SJER Scientific Journal of Engineering Research
futuristech PT. Teknologi Futuristik Indonesia
Date of publication November 16, 2025, date of current version November 16, 2025.
e-ISSN: 3109-1725
Digital Object Identifier 10.64539/sjer.v1i4.2025.43

Article

GIS-Based Flood Risk Assessment Using the Analytical Hierarchy Process

Heinrich Rakuasa[1,*], Ahmat Rifai[2]

[1] Department of Geography, Tomsk State University, Tomsk, 634050, Russian Federation; heinrich.rakuasa@yandex.ru
[2] School of Environmental Science, University of Indonesia, Jakarta 10430, Indonesia; rifaiahmad237@gmail.com
* Correspondence

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Abstract: Floods are a common hydrometeorological disaster in Teluk Ambon Sub-district ; therefore, modeling is necessary as a mitigation measure. To address this challenge, Geographic Information System (GIS) and Remote Sensing technologies have proven to be powerful tools in flood disaster analysis and modeling. This study uses 10 variables, including elevation, slope, TWI, NDVI, precipitation, land cover, soil type, drainage density, distance from roads, and distance from rivers. This study uses the Analytical Hierarchy Process (AHP) method. The results show that distance from rivers has the greatest contribution (14.08%) to flooding in Teluk Ambon Sub-district . The level of flood vulnerability in Teluk Ambon Sub-district is divided into three classes, namely low risk, covering an area of 8,642.26 ha or 64.71%; medium risk, covering an area of 4,066.79 ha or 30.45%; and high risk, covering an area of 646.44 ha or 4.84%. Settlements predicted to be affected by flooding in the low class cover an area of 130.36 ha, or 11.59%; the medium class covers an area of 649.29 ha, or 57.73%; and the high class covers an area of 345.07 ha, or 30.68%. The results of this study are very important in providing a more precise flood risk map to support spatial planning and disaster mitigation in the affected areas.

Keywords: AHP; Flood; GIS; Teluk Ambon; Remote Sensing.

1. Introduction

Floods are one of the most common hydrometeorological disasters that often cause significant economic, social, and environmental damage [1]. The frequency and intensity of flooding tend to increase in line with global and anthropogenic climate change, such as rapid urbanization and land use change [2]. In archipelagic regions such as Indonesia, the threat of flooding is exacerbated by vulnerable geographical conditions, varied topography, and high rainfall, making it a crucial issue in sustainable development planning and disaster mitigation [3]. Therefore, a thorough understanding of the characteristics and triggering factors of flooding is crucial for developing efficient risk governance approaches [4].

Teluk Ambon sub-district , Ambon City, Indonesia, is among the regions vulnerable to flooding [5]. Located in a coastal area with hilly and valley topography, and influenced by monsoon rainfall patterns, this area often experiences flooding that disrupts community activities and infrastructure [6]. Unplanned urbanization along riverbanks and low-lying areas, coupled with a lack of adequate drainage systems, further exacerbates this vulnerability [7-8]. Recurring flooding in Teluk Ambon not only causes damage to property and infrastructure, but also impacts the local economy and the quality of life of residents [9].

In 2024, the Ambon City National Disaster Management Agency recorded a total of 140 disaster events, including fallen trees, landslides, and floods, in Ambon City in June 2024 [10]. Moderate to heavy rainfall caused flooding and landslides accompanied by strong winds that knocked down trees in Ambon City on June 3-24 June 2024, increasing to 140 incidents in Ambon City covering 5 sub-district s, namely Baguala sub-district , Teluk Ambon sub-district , South Leitimur sub-district , Sirimau sub-district and Nusaniwe sub-district , which were dominated by landslides (93%). The victims affected by the disaster were 147 households, 284 men and 307 women, with 2 fatalities and 14 houses suffering minor to moderate damage. In August 2025, floods again hit Teluk Ambon sub-district and its surroundings, affecting 61 units [10].

To address these challenges, Geographic Information System (GIS) and Remote Sensing technologies have proven to be powerful tools in flood disaster analysis and modeling [9]. GIS enables the integration of various spatial data such as elevation, rainfall, land use, soil type, and drainage networks to identify flood-prone areas [8]. Meanwhile, Remote Sensing provides accurate temporal and spatial data from the earth's surface, including the detection of post-flood waterlogging and updates to land use data relevant to modeling [11].

In the context of flood vulnerability and hazard modeling, the Analytical Hierarchy Process (AHP) serves as a commonly applied multi-criteria decision-making (MCDM) approach for weighting flood-causing factors based on expert assessments [12]. AHP allows researchers to quantify subjective assessments into objective numerical weights, so that they can be integrated with spatial data in a GIS environment [13]. This approach is particularly relevant because flood trigger factors have varying degrees of influence, and accurate weighting will result in a more precise risk model [14]. The application of AHP in flood modeling has been widely used in various case studies, demonstrating its effectiveness in producing reliable flood vulnerability maps [15].

Although there have been many studies on flood modeling in Indonesia, studies that focus specifically on Teluk Ambon sub-district using a combination of GIS, remote sensing, and AHP are still limited. Most studies often rely on only one or two methods, or are conducted on a broader scale without sufficient local details. The limitations of specific field data and optimal use of technology are often obstacles [16]. Based on the above issues, this research aims to fill the gap by developing an accurate, locally-based flood model in Teluk Ambon sub-district , utilizing the power of GIS and Remote Sensing integration based on factor weighting using AHP.

Therefore, this research aims to provide valuable support for flood disaster reduction and adaptation initiatives in Teluk Ambon sub-district , Ambon City. The modeling results in the form of flood vulnerability maps will provide important information for local governments, disaster mitigation agencies, and communities in formulating better spatial planning policies, developing early warning systems, and increasing community adaptation capacity to future flood risks. The results of this research are expected to serve as a reference for similar studies in other island regions with similar geographical characteristics and hydrometeorological challenges.

2. Literature Review

2.1. Flood

Floods are one of the environmental disasters that commonly occur due to water overflowing onto land that is usually dry [17]. The causes of flooding are varied, including very high rainfall that lasts for a long time, causing rivers and waterways to be unable to contain the water, leading to river water levels overflowing [16]. Additionally, rapid snowmelt, high tides (especially in coastal areas), and dam or levee failures can also be factors contributing to flooding [18]. Climate change, which leads to an increase in the frequency and intensity of extreme rainfall and rising sea levels, also exacerbates flood risk [19].

In addition to natural factors, human actions also have a considerable impact on the occurrence of floods. [13, 20]. Deforestation reduces the soil's ability to absorb rainwater, while development in water catchment areas narrows the space for water to seep in. Indiscriminate waste disposal that clogs waterways and poor spatial planning also exacerbate the impact of floods [21]. These things show that poor environmental management can further increase the risk and damage caused by floods [14].

The impact of floods is very widespread, ranging from property damage and economic losses to threats to human safety [17]. Damage to infrastructure and public facilities causes significant social and economic disruption [16]. Therefore, understanding the causes and risk factors of floods is crucial for designing effective mitigation and disaster management efforts, including strengthening spatial planning systems, improving drainage capacity, and involving communities in sustainable environmental management [22].

2.2. Spatial Modeling

Spatial modelling is an analytical technique used to understand and represent phenomena in geographic space by linking data and variables that have a location component [23]. Spatial data is data that has positional values such as coordinates that reference locations on the Earth's surface. This spatial data can be in raster or vector format and is often used in Geographic Information Systems (GIS) to comprehensively integrate, visualise, and analyse spatial phenomena [24].

The use of spatial models is very important in various fields, including spatial planning, environmental monitoring, and disaster mitigation [25]. This method allows for the exploration of relationships between geographical and temporal variables to model the dynamics of regional change. For example, spatial interpolation is one of the main techniques in spatial modelling, used to estimate values at unmeasured locations based on existing data points. Interpolation methods can be categorised as deterministic and stochastic, with the choice of application depending on the nature of the data and the analysis objectives [26].

The development of GIS technology and spatial modelling methods now allows for the combination of multiple datasets from different origins, such as field surveys, satellite imagery, and remote sensing sensors, to produce adaptive and accurate spatial models [27]. Spatial modelling can also utilise dynamic systems that combine time series data and cross-sectional data, providing a more complete and detailed picture of spatial changes and trends [28]. This approach is important for supporting evidence-based decision making within the framework of sustainable development and resource management [29].

2.3. Analytical Hierarchy Process for flood modeling

AHP has become a widely used method in flood modeling worldwide [30]. AHP allows for the decomposition of complex problems into simpler hierarchies, enabling the systematic evaluation of flood-causing factors and related risks through pairwise comparisons [31]. In the context of flood modelling, AHP is typically used to combine various criteria such as land slope, soil type, rainfall, land use, and population density, all of which influence the level of vulnerability and flood risk in a region. By determining relative weights calculated from expert preferences or field data, accurate flood risk maps can be generated to support disaster mitigation planning [32].

The main advantage of AHP in flood modelling is its flexibility and ability to adjust factor weights according to local priorities and desired policies [33]. The consistency ratio verification process also ensures that the decision-makers' assessments are within acceptable tolerance limits, making the model results more reliable [34]. Additionally, AHP can be integrated with GIS for spatial mapping and with other techniques such as machine learning to improve modelling accuracy [30]. This approach makes it easier for policymakers to understand flood risk conditions while formulating appropriate adaptation strategies at the local and regional levels [35].

