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Identification and Mapping of Flood Vulnerability in the Meninting Watershed, West Lombok

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Abstract: Flooding is the inundation of a flat area as a result of overflowing water from the surrounding area or an overflowing river. The largest river that crosses West Lombok Regency is the Meninting River. The Meninting watershed area as a catchment area has an area of 12,307.75 hectares. This research aims to identify and map flood-vulnerability areas in the Meninting Watershed. Data collection was carried out through a geographic information system (GIS) using overlay and scoring methods. The variables used to assess the level of flood vulnerability were land slope, soil type, rainfall, land cover, and geological aspects. The level of flood vulnerability is divided into three classes, namely not vulnerable, moderately vulnerable, and very vulnerable. The results show that of the 41 villages/sub-districts in the Meninting watershed, 34 villages/urban- villages with a coverage area of 8.21% were very vulnerable to flooding. The four villages that have the largest flood-vulnerable areas were the villages of North Ampenan (120.16 hectares), Midang (87.43 hectares), Dasan Griya (79.68 hectares), and Sesela (77.32 hectares). Around 56.24% of all villages/urban villages in the Meninting watershed were quite vulnerable to flooding and 35.55% of the area was not vulnerable.

Keywords: Flood vulnerability; Mapping; Meninting watershed

Introduction

Floods are a global natural disaster and often occur because they are triggered by climate change which causes high rainfall, rapid urbanization, and changes in the hydrology of the watershed (Suhana et al., 2020). Floods can occur as a result of overflowing river water, as well as other factors such as sudden bursts of clouds in semi-arid locations, resulting in flash floods (Amen et al., 2023). Flood events are strongly influenced not only by climatic factors but also by human intervention such as storage and operation of reservoirs (Abhishek et al., 2021).

The Meninting watershed is one of the areas vulnerable to flood disasters. The Meninting Sub-watershed area is in West Lombok Regency and a small part in Mataram City and North Lombok Regency. This watershed area has an area of around 120.30 km². The Head of Gunungsari Sub-district stated that 16 villages in the sub-district are vulnerable to floods and landslides. Meanwhile, ten other villages are only vulnerable to flooding, namely Jatisela, Sesela, Midang, Kekeri, Ranjok, Mambalan, Gunungsari, Jeringo, Dopang and Penimbung (Virgota & Farista, 2023).

High rainfall and surface runoff, restricted river capacity, or malfunctioning drainage structures can all contribute to excessive water flow, which causes floods (Bera & Bhandari, 2016) and inadequate combination of soil type and land cover, so excessive water volume will cause puddles or flooding (Zech et al., 2022). Climate and land use change have increased the ratio of rainfall to surface flow, and the amount of water that directly becomes flood runoff has increased significantly so that peak discharge becomes greater (Nasir et al., 2017).

Based on the 2021 NTB BPBD report (Virgota & Farista, 2023), several floods have occurred in the

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Meninting River basin area, including on December 6, 2021, and June 17, 2022. The flooding that occurred in the Meninting watershed area caused several settlements to experience serious damage, resulting in loss of life. Rainfall with light to very heavy intensity for an extended period of time was the cause of flood events that happened in several NTB areas, including Mataram City, Gunungsari, and Batulayar. Daily rainfall in the Mataram City and Gunung Sari areas has been recorded as falling within the criteria for extreme rainfall, namely 180 mm/day and 216 mm/day. Floods are one of the natural disasters that cause massive destruction such as enormous infrastructure damage, large economic losses, and social disruption throughout the world. Flood damage has increased in recent years in several countries around the world. This flooding occurs due to climate change and environmental degradation caused by inappropriate land use management. Sustainable flood risk management depends on developing knowledge about the risks and likelihood of flood events (Riyansyah & Masturi, 2023; Purwanto & Paiman, 2023; Ulfah et al., 2021).

