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Remote sensing and Geographic Information System for flooding vulnerability zoning in Majalaya, Indonesia

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Abstract

The flood risk in Majalaya District, Bandung Regency, is on the rise due to climate change, alterations in river basin conditions, and changes in land use. Flood disasters pose significant threats to communities and the environment. To initiate disaster mitigation measures, it is imperative to conduct flood hazard mapping in the area. This study employs a quantitative descriptive approach using remote sensing and Geographic Information Systems analysis. The results reveal three flood vulnerability zones: low, moderate, and high. The high vulnerability zone, which covers 720 hectares and comprises nine villages, is predominantly situated in the northern part of the district. The moderate vulnerability zone encompasses an area of 512 hectares, while the low vulnerability zone covers approximately 1,194 hectares, constituting about 49 percent of the total area. This zoning serves as a foundational tool for disaster mitigation spatial planning in the Majalaya District.

Keywords: flood hazard zoning; remote sensing; Geographic Information Systems; spatial digital mapping

1. Introduction

Climate change is a natural phenomenon that has occurred and affected various aspects of life. According to Law Number 31 of 2009 concerning Meteorology, Climatology, and Geophysics, climate change is defined as a change caused, directly or indirectly, by human activities, leading to a transformation in the composition of the atmosphere globally as well as changes in natural climate variability, observed over a comparable period of time. In a study, Nurhayati et al. (2020) proposed that climate change is a consequence of global warming, which has deleterious effects on human activities and lives. Accordingly, humans play a crucial role in the occurrence of climate change, which in turn has affected their daily activities. In addition to human activities, Ratnaningayu (2009) indicates that climate change can also be attributed to instability in weather conditions, including uncertainty in rainfall patterns, frequent storms, extreme fluctuations in air temperature, and drastic changes in wind direction, among other factors.

The occurrence of climate change has been linked to a number of negative impacts on humans. A study conducted by the Meteorology, Climatology, and Geophysics Agency revealed that climate change has led to a number of changes, including the shifting of the location of the onset of El Niño, alterations in the average annual temperature, deviations in rainfall patterns, and an increase in the positive trend of rainy days. Further, this has resulted in an increasing number of flood cases in Indonesia (Hadi, 2020). In 2019, there were 784 cases of flood disasters, increasing to 1,080 cases in 2020. At the beginning of 2021, throughout January, there were 167 cases of flooding (National Disaster Management Agency, 2021). Besides,

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climate change also emanated an increase in extreme weather events, including heavy rainfall and flooding (Do Lago et al., 2019; Mohajervatan et al., 2021; Surminski & Oramas-Dorta, 2014; Wicaksono et al., 2021). Therefore, numerous instances of flooding that have occurred in Indonesia are inseparable from climate change and human activities. One of the regions most frequently affected by flooding is the Upper Citarum Watershed, situated in Bandung, Indonesia.

The administrative boundaries of the Upper Citarum Watershed encompass the Bandung Municipality, Bandung Regency, Cimahi City, and Sumedang Regency, all of which are situated within the boundaries of the West Java Province, Indonesia. This watershed encompasses seven subwatersheds, including the Citarik Subwatershed, Cisangkui Subwatershed, Cirasea Subwatershed, Ciwidey Subwatershed, Cihaur Subwatershed, Cikapundung Subwatershed, and Ciminyak Subwatershed. These regions encounter flooding annually, typically attributed to high rainfall intensity. A study by Dasanto et al. (2013) reported the flood distribution area in Bandung encompasses an estimated 22,725 hectares across 28 sub-districts and 79 urban villages situated on both sides of the Upper Citarum River. Boer et al. (2013) demonstrated that floods with a once-in-2-to-5-year occurrence have been reported in an area of 2,100 hectares. Meanwhile, the area affected by floods with a 5-to-10-year return period increased to 12,239 hectares, while for events with a 10-to-25-year return period, the area affected reached 19,165 hectares. The flood with returning period of more than 25 years, has reached an area of 22,725 hectares. In consideration of the High Emissions Scenario (SRES) of future climate change, areas that experience flooding once every two to four years will likely experience flooding almost every year with a larger area. This data indicates the need for conquering the situation.

One of the Upper Citarum Sub-drainage areas affected by climate change is Majalaya Sub-district. This sub-district is frequently subjected to severe floods and droughts. According to data from the Central Bureau of Statistics, this area experiences increasing annual rainfall year-by-year. In 2004, the annual precipitation ranged from 1,275 mm, which increased to 1,603 mm in 2005 and to 1,996 mm in 2018. In addition to rainfall, the air temperature in the region has also increased significantly. In 2009, the average temperature reached 19.5°C, and by 2014, it had increased to 24°C. Accordingly, this situation further exacerbated the floods and droughts in the region. In 2008, there were 20 cases of flooding in the region, while in 2016, there were 17 cases, with an annual average of 10-20 cases of flooding. This data positions the region as one of the most flood-prone areas to flooding. The high level of flood and drought vulnerability in the surrounding areas of the Upper Citarum Sub-watershed further leads to higher potential impacts of climate change. In addition to the aforementioned flooding, the region is also frequently affected by drought during the dry season. This has a significant impact on the communities in the area, as they often lack access to clean water or water for irrigation of their agricultural land.