Various recent studies have proven the effectiveness of AHP in the context of flood risk modelling, particularly in urban and river basin contexts [36]. AHP helps identify areas most vulnerable to flooding without relying on complex and expensive hydrodynamic modelling [37]. Thus, this method is very suitable for managing flood risk in areas with limited data and resources [38]. Furthermore, the research also proposes developing a combination of AHP with fuzzy logic and other approaches to improve the accuracy of dynamic flood risk analysis in the future [38].

3. Research Method

3.1. Study Area and Data Collection

This research was conducted in Teluk Ambon sub-district , Ambon City, Maluku Province. Geographically, Teluk Ambon sub-district is located on Ambon Island. Teluk Ambon District consists of eight villages, including Laha, Poka, Tawiri, Hunuth, Tihu, Wayame, Rumah Tiga, and Hativer Besar. The research location, Teluk Ambon District, can be seen in Figure 1.

This study used 10 variables consisting of elevation, slope, topography, wetness index, NDVI, precipitation, land cover, soil type, drainage density, distance from roads, and distance from rivers. The selection of variables causing flooding in Teluk Ambon sub-district was obtained from a literature review of previous studies and initial field observations. The research data was obtained from official Indonesian government agencies and international institutions that provide geospatial data. All data was processed using Arc GIS Pro and Microsoft Office 365 software. The complete sources of data for this study can be seen in Table 1.

2.2. Data Classification

All variable data was then classified and scored based on its level of influence on flood disasters using the Analytical Hierarchy Process (AHP). First introduced by Thomas L. Saaty in the 1970s, AHP is a structured multi-criteria decision-making method that breaks down complex problems into a hierarchy of more manageable parts [38]. Each part is evaluated separately, and the results are then integrated to support well-informed decisions [39]. The core of AHP lies in the use of pairwise comparisons to measure relative preferences between criteria and alternatives, which are then converted into priority weights through matrix calculations [39]. This process not only allows for the systematic weighting of factors based on subjective or expert assessments, but also provides a mechanism for checking the consistency of these assessments, resulting in more rational and structured decisions.

Based on the data presented, the Matrix of Variable Weighting Results Using AHP represents the weighting results of each variable used in flood modeling. This weighting was carried out using the AHP method, a multi-criteria decision-making technique used to determine the relative priorities of a number of factors or criteria [40]. The normalized principal eigenvector values in Figure 2 show the relative weight or influence of each variable on flooding in Teluk Ambon sub-district. The highest values, such as TWI (Topographic Wetness Index) at 13.78% and Precipitation at 13.48%, indicate that these two factors play the most dominant role in determining an area's vulnerability to flooding. Conversely, variables with the lowest weights, such as Distance from Road

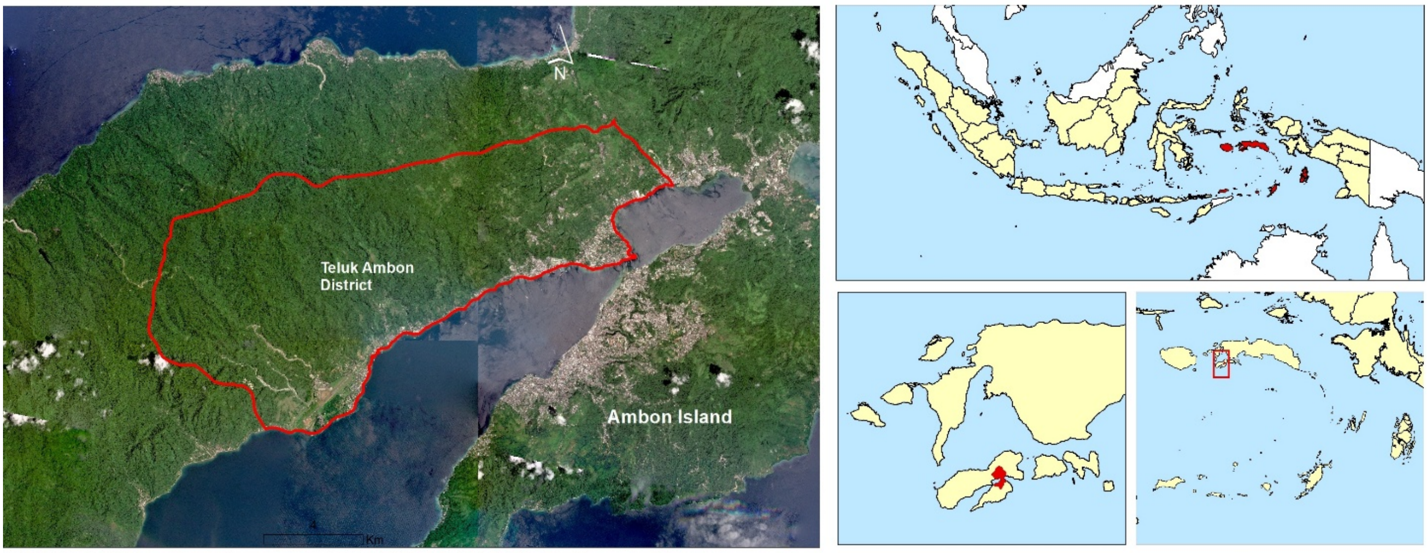


Figure 1. Research Location: Teluk Ambon sub-district , Ambon City.

Table 1. Research Data Sources.

No	Variable	Data Type	Scale/ Resolution	Unit	Source
1	Elevation	Raster	8 m	m	DEMNAS- Geospatial Information Agency https://tanahair.indonesia.go.id/portal-web/unduh/demnas
2	Slope	Raster	8 m	%	DEMNAS- Geospatial Information Agency https://tanahair.indonesia.go.id/portal-web/unduh/demnas
3	Topographic Wetness Index (TWI)	Raster	8 m	level	DEMNAS- Geospatial Information Agency https://tanahair.indonesia.go.id/portal-web/unduh/demnas
4	Normalized Difference Vegetation Index (NDVI)	Raster	3 m	level	Planet Scope satellite imagery. Planet Labs https://www.planet.com
5	Preciptation	Vector	1: 50.000	mm/year	Meteorology, Climatology, and Geophysical Agency
6	Land Cover	Raster	3 m	level	Planet Scope satellite imagery. Planet Labs https://www.planet.com
7	Soil Type	Vector	1: 50.000	level	Soil classification-FAO https://www.fao.org/soils-portal/data-hub/soil-classification/en/
8	Drainage Density	Vector	1: 50.000	m/km2	Geospatial Information Agency https://tanahair.indonesia.go.id
9	Distance from Road	Vector	1: 50.000	m	Geospatial Information Agency https://tanahair.indonesia.go.id
10	Distance from River	Vector	1: 50.000	m	Geospatial Information Agency https://tanahair.indonesia.go.id

(5.59%) and NDVI (5.87%), have relatively little influence in the model.

This weighting is crucial because it forms the basis for integrating spatial data from each variable in the Geographic Information System (GIS), which is then used to map and predict flood-prone areas with greater accuracy [41]. In other words, the AHP results provide a hierarchical picture of the importance of each factor in flood vulnerability analysis [42]. After assigning overall scores to the variables, an overlay process was conducted, followed by a simple classification into three flood vulnerability classes: low, moderate, and high.

2.3. Steps for processing AHP data

The Analytical Hierarchy Process (AHP) data processing begins with the collection of primary and sec-

Table 2. Environmental variables that influence flooding.

No	Variable	Class	Score
1	Elevation	<10	5
		10 - 50	4
		50 - 100	3
		100 - 200	2
		>200	1
2	Slope	0-8	5
		8-15	4
		15-25	3
		25-40	2
		>40	1
3	Topographic Wetness Index (TWI)	-4.33 - -1.44	1
		-1.43 - -0.08	2
		-0.07 - 1.39	3
		1.4 - 3.57	4
		3.58 - 10.7	5
4	NDVI	<-0.02	5
		-0.02 - 0.30	4
		0.31 - 0.40	3
		0.41 - 0.50	2
		0.51 - 1	1
5	Precipitation	>3000	5
		2500-3000	4
		2000-2500	3
		1500-2000	2
		>3000	5
6	Land Cover	Built-up Area	3
		Open Area	4
		Low Vegetation	2
		Agricultural Land	3
		River	5
		Mixed Forest	1
7	Soil Type	Rendzinas	2
		Orthic Acrisols	4
8	Drainage Density	0-150	1
		151 - 210	2
		211 - 250	3
		251 - 300	4
		>300	5
9	Distance from Road	0 - 25	5
		26 - 50	4
		51 - 100	3
		101 - 150	2
		>150	1
10	Distance from River	0 - 50	5
		51 - 100	4
		101 - 250	3
		251 - 500	2
		>5000	1

Source: [5, 38, 43, 44].