Therefore, monitoring the potential for flood disasters in an area is very necessary. Monitoring can take the form of identifying and mapping areas vulnerable to flood disasters which can provide an overview of the existing conditions of the area based on the factors that cause flooding. In recent years, potential flood risk mapping has been considered a strategic component that effectively manages, reduces, and mitigates the potential impact of flood hazards because these maps can provide information to residents and stakeholders about potential flood vulnerability areas (Negese et al., 2022).

As a result, further research on flood vulnerability is required in order to create flood vulnerability maps that illustrate the spatial distribution or patterns as well as levels of risk (low, medium, or high). Remote sensing and GIS tools are used for flood risk and vulnerability mapping. Various models can be run in a GIS for various inputs and yield pretty reasonable results with good accuracy (Rana et al., 2024). Before usage, the map is evaluated by a direct visit to the field to ensure its compatibility to current conditions. This direct visit activity consists of direct observations and interviews with local people who are familiar with the related problems (Virgota & Farista, 2023). Based on the background of the problem above, this research was carried out with the aim of knowing the classification of flood vulnerability and its distribution map in the Meninting watershed, West Lombok.

Method

Time and Place of Research

This research was carried out for four months, starting from April to June 2023, where the rainfall that occurred was in the range of 5 to 20 mm/day (light to moderate rainfall). This research was conducted in the Meninting sub-watershed, West Lombok Regency.

Tools and Materials

The tools used include cameras, GPS, and field stationery which are used to record data in the field. Meanwhile, Arc GIS 10.4 software and a computer were used to analyze spatial data. The materials used in this research are maps of land types, rainfall, altitude, slope, land cover, river density, Indonesian Landform (RBI) vectors, and 2022 sentinel image data, which consists of L1C_T50LLR_A 037180_20220805T023833 and L1C_T50LMR_A037180_2 0220805T023833.

Data Retrieval Procedure

The data sought for use in this research consists of two types, namely spatial and non-spatial data. Spatial data includes 2022 sentinel image data, RBI, soil type, rock type, and contour maps. Non-spatial data includes rainfall data for 2021-2022, photos of land cover types, and supporting data taken from the West Nusa Tenggara Watershed Management Center (BPDAS). These data were validated and processed using Arc GIS 10.4 software according to a method modified from Sari (2023), Murthy et al. (2023), Ghozali et al. (2023), Suek et al. (2023), and Fardani et al. (2023).

Data Analysis

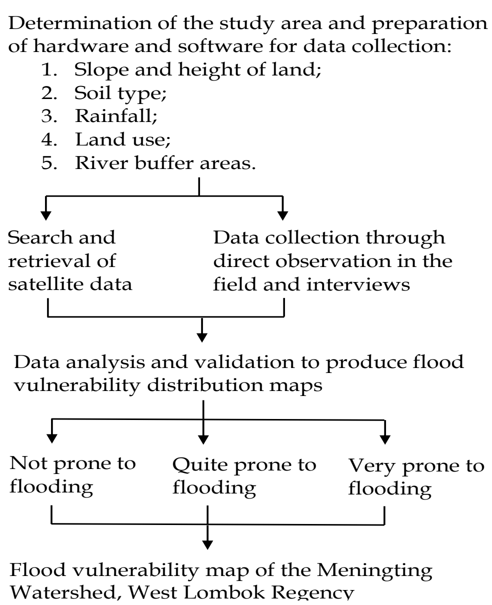

Figure 1. Work flow chart for data collection to identify and map flood vulnerability in the Meninting watershed

The 2022 sentinel data processing was carried out according to the supervised classification method, which was modified from Esmansyah et al. (2023), Marzuki et al. (2023), and Siregar et al. (2023). The sentinel data was classified into five land cover classes, namely rice fields, forests, fields, shrubs, and settlements. As a result, a test of accuracy or suitability to the actual conditions in the field was carried out according to a method modified from Awaliyah et al. (2023), Suripto et al. (2022), and Karimah et al. (2022a). Supporting data from direct observations in the field and from interviews with relevant sources in the field were analyzed descriptively to confirm accuracy and suitability.