In addition, floods cause significant damage and losses to the community, along with the city's infrastructure. According to Findayani (2015), floods rank third among the most damaging disasters worldwide, particularly in the economic sector. Aminudin (2013) posits that floods can have both physical and non-physical impacts, including damage to residential areas, difficulty in obtaining a clean water supply, damage to community infrastructure, damage to agricultural land, the emergence of disease, and the disruption of land transportation. Rosyidie (2013) further elaborated that the impact of flooding can be direct and indirect. Direct impacts include casualties from injuries to death, disruption of transportation, relocation of victims to refugee camps, as well as economic and social losses. The increasing prevalence of flooding in Majalaya Sub-district, Bandung Regency, is caused by various factors, including heavy rains, broken dams, and broken embankments. Furthermore, unregulated urbanization in flood-prone areas and deforestation also contribute to the increased frequency and magnitude of floods (Saudi et al., 2017). The February 2018 flood in Majalaya is an example of an extreme rainfall event that caused severe economic and social consequences (Burnama et al., 2023).

In the recent era, the advancement of remote sensing and Geographic Information System (GIS) technology through spatial digital mapping has become a prevalent methodology for the analysis of areas susceptible to flooding. A number of studies have employed this technology to map flood-prone zones in various locations across Indonesia (Arbi & Usman, 2022; Ariyora et al., 2015; Darmawan & Suprayogi, 2017; Haryani, 2017; Pryastuti & Nasri, 2021; Sari, 2014; Seftiani et al., 2023; Septian et al., 2020). The methodology employed in the existing research involved overlaying several parameters, including the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI), and the Simple Ratio (SR) (Hernoza et al., 2020). In their research, Arbi and Usman (2022) employed both primary and secondary data sources, including slope, topography, geology, soil type, rainfall, and land use, to assess the level of flood vulnerability in Pattallassang District. Their findings indicated that the inundation area in Pattallassang Subdistrict has exhibited a 9.45% increase over time.

In some studies, descriptive quantitative and remote sensing methods were employed to calculate and describe the calculation of flood hazard parameters (Seftiani et al., 2023). An analysis of flood vulnerability levels in Sampang Regency was conducted using the overlay method with GIS-based scoring (Darmawan & Suprayogi, 2017). Mapping the level of flood hazard using GIS-based scoring and overlay methods was also carried out in Jambi City (Pryastuti & Nasri, 2021). In another study, GIS-based identification of potential flood zones was conducted in Agam Regency, West Sumatra. This research employed both primary and secondary data, including topography, slope, geology, and soil type, as well as rainfall and land use data. The objective of this research was to determine the level of flood vulnerability using GIS on remote sensing with Weighted Scoring Analysis (Septian et al., 2020).

The application of GIS also facilitates the mapping of areas with flood hazard levels. In GIS, the overlay method is employed to identify flood parameters, including slope, land elevation, soil type, rainfall, land use, and river buffering. Consequently, enables the presentation of spatial information, particularly those related to determining the level of flood vulnerability. Furthermore, it can also be employed to analyze and garner novel information in identifying areas often targeted by floods (Nurdiawan, 2018). Meanwhile, the utilization of remote sensing technology and Geographic Information Systems through spatial digital mapping analysis enables the rapid and accurate identification of areas that may be affected by flooding.

In recent years, the integration of remote sensing and GIS has gained increased popularity in flood vulnerability zoning. These technologies provide valuable tools for mapping and analyzing flood events, enabling a better understanding of the intensity, frequency, as well as the extent of floods and their impacts (Adeyeri et al., 2017; Demirkesen, 2016; Gaurav et al., 2011). Further, the integration of remote sensing with Geographic Information Systems (GIS) enables the investigation and mapping of areas vulnerable or less vulnerable to flooding. This facilitates the design of flood management strategies and disaster response plans (Raufu et al., 2023; Tamiru & Dinka, 2021; Twumasi et al., 2020). When combined with remote sensing data, GIS facilitates the rapid acquisition and dissemination of quantitative information over large areas, thereby aiding the rapid assessment of flood damage and decision-making during flood events (Ding et al., 2021).

In the absence of measures for disaster adaptation and mitigation, it is increasingly difficult to regulate the effects of climate change. This study aims to analyze flood-prone zoning in the Majalaya Sub-district using remote sensing imagery and geospatial information systems in order to reduce the flooding risks experienced by the community. GIS modeling was adopted to garner information related to the level of flood threat in an area, which is crucial for policymaking. To date, flooding in the Majalaya Sub-district has occurred with considerable regularity, yet there has been no specific research on flood vulnerability zoning in the Majalaya Sub-district. The results of this research are of great significance for stakeholders, as they provide an overview of the zoning of flood-prone areas in the Majalaya Sub-district, which serves as a basis for policy determination and disaster mitigation.