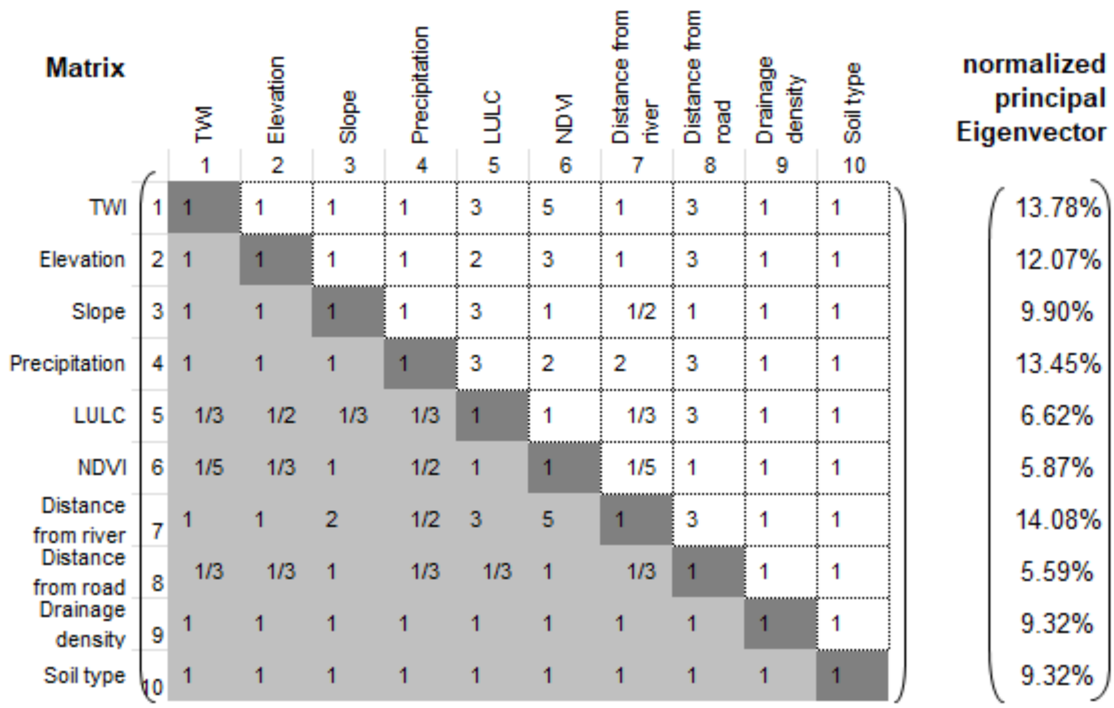
ondary data, including Digital Elevation Models (DEMs), Planet Scope satellite imagery, river networks, road networks, soil types, and rainfall data. DEM data were processed to generate derived variables such as slope, elevation, and the Topographic Wetness Index (TWI), which reflects the potential for waterlogging. PlanetScope image data were used to generate the Normalised Difference Vegetation Index (NDVI) and land cover classification variables. River network data was processed into the variables of distance from river and drainage density, while road data was processed into the variable of distance from road. Soil type and rainfall variables were also prepared as important inputs for further analysis. The full process is illustrated in Figure 3.

After these environmental variables are classified, the next step is to assign weights to each variable using the AHP method. This process involves creating a comparison matrix between variables to evaluate the significance of each factor influencing flood vulnerability. This weight assessment is conducted systematically and quantitatively based on empirical experience and relevant literature, while also considering the local context in the study area. The results of the AHP analysis, which are variable weights, were then applied in spatial overlay using GIS software to produce a flood vulnerability map. This map was then classified into three vulnerability classes: low, medium, and high. It will later be overlaid with built-up land data from 2025 to identify built-up areas affected by flooding, thus supporting the development of future policies for flood disaster mitigation. This method combines the strengths of the multi-criteria AHP analysis to consider various environmental factors with the capabilities of GIS in spatial data processing, resulting in a more accurate flood risk prediction model. The variables contributing to the occurrence of floods are classified based on Table 2.

3. Results and Discussion

3.1. Flood-Prone Variables

The elevation variable was obtained from the analysis of DEMNAS data, which was classified into five altitude classes, namely <10 m above sea level covering an area of 427.80 ha, 10–50 m above sea level covering an area of 1,339.42 ha, 50–100 m above sea level covering an area of 1,409.32 ha, 100–200 m above sea level covering an area of 2,785.02 ha, and >200 m above sea level covering an area of 7,376.95 ha. Areas located at an elevation of <10 m above sea level have the highest vulnerability to flood risk in this region [15]. The AHP analysis results show that elevation contributes 12.07% to the risk of flooding in Teluk Ambon sub-district . The elevation variable can be seen in Figure 4 (1).



Matrix		TWI 1	Elevation 2	Slope 3	Precipitation 4	LULC 5	NDVI 6	Distance from river 7	Distance from road 8	Drainage density 9	Soil type 10	normalized principal Eigenvector
TWI	1	1	1	1	1	3	5	1	3	1	1	13.78%
Elevation	2	1	1	1	1	2	3	1	3	1	1	12.07%
Slope	3	1	1	1	1	3	1	1/2	1	1	1	9.90%
Precipitation	4	1	1	1	1	3	2	2	3	1	1	13.45%
LULC	5	1/3	1/2	1/3	1/3	1	1	1/3	3	1	1	6.62%
NDVI	6	1/5	1/3	1	1/2	1	1	1/5	1	1	1	5.87%
Distance from river	7	1	1	2	1/2	3	5	1	3	1	1	14.08%
Distance from road	8	1/3	1/3	1	1/3	1/3	1	1/3	1	1	1	5.59%
Drainage density	9	1	1	1	1	1	1	1	1	1	1	9.32%
Soil type	10	1	1	1	1	1	1	1	1	1	1	9.32%

Figure 2. Matrix of variable weighting results using Analytical Hierarchy Process (AHP).

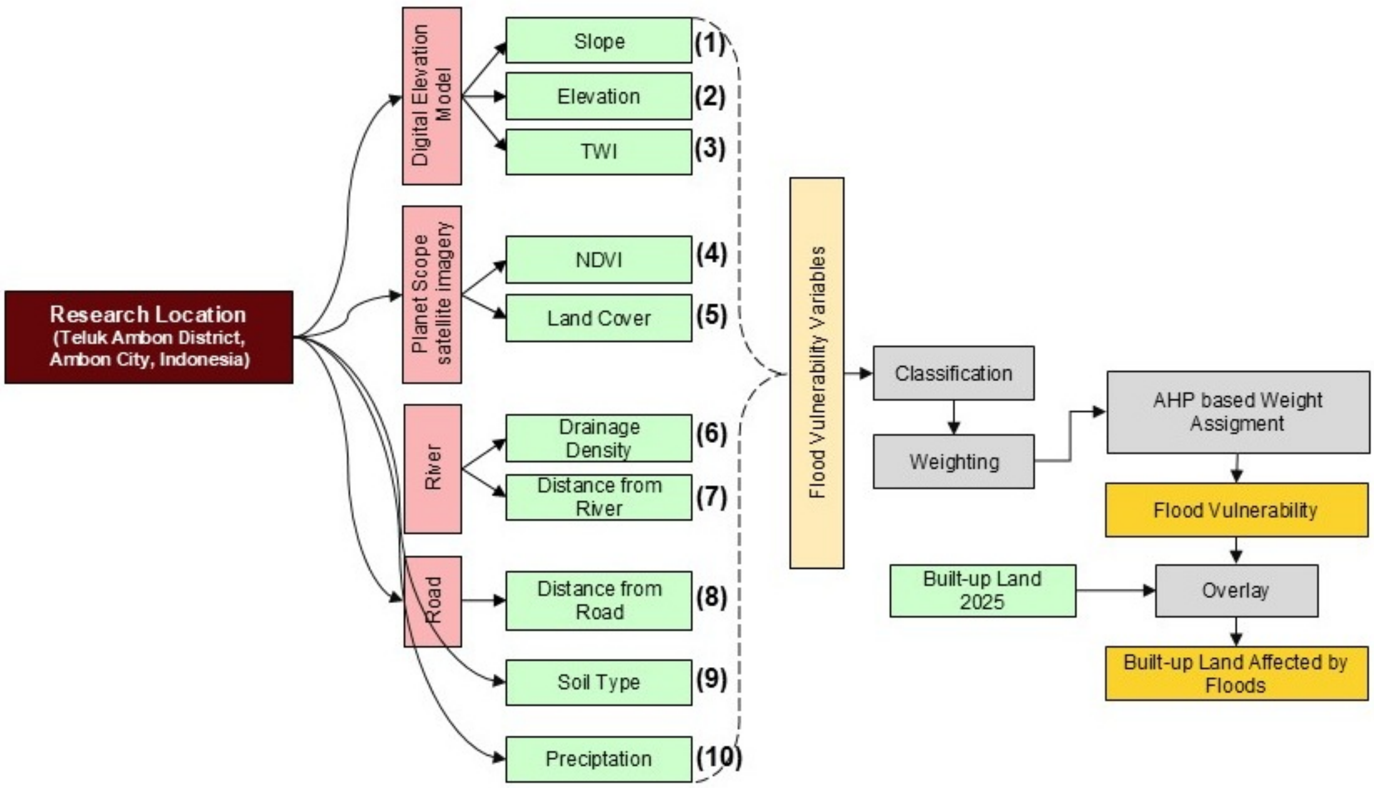


Figure 3. Research Flow.

The slope variable was also obtained from the analysis of DEMNAS data, which was classified into 5 slope classes (%), including 0-8% covering an area of 2,044.23 ha, 8-15% covering an area of 1,912.89 ha, 15-25% covering an area of 2,880.41 ha, 25-40% covering an area of 3,239.88 ha, and >40% covering an area of 3,360.11 ha. Areas with a slope <8% have the highest vulnerability to flood risk in this region. The results of the AHP analysis show that slope contributes 9.90% to flood hazards in Teluk Ambon sub-district . The slope variable can be seen in Figure 4 (2).

