-YOU NOTE

Sincere appreciation to LPPM ULM for their role as the organizer and distributor of university research grant funds for the fiscal year 2024. This study received financial support from DIPA Lambung Mangkurat University during the 2024 fiscal period. Gratitude is also extended to the Banjarmasin City Regional Disaster Management Agency, the Banjarmasin City Research and Development Agency, and all scholars, particularly those in the Geography Study Program, Faculty of Social and Political Sciences, Lambung Mangkurat University.

REFERENCE

Arthayanti, Y., Srinadi, IGAM, & Gandhiadi, GK (2017). Geographically weighted ridge regression in the case of multicollinearity in the human development index in regencies/cities of East Java Province. Journal of Mathematics, 7(2), 124.

Central Statistics Agency of South Kalimantan Province. (2022). Banjarmasin in figures 2021. Central Statistics Agency of South Kalimantan Province.

Chen, J., Hill, A. A., & Urbano, L. D. (2009). A GIS-based model for urban flood inundation. Journal of Hydrology, 373(1–2), 184–192. https://doi.org/10.1016/j.jhydrol.2009.04.021

Chen, Y., Liu, R., Barrett, D., Gao, L., Zhou, M., Renzullo, L., & Emelyanova, I. (2015). A spatial assessment framework for evaluating flood risk under extreme climates. Science of the Total Environment, 538, 512–523.

Drobne, S., & Lisec, A. (2009). Multi-attribute decision analysis in GIS: Weighted linear combination and ordered weighted averaging. Informatica, 33(4), 459–474.

Elkhrachy, I. (2015). Flash flood hazard mapping using satellite images and GIS tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). The Egyptian Journal of Remote Sensing and Space Sciences, 18(2), 261–278.

Fitriansyah, F. (2016). Study of Flooding in the North Banjarmasin Area, Banjarmasin City. Journal of Civil Engineering Media. https://doi.org/10.22219/JMTS.V14I2.3747

Forte, F., Strobl, R., & Pennata, L. (2006). A methodology using GIS, aerial photos and remote sensing for loss estimation and flood vulnerability analysis in the Supersano-Ruffano-Nociglia Graben, southern Italy. Environmental Geology, 50(4), 581–594.

Generino, P., Sony, E., & Proceso, L.F. (2014). Analytic hierarchy process (AHP) in spatial modeling for floodplain risk assessment. International Journal of Machine Learning and Computing, 4(5), 450.

Gumusay, M.U., Koseoglu, G., & Bakirman, T. (2016). An assessment of site suitability for marina construction in Istanbul, Turkey, using GIS and AHP multicriteria decision analysis. Environmental Monitoring and Assessment, 188(12), 677.

Hammami, S., Zouhri, L., Souissi, D., Souei, A., Zghibi, A., Marzougui, A., & Dlala, M. (2019). Application of the GIS-based multi-criteria decision analysis and analytical hierarchy process (AHP) in the flood susceptibility mapping (Tunisia). Arabian Journal of Geosciences, 12, 1–16.

Ikhvan, M.A., & Mera, M. (2021). Case study: Significant factors in hazard and vulnerability assessments in flood mitigation in Padang City. International Journal of Disaster Risk Reduction, 56, 102142. https://doi.org/10.1016/j.ijdrr.2021.102142

Kamali, M., Alesheikh, A.A., Khodaparast, Z., Hosseinniakani, S.M., & Borazjani, S.A.A. (2015). Application of Delphi-AHP and fuzzy-GIS approaches for site selection of large extractive industrial units in Iran. Journal of Settlements and Spatial Planning, 6(1), 9.

Karagöz, E., & Yaralioğlu, K., (2018). The Effective Personnel Selection Via Multi Criteria Decision Making Method Analytic Hierarchy Process (AHP): A Web Based Application. EBEEC2018

Kazakis, N., Kougias, I., & Patsialis, T. (2015). Assessment of flood hazard areas at a regional scale using an index-based approach and analytical hierarchy process: Application in Rhodope–Evros region, Greece. Science of the Total Environment, 538, 555–563.

Khodaparast, M., Rajabi, A.M., & Edalat, A. (2018). Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): A case study in Qom City, Iran. Environmental Earth Sciences, 77(2), 52.

Marfai, MA, King, L., Sartohadi, J., Sudrajat, S., Budiani, SR, & Yulianto, F. (2008). The impact of tidal flooding on a coastal community in Semarang, Indonesia. The Environmentalist, 28(3), 237–248.

Nugraha, AL (2018). Improving the accuracy and precision of spatial analysis of flood modeling in Semarang City using a combination of geographic information systems and fuzzy logic methods. Engineering, 39(1), 16–24.

Nuissl, H., Haase, D., Lanzendorf, M., & Wittmer, H. (2009). Environmental impact assessment of urban land use transitions: A context-sensitive approach. Land Use Policy, 26(2), 414–424.

Ouma, Y.O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: Methodological overview and case study assessment. Water, 6, 1515–1545.

Papaioannou, G., Vasiliades, L., & Loukas, A. (2015). Multi-criteria analysis framework for potential flood prone areas mapping. Water Resources Management, 29(2), 399–418.

Popescu, D., Ichim, L., & Stoican, F. (2017). Unmanned aerial vehicle systems for remote estimation of flooded areas based on complex image processing. Censorship, 17(3), 446.

Rahardjo, J., Yustina, R., & Stok, RE (2004). Application of multi-criteria decision making in maintenance system decision making. Journal of Industrial Engineering, 2(1), 1–12.

Rotzoll, K., & Fletcher, C. H. (2013). Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change, 3(5), 477–481.

Saaty, T.L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), 83–98.

Santama, J. (2017). 50 cm tidal flood in Belawan, North Sumatra, hundreds of houses submerged. Retrieved from https://news.detik.com

Serbu, R., Marza, B., & Borza, S. (2016). A spatial analytic hierarchy process for identification of water pollution with GIS software in an eco-economic environment. Sustainability, 8(11), 1208.

Setiawan, A., Ramdhon, A., & Utami, L.A. (2022). Establishing a co-design framework for disaster mitigation agenda in the urban context: A case study of SIBAT Solo. IOP Conference Series: Earth and Environmental Science, 1114(1), 012025. https://doi.org/10.1088/1755-1315/1114/1/012025

Stroppiana, Daniela & Antoninetti, Massimo & Brivio, Pietro. (2014). Seasonality of MODIS LST over Southern Italy and correlation with land cover, topography and solar radiation. European Journal of Remote Sensing. 47. 133-152. 10.5721/EuJRS20144709.

Tingsanchali, T. (2012). Urban flood disaster management. Procedia Engineering, 32, 25–37. https://doi.org/10.1016/j.proeng.2012.01.1233

Wang, Y., Li, Z., Tang, Z., & Zeng, G. (2011). A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake region, Hunan, Central China.

Wątróbski, J., Jankowski, J., Ziemba, P., Karczmarczyk, A., & Zioło, M. (2019). Generalized framework for multi-criteria method selection. Omega, 86, 107–124.

Youssef, A.M., Pradhan, B., & Hassan, A.M. (2011). Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS-based morphometry and satellite imagery. Environmental Earth Sciences, 62(3), 611–623.