2. Method

This descriptive quantitative study conducted Remote Sensing and Geographic Information System analysis to assist in the description and modeling of the research related to flood-prone zoning. The research was performed in the entire area of Majalaya Sub-district, Bandung Regency, Indonesia, which encompasses approximately eight villages.

The research garnered two types of data: primary data and secondary data. Primary data was obtained directly from field observations of the object under analysis, employing Remote Sensing and Geographic Information System (GIS) methods. In contrast, secondary data encompassed supplementary information, including soil data, topographic information, land use patterns, Citarum River hydrology reports, and a multitude of other data sources.

The data analysis was performed through remote sensing processing to obtain a land use database and Geographic Information System (GIS) analysis for modeling flood vulnerability zoning based on predetermined parameters, including land use data, soil, slope, topography, and the distance of an area from the Upper Citarum main river. Detailed information on the parameters is presented in Table 1.

In this research, the data analysis was performed through descriptive analysis. This descriptive analysis entailed the interpretation of the data based on the researcher's knowledge and expertise. The analysis results were presented in the form of a narrative description or explanation. Further, the process also involved the review and interpretation of the collected data and information. Ideas, expressions, and views revealed during field observations were grouped and classified. Detailed information concerning the process of data collection and analysis is described in the following.

Table 1. Parameters of Flood Vulnerability Zoning

No	Variable	Wight	Indicator	Important Value	Score
1	Land Use	15	Rice Fields and Other Water Bodies	5	100
			Settlements	4	80
			Fields and Plantations	3	60
			Vacant Land	2	40
			Forest	1	20
2	Topography	20	Flat Territory	5	100
			Hilly Territory	4	80
3	Slope	15	0-8	5	100
			8-16	4	80
			16-27	3	60
			27-40	2	40
			>40	1	20
4	Soil	5	0-8	5	100
			8-16	4	80
			16-27	3	60
5	Distance From River	10	<50	5	100
			50 – 75	4	80
			75 – 100	3	60
			100 – 300	2	40
			>300	1	20

In this research, the data analysis was performed through descriptive analysis, which entailed interpreting the data based on the researcher's knowledge and expertise. The analysis results were presented as a narrative description or explanation, involving the review and interpretation of the collected data and information. Ideas, expressions, and views revealed during field observations were grouped and classified. Detailed information concerning the process of data collection and analysis included several stages. The data collection stage aimed to examine the overall data collected from various sources, such as rainfall maps, elevation and slope data, land use patterns, soil types, contours, and geological formations obtained from relevant agencies. Delineation involved creating boundaries and identifying maps based on predetermined sub-indicators. The designation of attributes entailed compiling data on weights, values, and scores for each indicator and sub-indicator. The overlay process involved equalizing the scale of each map to facilitate the overlay of layers. Map data analysis aimed to obtain the value of each indicator by multiplying the specified weight with the importance value, thereby deriving a score for each indicator. This process enabled the classification of zones of vulnerable areas to flooding in the Majalaya Sub-district. The results of the score times the weight of all parameters were then fuzzified to produce a value with an interval of 0–1, representing flood zoning. Table 2 illustrates the interval of flood vulnerability classes, categorizing them into low, medium, and high vulnerability zones.

$$I = \frac{(c-b)}{k} \quad (1)$$

Description:
I = the size of the class interval
c = number of highest scores

b = number of lowest scores
k = number of desired classes

Table 2. Interval of Flood Vulnerability Class

Vulnerability Class	Class Interval	Vulnerability Zonation
Low class	0 – 0.33	Low vulnerability zone
Medium class	0.33 – 0.66	Medium prone zone
High class	0.67 – 1	High vulnerability zone

3. Results and Discussion

3.1. Topography

A topographic analysis of the Majalaya Sub-district revealed that the area can be divided into two distinct morphological zones, namely the plain and the hilly areas. The plain area, which encompasses six villages or sub-districts, has an altitude below 680 meters above sea level. In contrast, the hilly area, which covers five villages, has an altitude between 680 and 790 meters above sea level. These distinct topographic classes further influence the potential and frequency of flood occurrence. Weday et al. (2023) posit that elevation is also the key factor for the assessment of flood hazard and risk since surface water flows from highlands to lowlands, which exacerbates the severity of flooding in lowland areas.

The topographic properties of an area, including its elevation and slope, potentially carry a significant impact on flood risk and hazard. In particular, these properties affect the flow and accumulation of water during a flood (Taherizadeh et al., 2023). Flooding generally affects flatter areas more than steeper areas. Besides, flat areas are more likely to be used as built-up areas, which increases the danger and risk of flooding in these areas. Figure 1 illustrates the flat and hilly areas in the research location. The flat area is situated in the northern region, while the hilly area is mostly located in the southern region.