The Topographic Wetness Index (TWI) variable was obtained from DEMNAS data analysis, which was classified into five classes with the following value ranges and area sizes:-4.33 to -1.44 covering an area of 41.40 ha, -1.43 to -0.08 covering an area of 419.73 ha, -0.07 to 1.39

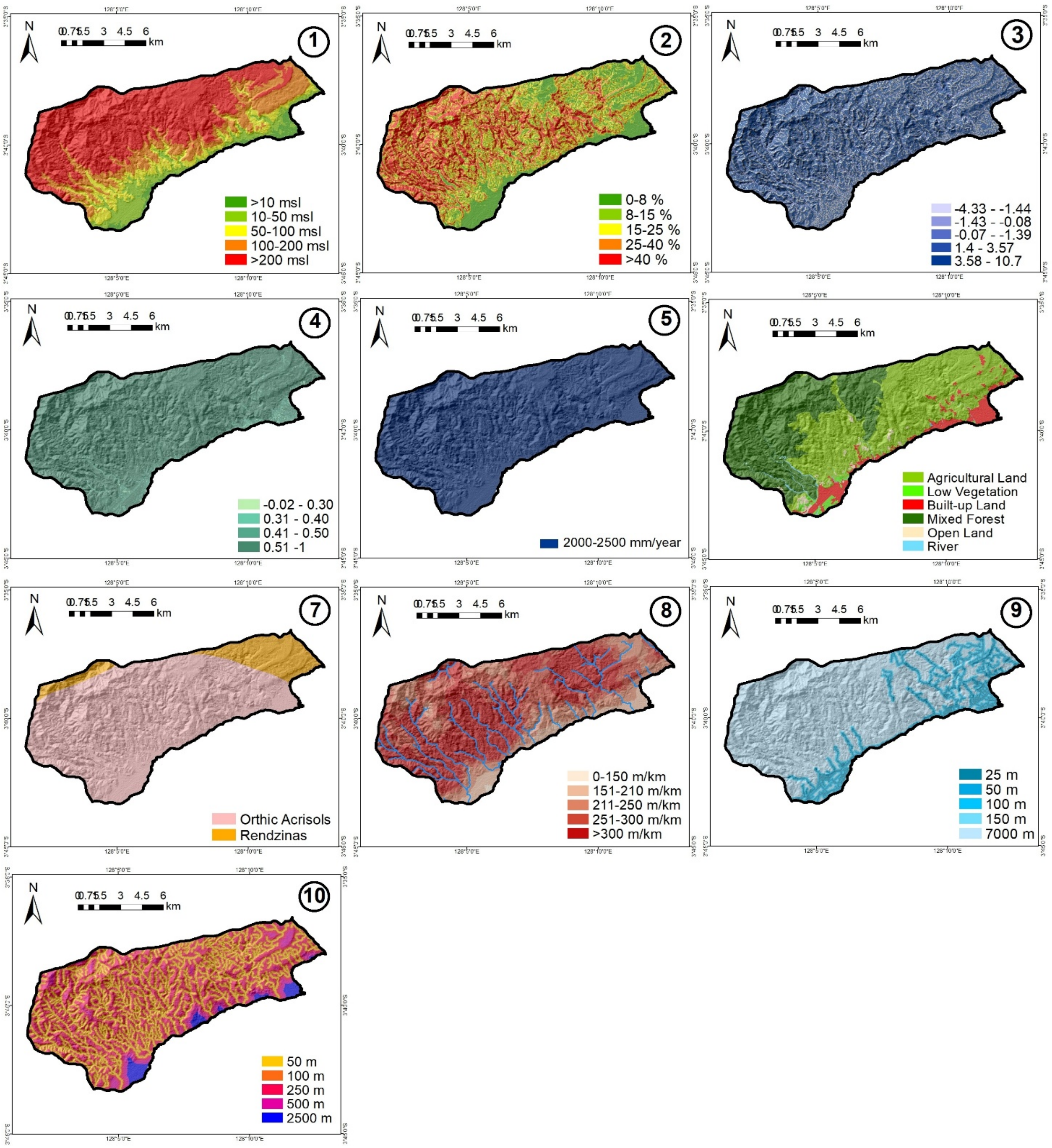


Figure 4. Flood Vulnerability Variables: (1) Elevation, (2) Slope, (3) TWI, (4) NDVI, (5) Precipitation, (6) Land Cover, (7) Soil Type, (8) Drainage Density, (9) Distance from Road, (10) Distance from River.

covering an area of 438.74 ha, 1.40 to 3.57 covering an area of 703.23 ha, and 3.58 to 10.7 covering an area of 7,332.30 ha. Higher TWI values indicate greater water accumulation on the ground surface, so that areas with a TWI class of 3.58–10.7 have the highest potential risk of flooding in Teluk Ambon sub-district . The AHP analysis results show that the TWI variable contributes significantly to the flood hazard level in the region, namely 13.78%, reflecting its important role in GIS-based flood risk modeling and remote sensing [45]. The TWI variable can be seen in more detail in Figure 4 (3).

The Normalized Difference Vegetation Index (NDVI) variable was obtained from the analysis of Sentinel-2 satellite images, which were classified into four classes with the following value ranges and area sizes:-0.02 to 0.30 covering an area of 41.57 ha, 0.31 to 0.40 covering an area of 318.49 ha, 0.41 to 0.50 covering an area of 623.28 ha, and 0.51 to 1 covering an area of