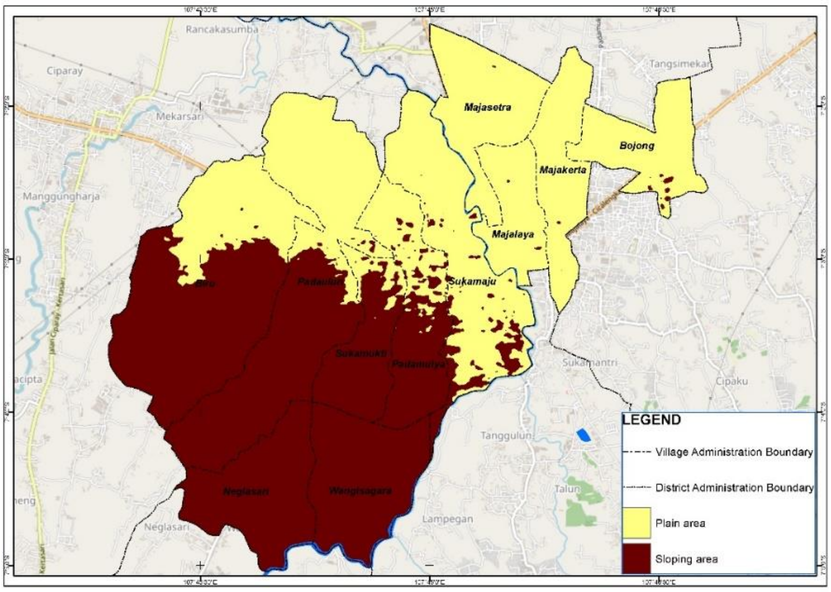

Figure 1. Topography Map of Majalaya Sub-district

Figure 1 indicates that certain areas, including Majalaya, Majasetra, and Majakerta Villages, exhibit a relatively flat topography. These areas are also traversed by the main Citarum River, which increases the potential for and frequency of flooding in these regions.

3.2. Slope

A slope is defined as an inclined area of land that forms a certain angle to a flat plane. In the Majalaya Sub-district, the slope ranges from 0 to 53%. The smaller the slope indicates a flatter area. The slope class in this study adheres to the classification system devised by the Soil and Agroclimate Research Center (Puslitanak), which categorizes slopes as follows, into 0-8%, 8-15%, 15-25%, 25-40%, and >40%, as described in Table 3.

Table 3. Slope in the Research Location

N	Class of Slope (%)	Area (Ha)
1	0 – 8	1,244.80
2	8 – 15	963.10
3	15 – 25	222.60
4	25 – 40	28.70
5	>40	2.10
Total		2,461.30

The slope of an area can be used to predict its susceptibility to flooding. Areas with a low slope and minimal elevation changes are more vulnerable to flooding because the flow of floodwater is impeded by the influence of gravity. Conversely, steep slopes can facilitate the rapid and strong collection of water, making the area more vulnerable to flash floods (Ramesh & Iqbal, 2022; Ziegelaar & Kuleshov, 2022). Further, the flow of water will tend to stagnate, thereby increasing the severity of floods. In areas with higher slopes, water will flow more easily, thereby reducing the risk of flooding (Ziegelaar & Kuleshov, 2022). In contrast, areas with gentle slopes are more prone to flooding due to slower runoff rates, which allow water to accumulate and potentially cause more severe flooding (Ramesh & Iqbal, 2022; Ziegelaar & Kuleshov, 2022). Consequently, in order to assess flood-prone zoning, areas with a slope of 0–8 will be assigned a score of 5, areas with a slope of 8–16 will be assigned a score of 4, areas with a slope of 16–27 will be assigned a score of 3, and areas with a slope of 27 to 40 is scored 2, while a score of one will be assigned to areas with a slope of 40 or greater. The slope map for Majalaya Sub-district is presented in Figure 2.

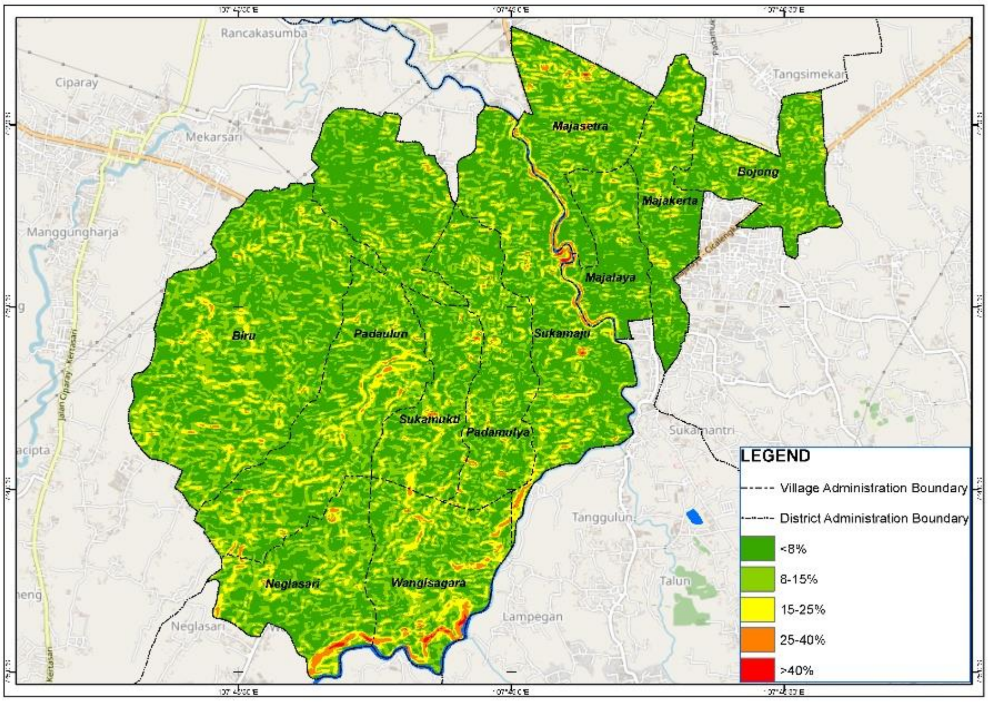

Figure 2. Maps of Slope in the Majalaya Sub-District

3.3. Type of Soil

Soil classification represents the process of grouping different soil types based on their characteristic properties. This classification aims to assess the capability of soils for specific uses and provide basic information about soil conditions in one area to another. This involves assessing characteristics such as density, strength, specific gravity, and other attributes (Bowles, 1989). Further, the classification also determines the response of the land surface when flooding occurs. In the Majalaya subdistrict, the most prevalent soil type is alluvial which is typically identified in areas with close proximity to rivers.

The permeability of different soil types varies considerably, influencing the manner in which water interacts with the soil during flooding. For instance, clay soils exhibit low permeability, which results in waterlogging and heightened vulnerability to flooding due to their limited capacity to absorb water. Conversely, more permeable soils with higher infiltration capacity can mitigate surface runoff and reduce flood risk. Further, soil properties have a direct impact on the likelihood of flooding and people's vulnerability to flooding, thereby, representing a key factor in flood risk assessment and disaster management (Azmeri & Isa, 2018; Munyai et al., 2019).

The area of alluvial and its associated soils in the Majalaya Sub-district covers 1,693.15 Ha, representing approximately 68% of the total area. The least common soil type is Reddish Brown Latosol, which occupies 260,075 Ha, or 10.5% of the total area. Meanwhile, red latosol is more prevalent in Wangisagara Village, which exhibits greater topographic characteristics than other areas. Both the latosol and regosol soils are susceptible to erosion, which may lead to sedimentation in the northern part of Majalaya due to erosion transported from upstream areas.

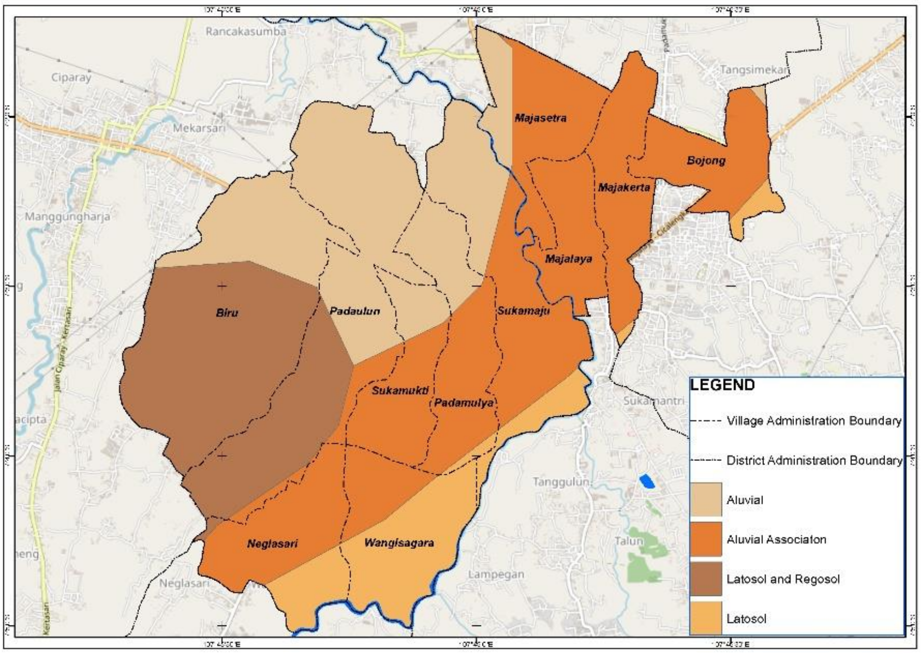

Figure 3. Map of Land Type of Majalaya Sub-District

3.4. Land Use

Land use also represents a crucial aspect of flood vulnerability, flood risk assessment, and management. Land use and land cover are significant factors in assessing vulnerability to flood risk, as they affect the amount of water flowing into an area. For instance, areas covered with concrete or asphalt have low infiltration rates, increasing the likelihood of flooding and exposure, while areas covered with grass or vegetation have high infiltration rates, thereby, reducing the risk of flood vulnerability (Ibrahim et al., 2024). The land use in the Majalaya Sub-district remains diverse, with a transition from agricultural land to urban areas. The identified land uses are divided into five classifications, namely buildings, settlements, paddy fields, vacant land, and fields, as shown in Table 4.