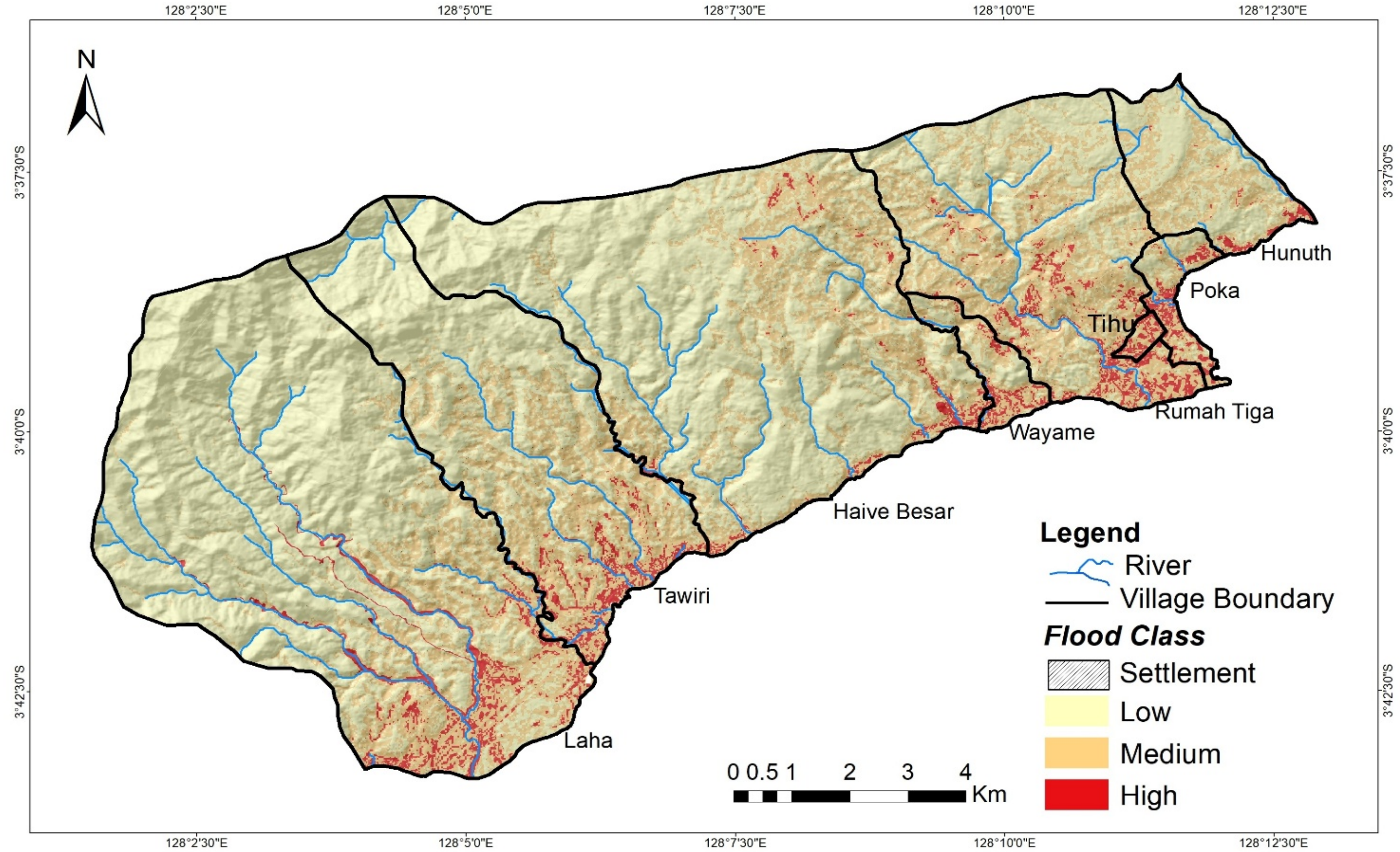


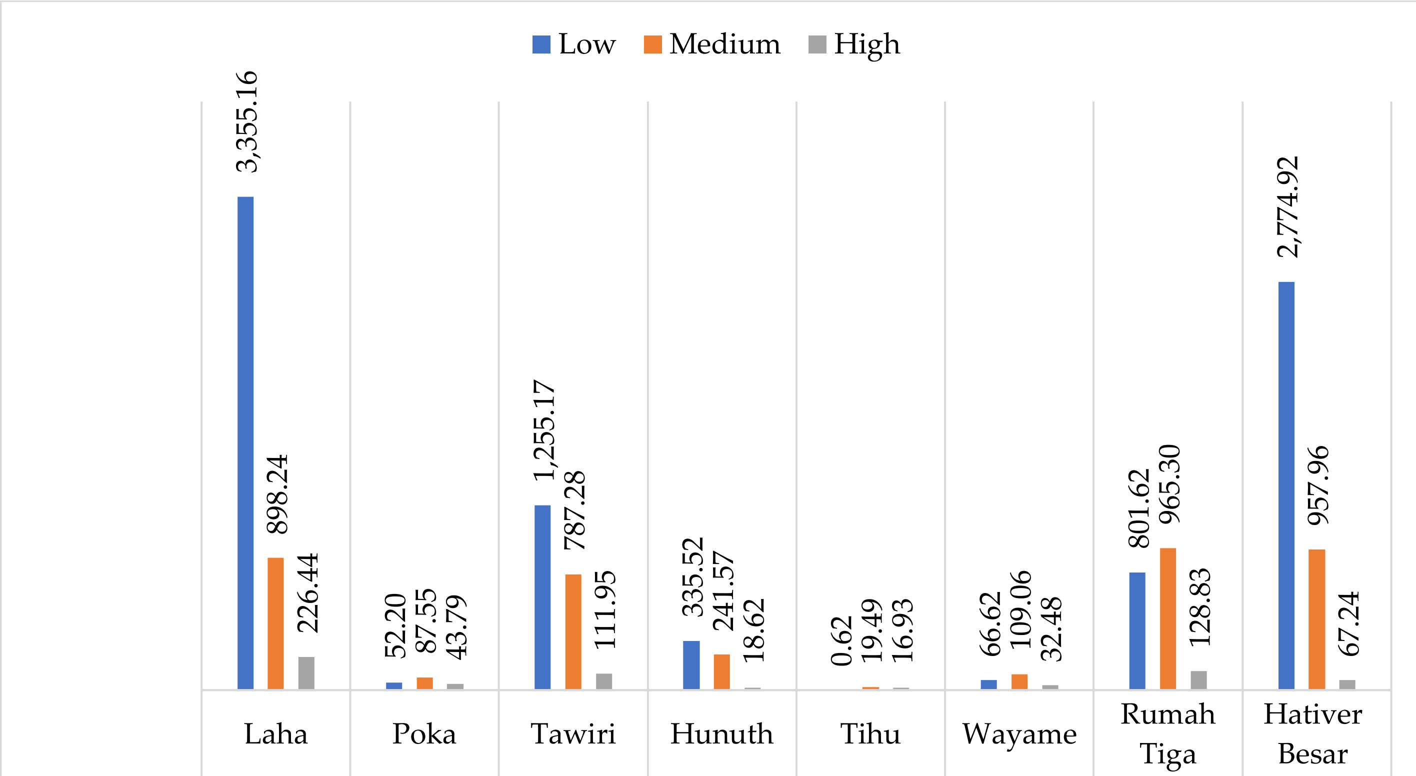
Figure 5. Flood Vulnerability Level of Teluk Ambon sub-district.

12,372.02 ha. NDVI reflects the level of vegetation cover and health, where classes with higher NDVI values indicate denser and healthier vegetation, which has the potential to reduce flood risk due to the vegetation's ability to absorb water and inhibit surface runoff [46]. The results of the AHP analysis indicate that the NDVI variable makes an important contribution to flood hazard modeling in Teluk Ambon sub-district at 5.87%, with areas with high NDVI dominating the study area. The NDVI variable can be seen in detail in Figure 4 (4).

The precipitation variable was obtained from data from the Meteorology, Climatology, and Geophysics Agency (BMKG), which shows that the entire Teluk Ambon sub-district has a rainfall class of between 1,500 and 2,000 mm per year. This high level of rainfall is an important factor in flood hazard analysis because rainfall plays a direct role in determining the volume of rainwater that can cause flooding and excessive surface runoff [47]. In the results of the Analytical Hierarchy Process (AHP) analysis, the rainfall variable contributed significantly to 13.45% of the potential flood risk in Teluk Ambon sub-district , making it a key parameter in GIS-based flood modeling and remote sensing [48]. The rainfall variable can be seen in detail in Figure 4 (5).

The land cover variable was obtained from the interpretation of PlanetScope satellite images with a spatial resolution of 3 meters and classified into several classes, namely Built-up Area covering an area of 1,028.00 ha, Open Area covering an area of 169.14 ha, Rivers covering an area of 120.22 ha, Mixed Forest covering an area of 5,304.34 ha, Low Vegetation covering an area of 180.46 ha, and Agricultural Land covering an area of 6,536.34 ha. This land cover classification is very important in flood risk modeling because the type and condition of the land affect water infiltration, surface runoff, and the potential for flooding in Teluk Ambon sub-district [49]. The AHP analysis results reveal that the land cover variable contributes 6.62% to determining the flood hazard level in the area [50]. Details of land cover can be seen in Figure 4 (6).

Soil type variables were obtained from the Geospatial Information Agency, which showed that the Teluk Ambon sub-district consists of two main soil types, namely Rendzinas, covering an area of 2,039.79 ha, and Orthic Acrisols, covering an area of 11,298.74 ha. The physical and chemical characteristics of these two soil types affect water infiltration and retention capabilities, thereby directly impacting the level of vulnerability to flood risk in the area [51, 52]. The results of the Analytical Hierarchy Process (AHP) analysis indicate that the soil type variable contributes 9.32% to determining the potential for flooding in Teluk Ambon sub-district , reinforcing the important role of soil aspects in GIS-based flood modeling and remote sensing. The soil type variable can be seen in Figure 4 (7).



	Laha	Poka	Tawiri	Hunuth	Tihu	Wayame	Rumah Tiga	Hativer Besar
Low	3,355.16	52.20	1,255.17	335.52	0.62	66.62	801.62	2,774.92
Medium	898.24	87.55	787.28	241.57	19.49	109.06	965.30	957.96
High	226.44	43.79	111.95	18.62	16.93	32.48	128.83	67.24

Figure 6. Area (ha) of Flood Vulnerability per Village in Teluk Ambon sub-district.

The drainage density variable was obtained from the analysis of DEMNAS data, which was classified into five classes based on drainage network density, namely 0–150 m/km covering an area of 33.01 ha, 151–210 m/km covering an area of 783.27 ha, 211–250 m/km covering an area of 2,425.79 ha, 251–300 m/km covering an area of 3,622.37 ha, and >300 m/km covering an area of 6,474.07 ha. Areas with higher drainage density values indicate a higher concentration of drainage channels, increasing the potential for rapid surface runoff and increasing the risk of flooding [53]. The results of the Analytical Hierarchy Process (AHP) analysis revealed that the drainage density variable contributed 9.32% to determining the level of flood hazard in Teluk Ambon Sub-district . This variable can be seen in detail in Figure 4 (8).

The variable Distance from road was obtained from distance buffer analysis of the road network and classified into five classes, namely 0–25 m covering an area of 801.56 ha, 26–50 m covering an area of 633.53 ha, 51–100 m covering an area of 977.46 ha, 101–150 m covering an area of 758.81 ha, and >150 m covering an area of 10,167.15 ha. Closer distance classes to the road tend to have different flood risks due to the influence of surface water flow and changes in hydrological conditions triggered by road infrastructure [54]. The results of the Analytical Hierarchy Process (AHP) analysis show that the Distance from Road variable contributes 5.87% to the flood hazard level in Teluk Ambon Sub-district , making it one of the important variables in flood modeling using GIS and remote sensing [55]. The distance from the road variable can be seen in detail in Figure 4 (9).

The variable Distance from the River was obtained through buffer analysis, measuring the distance from the river and then classifying it into five categories. The first category is a distance of 0–50 metres, covering an area of 3,937.82 hectares. The next is a distance of 51–100 metres, covering 3,591.48 hectares, followed by 101–250 metres with an area of 4,655.46 hectares. The 251–500 metre distance category covers 727.06 hectares, while distances over 500 metres cover an area of 426.69 hectares. The closer a location is to the river, the higher the potential flood risk, due to the possibility of runoff and river overflow into the surrounding areas [56]. The results of the Analytical Hierarchy Process (AHP) analysis show that the Distance from River variable contributes significantly to flood hazards in Teluk Ambon sub-district [57]. This variable is one of the important parameters in GIS-based flood risk modeling and remote sensing. Details of the distance from river variable can be seen in Figure 4 (10).