Table 4. Class of Land Use and Its Area Kelas

No	Class of Land Use	Area (Ha)
1	Building	34.5
2	Settlements and places for activity	962.9
3	Rice fields/agricultural land	1,433.11
4	Vacant land	21.8
5	Farmland/fields	9.0
Total		2,461.3

The data presented in Table 4 indicates that the predominant land use in the Majalaya Sub-district is for agriculture and residential areas. The identification of land use is of paramount importance in determining the zoning of flood-prone areas within an area. The unplanned and unsustainable use of land, coupled with infrastructure development, will increase the risk of flooding in flood-prone areas, particularly in urban areas (Ibrahim et al., 2024; Mohajervatan et al., 2021). The vulnerability of land use in the form of settlements to the threat of flood disasters, particularly those situated in proximity to river flows, is well documented. Consequently, in the context of flood-prone zoning assessments, settlements are assigned a score of 5, rice fields a score of 4, and vacant land and fields/fields a score of 3. For further insight, the information is illustrated in Figure 4.

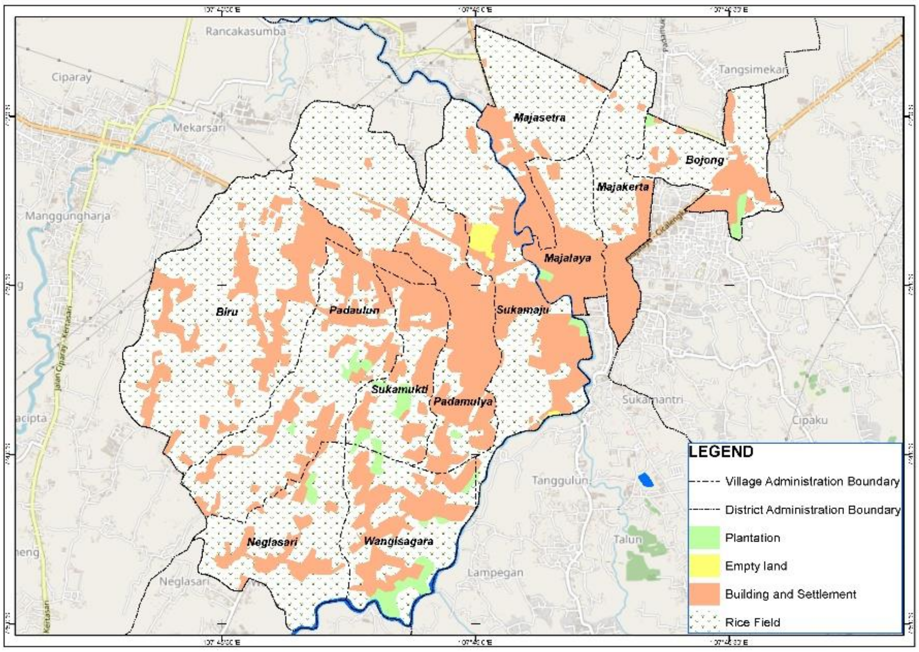

Figure 4. Map of Land Use in Majalaya Sub-district

3.5. Distance from River

The distance from rivers presents considerable effects on flood vulnerability, as proximity to rivers or other water sources increases the likelihood of flooding and exposure to floodwater. Besides, it also influences the potential and frequency of flooding. A closer proximity to a river enhances the potential and risk of flooding in an area. This proximity also affects the severity of flooding, as areas closer to the river are more likely to experience more severe flooding due to increased water flow and pressure (Hamidi et al., 2022). Majalaya sub-district itself is traversed by the Upper Citarum River, which often overflows and causes flooding in the surrounding areas. The distance from the river flow is classified into several classes, as illustrated in Figure 5.

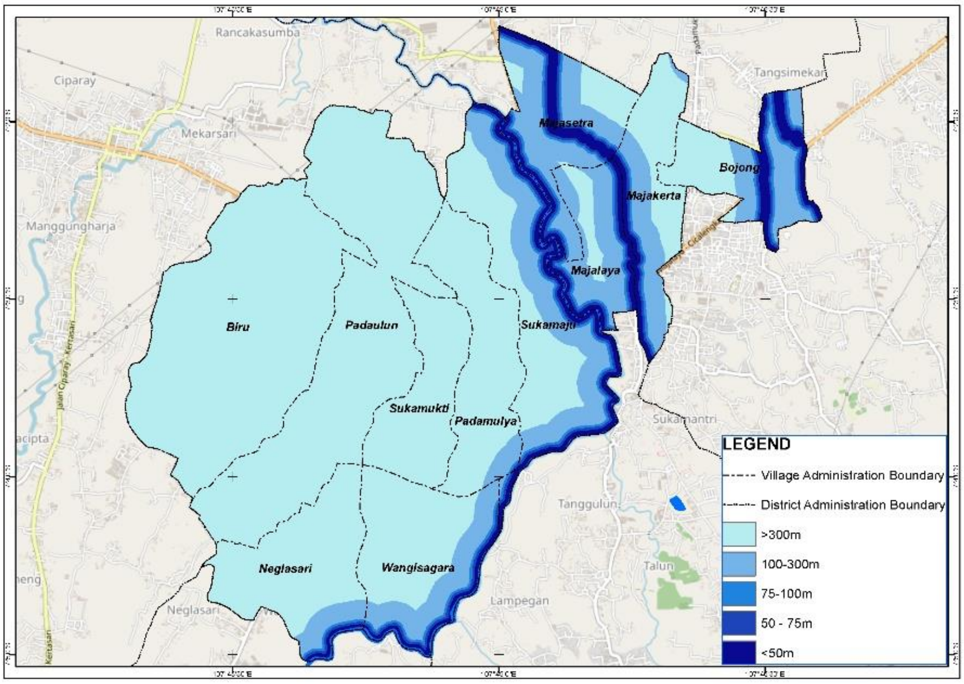

Figure 5. Map of Distance from Main River of Majalaya Sub-district

Figure 5 illustrates the extent to which the Main Citarum Hulu River traverses the villages of the Majalaya Sub-district. Areas situated at a distance of less than 50 meters from the river are particularly susceptible to flooding, especially in areas with relatively flat topography, such as Sukamaju, Majalaya, Majakerta, and Majasetra Villages.

3.6. Flood Vulnerability Zoning

The results of the overlay analysis using a Geographic Information System on the five parameters above led to the production of a flood-prone zoning map in the Majalaya Sub-district. The flood-vulnerability index result indicated that this sub-district has low-high vulnerability. High vulnerability is spatially concentrated in areas with flat topography, such as in Padamulya, Sukamaju, Majalaya, Majakerta, and Majasetra Villages, as presented in Table 5. In contrast, the majority of other villages exhibit low flood vulnerability.

The low vulnerability index encompasses an area of 1,194.3 Ha. This low-flood-prone zone is concentrated in the southern part of the Majalaya Sub-district. The area is characterized by a hilly topography, with a notable contrast to the northern part, which is relatively flat (Figure 6). The most prevalent land uses are rice fields and settlements. This area is the center of agriculture, particularly rice production, in the Majalaya Sub-district. The soil of this area is derived from the volcanic weathering of several ancient volcanoes, which has resulted in its fertility. Despite being traversed by the main upstream Citarum River, this area has no flood potential.

Table 5. Area of Each Zoning Class (Ha)

Village	Flood Vulnerability Zoning Low Class	Moderate Class	High Class
Biru	318	77.60	67.50
Bojong	2.49	35.00	95.68
Majakerta	0.13	51.33	85.50
Majalaya	0.32	27.15	75.40
Majasetra	0.22	34.25	129.35
Neglasari	184.13	3.12	0
Padamulya	105.16	61.27	13.84
Padaulun	251.36	100.00	100.76
Sukamuja	34.12	94.59	150.25
Sukamukti	110.10	17.94	1.92
Wangisagara	188.30	10.12	0
Total	1,194.33	512.37	720.20

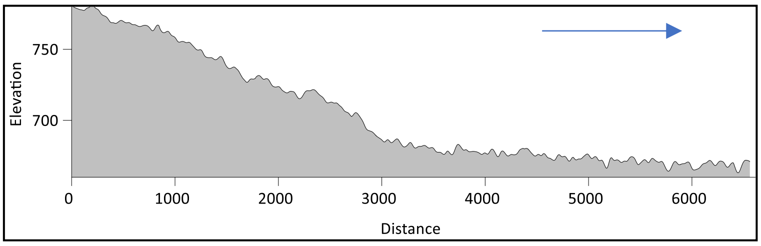

Figure 6. Cross-Section of Majalaya Sub-District from South to North

The moderate vulnerability index is generally distributed in the northern region. Areas with moderate vulnerability are characterized by a flat slope, proximity to the river, as well as land use of plantations, fields, and settlements. Nearly all villages situated on flat terrain exhibit a medium vulnerability index. The area of medium vulnerability encompasses 512.7 ha of the total area of the Majalaya Sub-district. The area with a medium vulnerability index may increase in the event of climate change, geophysical river flow, and land use change. In contrast, the high vulnerability index is more prevalent in areas situated within 100 meters of the river flow. The condition of the Citarum River in Majalaya, particularly in the northern section, is less conservative than in other areas. Therefore, in that area, flood prevention relies on flood gates and river embankments located 3-4 meters above the normal water level. Consequently, high water discharge is not always accommodated, resulting in an overflow of the surrounding areas. This high vulnerability area covers 720.2 hectares and encompasses nine villages, as presented in Figure 7.