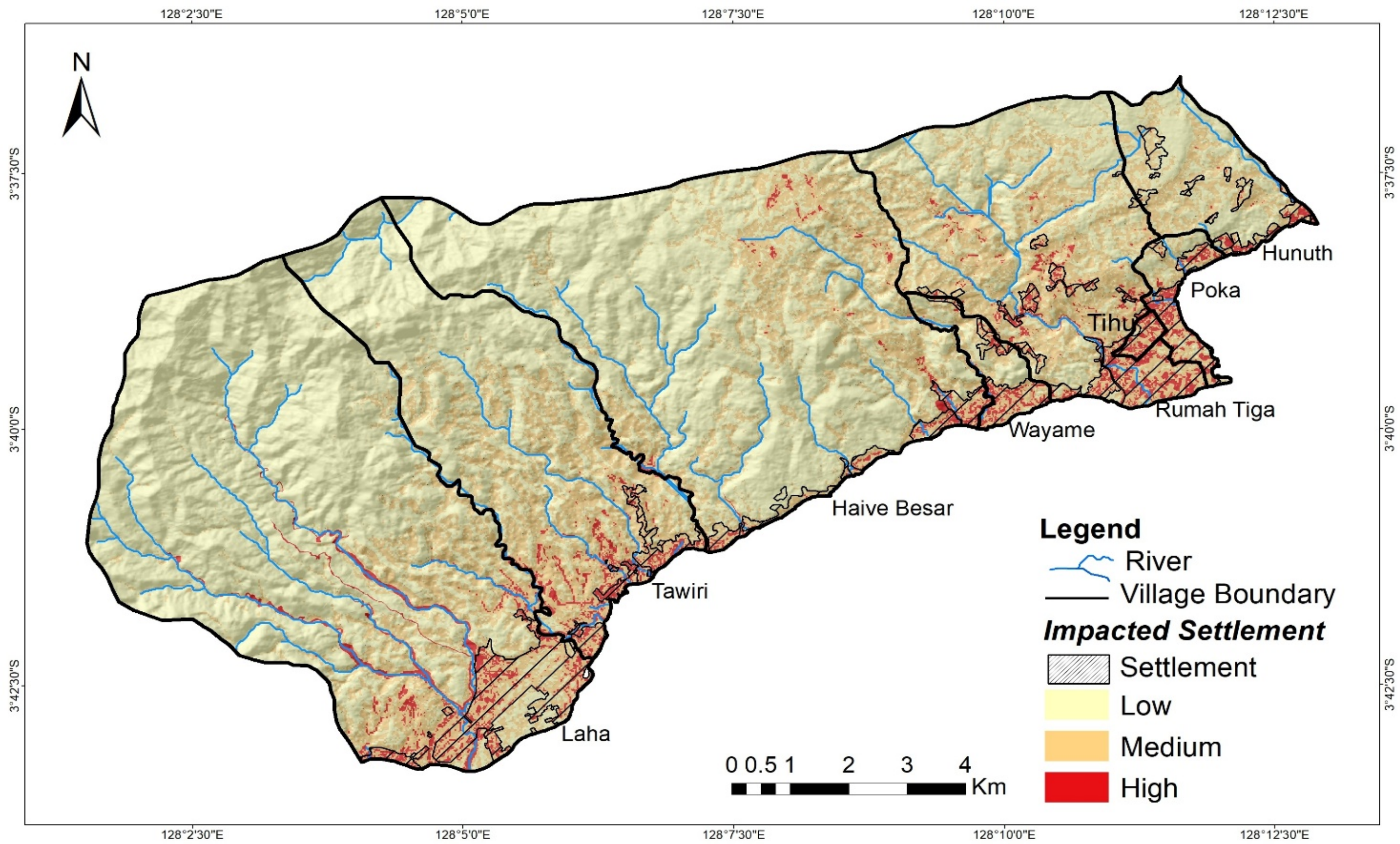


Figure 7. Built-up land in Teluk Ambon District predicted to be affected by floods.

3.2. Flood Vulnerability Level of Teluk Ambon sub-district

The susceptibility to flooding in Teluk Ambon sub-district is categorized into three tiers: low risk, which encompasses 8,642.26 hectares or 64.71% of the area; moderate risk, covering 4,066.79 hectares or 30.45%; and high risk, accounting for 646.44 hectares or 4.84%. This vulnerability level is complexly influenced by various environmental variables analyzed through the AHP method, which produced the following variable contributions: Elevation (12.07%), Slope (9.90%), TWI (13.78%), NDVI (5.87%), Rainfall (13.45%), Land Cover (6.62%), Soil Type (9.32%), Drainage Density (9.32%), Distance from Roads (5.59%), and Distance from Rivers (14.08%). Variables with the largest weights, such as Distance from River, TWI, and Precipitation, play a central role in increasing flood risk, particularly in regulating the volume and rate of surface water flow and the potential for flooding. A study by Khoeun confirms that the integration of topography, hydrology, and surface condition variables through AHP and GIS can provide a comprehensive picture of flood risk levels in tropical regions, making the results of this modeling highly relevant to support mitigation policies and spatial planning in Ambon City and its surroundings [58].

The level of flood vulnerability shows variation between sub-districts, with the highest concentration at low to moderate levels of vulnerability, and several areas with high levels of vulnerability (Figure 5). Figure 6 shows that the largest areas with low flood vulnerability are in Laha (3,355.16 ha) and Tawiri (1,255.17 ha), while the largest areas with moderate vulnerability are in Rumah Tiga (965.30 ha) and Laha (898.24 ha). High vulnerability is relatively smaller but significant, especially in Laha, Tawiri, and Rumah Tiga. This vulnerability occurs due to a combination of environmental factors such as topography, land use, high rainfall, and proximity to rivers and densely populated residential areas, which cause a high risk of flooding in Teluk Ambon [59]. This study is in line with other studies that state that Ambon City generally has a moderate level of flood vulnerability, with areas of high and very high vulnerability concentrated around Ambon Bay, which is an area with a complex accumulation of flood risk factors such as low elevation and high population density [60].

3.3. Prediction of Flood-Affected Settlements

The results of the flood vulnerability analysis were then overlaid with built-up land to identify the affected areas (Figure 7). The results of the study show that the affected settlement areas have varying levels of vulnerability, ranging from low, moderate, and high, with a significant area at the moderate level (649.29 ha) and high level (345.07 ha). These settlements with moderate and high vulnerability levels are generally located in areas near rivers and lowlands that are prone to flooding, according to spatial modeling results that incorporate factors such as topography, distance from rivers, rainfall, and land use [61].

This approach is important for providing more accurate flood risk maps to support spatial planning and disaster mitigation in affected areas [29]. Similar research integrating GIS and AHP in Ambon also shows that detailed wet risk mapping is very helpful in decision-making for disaster risk management, especially in urban areas with complex vulnerability characteristics [62].

4. Conclusion

The findings of this study indicate that flood vulnerability in Teluk Ambon sub-district is categorized into three primary classes: low risk (64.71%), medium risk (30.45%), and high risk (4.84%). These risk levels are shaped by a range of complex environmental factors analyzed through the application of AHP and GIS techniques. The dominant factors contributing to flood vulnerability are distance from rivers (14.08%), TWI (13.78%), and rainfall (13.45%), which significantly regulate the potential for flooding and surface runoff. This vulnerability varies between subdistricts, with high-risk areas concentrated in areas with low topography and high settlement density, such as Laha and Rumah Tiga. Overlaying this with settlement data shows that areas with moderate and high risk are vulnerable to flooding, confirming the need to utilize precise flood risk maps as an important tool in spatial planning and disaster mitigation in this region.

5. Declarations

5.1. Author Contributions

Heinrich Rakuasa: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources; **Ahmat Rifai:** Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Funding acquisition.

5.2. Institutional Review Board Statement

Not applicable.

5.3. Informed Consent Statement

Not applicable.

5.4. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.5. Acknowledgment

The author would like to thank all parties who assisted in this research.

5.6. Conflicts of Interest

The authors declare no conflicts of interest.

6. References

[1] R. Riaz and Md. Mohiuddin, "Application of GIS-based multi-criteria decision analysis of hydro-geomorphological factors for flash flood susceptibility mapping in Bangladesh," *Water Cycle*, vol. 6, pp. 13–27, 2025, https://doi.org/10.1016/j.watcyc.2024.09.003.

[2] S. Bamrungkhul and T. Tanaka, "The assessment of land suitability for urban development in the anticipated rapid urbanization area from the Belt and Road Initiative: A case study of Nong Khai City, Thailand," *Sustainable Cities and Society*, vol. 83, p. 103988, Aug. 2022, https://doi.org/10.1016/j.scs.2022.103988.

[3] Md. N. Hossain and U. H. Mumu, "Flood susceptibility modelling of the Teesta River Basin through the AHP-MCDA process using GIS and remote sensing," *Natural Hazards*, vol. 120, no. 13, pp. 12137–12161, Oct. 2024, https://doi.org/10.1007/s11069-024-06677-z.

[4] P. Dutta and S. Deka, "A novel approach to flood risk assessment: Synergizing with geospatial based MCDM-AHP model, multicollinearity, and sensitivity analysis in the Lower Brahmaputra Floodplain, Assam," *Journal of Cleaner Production*, vol. 467, 2024, https://doi.org/10.1016/j.jclepro.2024.142985.

[5] H. Rakuasa and V. V. Khromykh, “Utilization of GIS Technology for Mapping Flood-Prone Areas in Ambon Island, Indonesia,” *KnE Social Sciences*, vol. 10, no. 10, pp. 296–310, May 2025, https://doi.org/10.18502/kss.v10i10.18679.

[6] D. A. Rakuasa, H., Helwend, J. K., & Sihasale, “Pemetaan Daerah Rawan Banjir di Kota Ambon Menggunakan Sistim Informasi Geografis,” *Jurnal Geografi: Media Informasi Pengembangan dan Profesi Kegeografian*, vol. 19, no. 2, pp. 73–82, 2022, https://doi.org/10.15294/jg.v19i2.34240.

[7] V. Chauhan, L. Gupta, and J. Dixit, “Machine learning and GIS-based multi-hazard risk modeling for Uttarakhand: Integrating seismic, landslide, and flood susceptibility with socioeconomic vulnerability,” *Environmental and Sustainability Indicators*, vol. 26, p. 100664, Jun. 2025, https://doi.org/10.1016/j.indic.2025.100664.

[8] H. Salakory, M., Rakuasa, “Modeling of Cellular Automata Markov Chain for predicting the carrying capacity of Ambon City,” *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (JPSL)*, vol. 12, no. 2, pp. 372–387, 2022, https://doi.org/10.29244/jpsl.12.2.372-387.

[9] I. Hasan, M. M. H. Rakib, D. K. Roy, M. H. Ovi, M. F. Hasan, and M. S. I. Majumder, “Geospatial flood susceptibility modelling using analytical hierarchy process: A case study in the south-central coastal region of Bangladesh,” *Geosystems and Geoenvironment*, vol. 5, no. 1, 2026, https://doi.org/10.1016/j.geogeo.2025.100457.

[10] Badan Nasional Penanggulangan Bencana, *Indeks Resiko Bencana Indonesia 2024*. Jakarta: Badan Nasional Penanggulangan Bencana, 2025.

[11] Y. A. Berrezel, C. Chérifa, A. Megnounif, M. Saber, M. E. A. Benabdelkrim, and N. Kumar, “Assessment of flood risk using integrated GIS and analytic hierarchy process in the Mekerra basin, Northwestern Algeria,” *Journal of African Earth Sciences*, vol. 233, 2026, https://doi.org/10.1016/j.jafrearsci.2025.105830.

[12] G. S. Dwarakish, B. J. Pai, and R. Rajeesh, “Urban Flood Hazard Zonation in Bengaluru Urban District, India,” *Journal of Landscape Ecology (Czech Republic)*, vol. 17, no. 1, pp. 89–106, 2024, https://doi.org/10.2478/jlecol-2024-0006.

[13] M. Kasahun, D. Diriba, T. Lemma, S. Karuppannan, and N. Kanko, “Flood vulnerability and risk mapping in Arba minch city using remote sensing, GIS and AHP,” *Scientific African*, vol. 30, 2025, https://doi.org/10.1016/j.sciaf.2025.e02976.

[14] H. Deopa and M. R. Resmi, “Assessing Flood-Induced Soil Loss and Vulnerability in the Luni River Basin: A GIS-MCDM, AHP, and RUSLE Integration,” *Water Conservation Science and Engineering*, vol. 10, no. 3, 2025, https://doi.org/10.1007/s41101-025-00418-4.

[15] A. Gebremichael, E. Gebremariam, and H. Desta, “GIS-based mapping of flood hazard areas and soil erosion using analytic hierarchy process (AHP) and the universal soil loss equation (USLE) in the Awash River Basin, Ethiopia,” *Geoscience Letters*, vol. 12, no. 1, 2025, https://doi.org/10.1186/s40562-025-00382-w.

[16] M. D. J. Nyereyegona, A. N. Mazhindu, and K. C. Chirenje, “Suitability analysis to determine optimal locations of local community radio transmitters using GIS and remote sensing: a case study of Chipinge district, Zimbabwe,” *Scientific Reports*, vol. 15, no. 1, 2025, https://doi.org/10.1038/s41598-025-90220-y.

[17] A. Mulu, S. B. Kassa, M. L. Wossene, S. Adefris, and T. M. Meshesha, “Identification of flood vulnerability areas using analytical hierarchy process techniques in the Wuseta watershed, Upper Blue Nile Basin, Ethiopia,” *Scientific Reports*, vol. 15, no. 1, 2025, https://doi.org/10.1038/s41598-025-13822-6.

[18] H. Latue, P. C., & Rakuasa, “Identification of Flood-Prone Areas Using the Topographic Wetness Index Method in Fena Leisela District, Buru Regency,” *Journal Basic Science and Technology*, vol. 12, no. 2, 2032, https://doi.org/10.35335/jbst.v12i1.3673.

[19] H. Rakuasa and P. C. Latue, “Modeling Flood Hazards in Ambon City Watersheds: Case Studies of Wai Batu Gantung, Wai Batu Gajah, Wai Tomu, Wai Batu Merah and Wai Ruhu,” *Journal of Engineering and Science Application*, vol. 1, no. 2, pp. 1–8, Oct. 2024, https://doi.org/10.69693/jesa.v1i2.6.

[20] M. Husein, T. Takele, D. Diriba, and S. Karuppannan, “Flood hazard and risk assessment using GIS and remote sensing in the case of Ziway Lake watershed, central Main Ethiopian Rift,” *Environmental and Sustainability Indicators*, vol. 28, 2025, https://doi.org/10.1016/j.indic.2025.100920.

[21] K. C. Oliveira Lima *et al.*, “Integrated use of the analytical hierarchy process method for mapping areas susceptible to flooding in the urban area in a city in southwest Bahia, Brazil,”

Journal of South American Earth Sciences, vol. 167, 2025, https://doi.org/10.1016/j.jsames.2025.105778.

[22] O. A. Rahim, H. Yin, S. Ullah, and A. N. Durrani, "Delineation of groundwater potential zones and recharge using multi-source big data and systematic analysis approach," *Sustainable Futures*, vol. 10, 2025, https://doi.org/10.1016/j.sftr.2025.100872.

[23] H. Chihi, M. A. Hammami, and I. Mezni, "Flood susceptibility mapping in data-scarce arid environments: guided by geology-driven knowledge and multi-event cloud-based validation," *Natural Hazards*, vol. 121, no. 18, pp. 20855–20901, 2025, https://doi.org/10.1007/s11069-025-07533-4.

[24] A. Tiangtrong, T. Mangmoon, S. Apirak, N. Amornwech, N. Noipow, and C.-D. Jan, "Optimized shelter planning in flood-prone areas using geographic information systems (GIS) and the analytical hierarchy process (AHP): an analysis of Ubon Ratchathani, Thailand," *Natural Hazards*, vol. 121, no. 18, pp. 21097–21119, 2025, https://doi.org/10.1007/s11069-025-07604-6.

[25] H. Rakuasa, "Spatial Modeling of Flood Prone Areas in Huamual Sub-district Seram Bagian Barat Regency Indonesia," *Journal of Geographical Sciences and Education*, vol. 1, no. 2, pp. 47–57, 2023.

[26] Q. N. X. Chau, G. N. H. Ngo, D. D. Tran, T. T. N. Huynh, and T. T. M. Thy, "A Systematic Approach to Spatial Allocation in Sustainable Urban Drainage Systems (SUDS) Implementation: a Case Study in the Nhieu Loc – Thi Nghe Basin, Ho Chi Minh City, Vietnam," *International Journal of Environmental Research*, vol. 19, no. 5, 2025, https://doi.org/10.1007/s41742-025-00849-w.

[27] D. R. Maru, V. Kumar, K. V Sharma, Q. B. Pham, and A. Patel, "Integrating GIS, MCDM, and Spatial Analysis for Comprehensive Flood Risk Assessment and Mapping in Uttarakhand, India," *Geological Journal*, vol. 60, no. 9, pp. 2263–2280, 2025, https://doi.org/10.1002/gj.5172.

[28] I. Bishikwabo, H. Mambo, J. K. Kamanda, C. Chérifa, M. A. Nanyunga, and N. Kumar, "Urban Flood Susceptibility Mapping Using GIS and Analytical Hierarchy Process: Case of City of Uvira, Democratic Republic of Congo," *GeoHazards*, vol. 6, no. 3, 2025, https://doi.org/10.3390/geohazards6030038.

[29] H. Al-Kordi, A. al-Amri, and G. Raju, "Flash Flood Susceptibility Mapping Using Geospatial and Analytical Hierarchy Process Modeling-A Study of Wadi Habban Basin, Shabwah, Yemen," *Nature Environment and Pollution Technology*, vol. 24, no. 3, 2025, https://doi.org/10.46488/NEPT.2025.v24i03.B4280.

[30] T. Morimoto, H. Jin, S. Tong, and Y. Bao, "Assessment of Flood Risk of Residential Buildings by Using the AHP-CRITIC Method: A Case Study of the Katsushika Ward, Tokyo," *Buildings*, vol. 15, no. 12, 2025, https://doi.org/10.3390/buildings15122016.

[31] J. Gacu *et al.*, "Integrated multi-hazard risk assessment under compound disasters using analytical hierarchy process (AHP)," *Heliyon*, vol. 11, no. 11, 2025, https://doi.org/10.1016/j.heliyon.2025.e43173.

[32] M. S. Kendagannaswamy, C. K. Roopa, B. S. Harish, and M. S. Mukesh, "Multi-criteria decision analysis for regional-scale flood susceptibility mapping in Kerala state, India," *Discover Applied Sciences*, vol. 7, no. 6, 2025, https://doi.org/10.1007/s42452-025-07182-z.

[33] S. K. Aswin, V. S. Pitchaimani, and A. J. A. A. Promilton, "Flood Susceptibility Assessment for Coastal Villages of Southern Tamil Nadu: An Integrated GIS and AHP Approach," *Disaster Advances*, vol. 18, no. 6, pp. 18–27, 2025, https://doi.org/10.25303/186da018027.

[34] A. Kalita, A. P. Saikia, and P. Singh, "Integrated water management and agroforestry planning in the Kulsi river basin: a data-driven decision-making approach," *Agroforestry Systems*, vol. 99, no. 5, 2025, https://doi.org/10.1007/s10457-025-01191-y.

[35] T. Agaj, "Integrating AHP and MCDA for flood risk assessment in Kosovo: a catchment-based perspective," *Natural Hazards*, vol. 121, no. 9, pp. 10711–10747, 2025, https://doi.org/10.1007/s11069-025-07212-4.