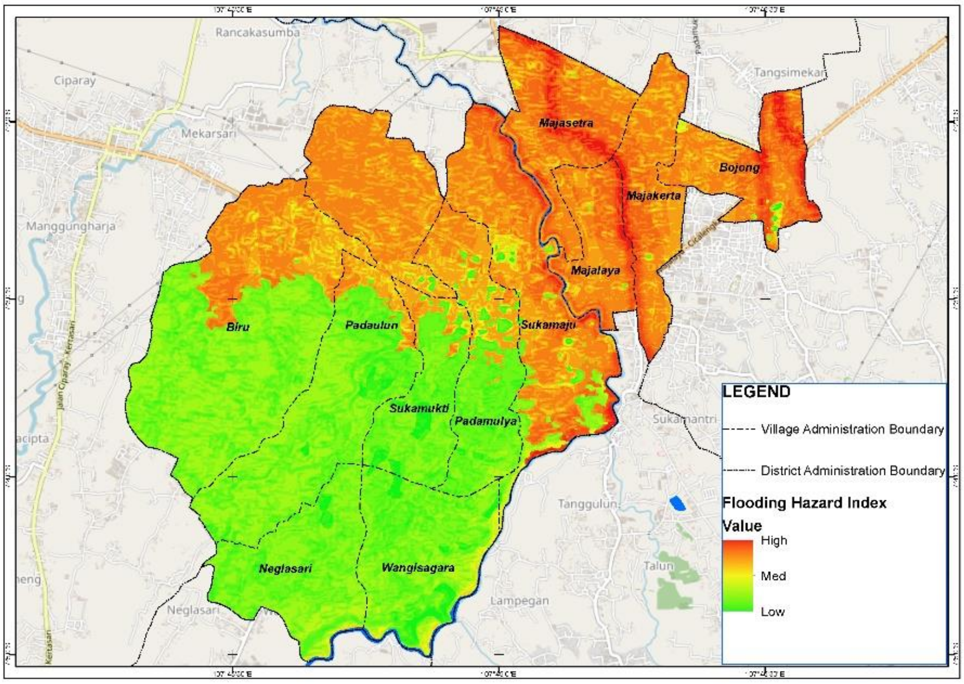

Figure 7. Map of Flooding Vulnerability Zoning in Majalaya Sub-district

Research by Hassani (2016) conducted in the Majalaya Subdistrict indicates the area's high potential for flooding due to its relatively flat topography and hydrological conditions, which are influenced by the Citarum River and its tributaries. The causes of flooding in the Majalaya Subdistrict are complex. One of the influencing factors is the river flow, which tends to have a large discharge but a slow flow speed, resulting in suspended sediments carried from upstream being deposited in flat areas. This accumulation of silt in the river reduces the river's capacity to accommodate water discharge. During the rainy season, when water discharge can increase significantly, the river is unable to accommodate the water, leading to flooding that can inundate roads, settlements, and agricultural land in Majalaya Subdistrict. This was also described in the Ministry of Public Work (2017), which indicated that the causes of flooding in various segments of the Citarum River include sedimentation and erosion from upstream. Another study corroborates this assertion, indicating that the fluctuation of flow discharge in the upstream Citarum is considerable, reaching 573 m^3/s during the rainy season, which results in flooding in the Majalaya, Banjaran, and Dayeuhkolot areas (Hidayat et al., 2013).

The high sedimentation observed in the Majalaya Sub-district is inextricably linked to the erosion and sedimentation process occurring in the upstream area. The upstream and central regions of the Majalaya Sub-district catchment area are characterized by hilly topography, with Andosol and Regosol soil types, which are the result of the weathering of volcanic rocks. These soil types are particularly susceptible to erosion. This is also corroborated by Fahliza et al. (2013), who asserts that Andosol and Podsolik soil types are susceptible to erosion in the Upper Lematang River Watershed. The Agricultural Research and Development Agency (Balitbang) also posits that erosion and landslides frequently occur in areas with sandy (Regosol), Andosol, rocky shallow soils (Litosol or Entisol), and calcareous shallow soils. The Majalaya catchment is characterized by the prevalence of Andosol and

Regosol soils, which are located in mountainous and hilly areas that have been formed as a result of past volcanic activity.

Following the analysis finding, Flood-prone zoning must be assessed as a preliminary step in the mitigation of disasters in the area. The government should prioritize flood hazard zoning and risk management in its policies, ensure that regulatory instruments are effective and enforced, as well as allocate public resources to achieve spatial balance and reduce the impact of flooding. Once zoning is in place, the government and community can be more vigilant and can carry out spatial planning in areas with high vulnerability zones. This will reduce the potential and frequency of flooding in the Majalaya Sub-district when the rainy season arrives. Therefore, the government must increase its capacity to deal with the threat of floods, increase public awareness of the importance of flood mitigation, and increase the ability of the community to deal with the disaster.

4. Conclusion

The analysis results revealed that the zoning of flood-prone areas in the Majalaya Sub-district resulted in the delineation of three distinct zones: low, medium, and high. The low-grade flood-prone zone is predominantly situated in the southern region of Majalaya Sub-district, encompassing an area of 1,194 Ha and 11 villages. In contrast, the moderate zone is distributed across the majority of the sub-district, with a greater concentration in the northern region, covering an area of 512 Ha. In contrast, the high vulnerability zone is situated in the Northern region, in close proximity to the primary river flow of the Upper Citarum. It encompasses an area of 720 hectares and nine villages. This zoning is of paramount importance in the initial phase of disaster mitigation in the Majalaya Sub-district. This zoning can be employed for spatial planning or flood control in the Majalaya Sub-district and its surrounding areas.

Conflict of Interest

Authors state no conflict of interest.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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