[36] A. Nath, B. Koley, T. Choudhury, and A. Biswas, "Prioritizing flood drivers: an AHP-based study of physical factors in Digha's coastal belt, East Coast, India," *Spatial Information Research*, vol. 33, no. 2, 2025, https://doi.org/10.1007/s41324-025-00615-2.

[37] A. Sood, K. S. Vignesh, and V. N. Prapanchan, "Multi-hazard vulnerability zone identification using GIS-based fuzzy AHP and MCDM techniques," *Natural Hazards*, vol. 121, no. 7, pp. 8501–8539, 2025, https://doi.org/10.1007/s11069-025-07125-2.

[38] P. Thammaboribal, N. K. Tripathi, and S. Lipiloet, "Using of Analytical Hierarchy Process (AHP) in Disaster Management: A Review of Flooding and Landslide Susceptibility Mapping," *International Journal of Geoinformatics*, vol. 21, no. 4, pp. 177–196, 2025, https://doi.org/10.52939/ijg.v21i4.4091.

[39] P. B. Borah, A. Handique, C. K. Dutta, D. Bori, S. Acharjee, and L. Longkumer, "Assessment of flood susceptibility in Cachar district of Assam, India using GIS-based multi-criteria decision-making and analytical hierarchy process," *Natural Hazards*, vol. 121, no. 6, pp. 7625–7648, 2025, https://doi.org/10.1007/s11069-024-07100-3.

[40] B. Das, T. K. Ray, and E. Boral, "Identification of urban waterlogging risk zones using Analytical Hierarchy Process (AHP): a case of Agartala city," *Environmental Monitoring and Assessment*, vol. 197, no. 3, 2025, https://doi.org/10.1007/s10661-025-13725-z.

[41] R. Sharker *et al.*, "GIS-based AHP approach to flood susceptibility assessment in Tangail district, Bangladesh," *Journal of Earth System Science*, vol. 134, no. 1, 2025, https://doi.org/10.1007/s12040-024-02480-3.

[42] M. Aliyu, A. A. Dandajeh, S. B. Igboro, and N. I. Abdullahi, "Flood Hazard Assessment and Mapping in River-Rima Floodplain, Birnin Kebbi-Nigeria," *Nigerian Journal of Technological Development*, vol. 22, no. 1, pp. 279–293, 2025, https://doi.org/10.4314/njtd.v22i1.2862.

[43] R. Ch. Raghava and G. K. Viswanadh, "Flood Susceptibility Assessment of Wyra River Catchment, South India using AHP-GIS Multi Criteria Approach," *Disaster Advances*, vol. 18, no. 2, pp. 38–51, 2025, https://doi.org/10.25303/182da038051.

[44] M. Narzary, P. Dey, S. K. Patnaik, and T. Riming, "Assessment and Monitoring of Flood Susceptibility Zones Using Analytical Hierarchy Process (AHP) Model and Geospatial Techniques in the Lakhimpur Block, Lakhimpur District, Assam, India," in *Environmental Science and Engineering*, vol. Part F264, Rajiv Gandhi University, Doimukh, Department of Geography, Doimukh, India: Springer Science and Business Media Deutschland GmbH, 2025, pp. 179–208. https://doi.org/10.1007/978-3-031-82311-4_8.

[45] M. Benaiche, E. Mokhtari, A. Berghout, B. Abdelkebir, and B. Engel, "Sensitivity of flood-prone areas to extreme rainfall using AHP and fuzzy AHP: A case study of Boussellam and K'sob watersheds, Algeria," *Journal of Water and Climate Change*, vol. 16, no. 6, pp. 1948–1968, 2025, https://doi.org/10.2166/wcc.2025.520.

[46] N. Sar, P. K. Ryngnga, and D. K. De, "Application of the analytical hierarchy process (AHP) for flood susceptibility mapping using GIS techniques in lower reach of Keleghai River Basin, West Bengal, India," *Geohazard Mechanics*, vol. 3, no. 2, pp. 123–135, 2025, https://doi.org/10.1016/j.ghm.2025.06.002.

[47] S. K. Ray, "Flood risk index mapping in data scarce region by considering GIS and MCDA (FRI mapping in data scarce region by considering GIS and MCDA)," *Environment, Development and Sustainability*, vol. 27, no. 7, pp. 17329–17381, 2025, https://doi.org/10.1007/s10668-024-04641-2.

[48] N. Taoukidou, D. Karpouzos, and P. Georgiou, "Flood Hazard Assessment Through AHP, Fuzzy AHP, and Frequency Ratio Methods: A Comparative Analysis," *Water (Switzerland)*, vol. 17, no. 14, 2025, https://doi.org/10.3390/w17142155.

[49] S. Ashfaq, M. Tufail, A. Niaz, S. Muhammad, H. Alzahrani, and A. Tariq, "Flood susceptibility assessment and mapping using GIS-based analytical hierarchy process and frequency ratio models," *Global and Planetary Change*, vol. 251, 2025, https://doi.org/10.1016/j.gloplacha.2025.104831.

[50] K. Chomani and D. M. Al-Shrafany, "Innovative Approaches to Flood Hazard Assessment in Semi-Arid Environments: A Comparative Analysis of Multi-Criteria and Geospatial Techniques," *Iraqi Geological Journal*, vol. 58, no. 2, pp. 86–109, 2025, https://doi.org/10.46717/igj.2025.58.2A.6.

[51] S. K. Patel, P. Ghosh, D. Sen Gupta, and A. Kumar, "Flood modeling using GIS-based analytical hierarchy process in Gandak river basin of Indian territory," *Natural Hazards*, vol. 121, no. 14, pp. 16515–16557, 2025, https://doi.org/10.1007/s11069-025-07439-1.

[52] H. Latue, P. C., Imanuel Septory, J. S., Somae, G., & Rakuasa, "Pemodelan Daerah Rawan Banjir di Kecamatan Sirimau Menggunakan Metode Multi-Criteria Analysis (MCA)," *Jurnal Perencanaan Wilayah Dan Kota*, vol. 18, no. 1, pp. 10–17, 2023, https://doi.org/10.29313/jpwk.v18i1.1964.

[53] A. Mehmood, M. A. Basheer, H. S. H. Arshad, S. Zia, S. T. Muntaha, and A. R. Riaz, "Assessing the potential of rainwater harvesting through GIS and remote sensing

techniques in combating urban flooding in Lahore, Pakistan," *GeoJournal*, vol. 90, no. 4, 2025, https://doi.org/10.1007/s10708-025-11446-x.

[54] A. Mulu, S. B. Kassa, M. Lakew, and T. M. Meshesha, "Flood susceptibility mapping using integrated geospatial and analytical hierarchy process analysis in highly expansive Debre Markos Town, Amhara Region, Ethiopia," *Discover Applied Sciences*, vol. 7, no. 8, 2025, https://doi.org/10.1007/s42452-025-07563-4.

[55] N. Alafostergios, N. Evelpidou, and E. Spyrou, "Flood Susceptibility Assessment Based on the Analytical Hierarchy Process (AHP) and Geographic Information Systems (GIS): A Case Study of the Broader Area of Megala Kalyvia, Thessaly, Greece," *Information (Switzerland)*, vol. 16, no. 8, 2025, https://doi.org/10.3390/info16080671.

[56] L. Pimenta, L. Duarte, A. C. Teodoro, N. Beltrão, D. Gomes, and R. Oliveira, "GIS-Based Flood Susceptibility Mapping Using AHP in the Urban Amazon: A Case Study of Ananindeua, Brazil," *Land*, vol. 14, no. 8, 2025, https://doi.org/10.3390/land14081543.

[57] C. Rodopoulos, G. Saitis, and N. Evelpidou, "Physical Flood Vulnerability Assessment in a GIS Environment Using Morphometric Parameters: A Case Study from Volos, Greece," *Water (Switzerland)*, vol. 17, no. 16, 2025, https://doi.org/10.3390/w17162449.

[58] C. Khoeun *et al.*, "Assessing Flood Hazard Index using Analytical Hierarchy Process (AHP) and Geographical Information System (GIS) in Stung Sen River Basin," in *IOP Conference Series: Earth and Environmental Science*, 2022. https://doi.org/10.1088/1755-1315/1091/1/012031.

[59] M. R. Al-Gburi, "GIS-Based Spatial Distribution of Flood Hazards in the Chamchamal Basin, Sulaymaniyah, NE Iraq," *Iraqi Geological Journal*, vol. 58, no. 2, pp. 155–168, 2025, https://doi.org/10.46717/igj.2025.58.2B.11.

[60] E. Stemn, B. Kumi-Boateng, and S. Fosu, "Flood susceptibility assessment using a GIS and multicriteria decision modelling approach: A case of the Wassa west mining area of Ghana," *Journal of African Earth Sciences*, vol. 229, 2025, https://doi.org/10.1016/j.jafrearsci.2025.105706.

[61] V. Kumar, A. Rashiq, and O. Prakash, "Integrated flood risk prediction and zonation in bihar: observations from climate change projection using GIS-based AHP-Multicriteria approach," *Theoretical and Applied Climatology*, vol. 156, no. 9, 2025, https://doi.org/10.1007/s00704-025-05669-8.

[62] E. Barlian *et al.*, "GIS and AHP-Based Flood Zoning and Conservation Strategies in The Tarusan Watershed, Indonesia," *Geographia Technica*, vol. 20, no. 2, pp. 114–133, 2025, https://doi.org/10.21163/GT_2025.202.08.