Furthermore, each spatial sentinel data described above was classified using the scoring and overlay method using the Arc GIS 10.4 program in the same way as Virgota et al. (2023) and Suripto et al. (2022), so that each produces five levels based on scores (Table 1).

Table 1. Parameters for Determining the Level of Flood Vulnerability

Parameter	Size	Score	Weight
Land slope	< 8%	1	0.20
	8 < x < 15%	2	
	15 < x < 25%	3	
	25 < x < 45%	4	
	> 45%	5	
Altitude	< 10	1	0.10
	10-50	2	
	50-100	3	
	100-200	4	
	>200	5	
Type of soil	Not sensitive	1	0.20
	A bit sensitive	2	
	Less sensitive	3	
	Sensitive	4	
	Very sensitive	5	
Rainfall (mm/day)	Very light <5	1	0.15
	Light 5-20	2	
	Medium 21-50	3	
	Heavy 51-100	4	
	Very heavy >100	5	
Land use	Forest	1	0.15
	Shrubs	2	
	Field/moor/garden	3	
	Rice field/pond	4	
	Settlement	5	
River density	>3.10	1	0.10
	2.28-3.10	2	
	1.44-2.27	3	
	0.62-1.43	4	
	<0.62	5	

Disaster information systems are directly related to mapping flood vulnerability areas. Information collected through the disaster information system is used as basic data in mapping flood vulnerability areas. On the other hand, the results of mapping flood vulnerability areas also provide input and information needed in the development and operation of the Disaster Information System. This linkage helps in monitoring, analysis, early warning, planning, and response to floods as well as overall disaster risk management. The overall work flow chart for data collection and analysis in this research can be seen in Figure 1.

Result and Discussion

Location, Wide and Boundaries of the Study Area

The Meninting watershed is a river basin located in the western part of Lombok Island. The upstream part of the Meninting watershed is located at coordinates 8°3 2' 0.710" South Latitude and 116° 9' 3.166" East Longitude, the downstream part is located at coordinates 8° 33 ' 14.313" South Latitude and 116° 4' 27.520" East Longitude. The Meninting watershed is at an altitude of 0-1,425 meters above sea level with a total area of around 12,300 hectares. The Meninting watershed covers 41 villages and sub-districts, namely 6 villages in North Lombok Regency. 6 sub-districts in Mataram City, and 29 villages in West Lombok Regency. Most of the Meninting watershed is within the administrative area of West Lombok Regency. These regional borders are the result of the expansion of administrative regions five years ago, as reported by Virgota et al. (2023). A description of the Meninting watershed area boundaries can be seen in Table 2.

Table 2. Regional boundaries of the Meninting Watershed, West Lombok

Points of the compass	Description of area boundaries
West	Borders with Bengkaung Village
East	Borders with Karang Bayan Village
Northeast	Borders with Jenggala Village
Southwest	Borders with Bintaro, Meninting, and Sandik Sub-Districts
Northwest	Borders with Bengkaung and Pusuk Lestari Villages
North	Borders with the villages of North Selamat, Sigar Panjalin, Teruga and Tegal Maja
South	Borders with Kekeri Village, Dasan Geria, North Ampenan and Sigerongan Villages
Southeast	Borders with Karang Bayan Village

Climate and Rainfall

Based on the processing of rainfall data obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) for the period December 2021 to December 2022, the results showed that rainfall in the Meninting watershed is in the light category with a range of 5-20 mm/day. The air temperature ranges between 20°–30° C, while the average air temperature in the upstream section is 24.20° C and downstream 29.50° C. Annual rainfall at Sesaot, Lingkok Lime, and Santong stations ranges between 2014.68–2526.27 mm/year, except for a small part in the Gunung Sari station area with rainfall of less than 2,000 mm, namely the average annual rainfall is 1490.41 mm/year. Based on data from December 2021 to December 2022, the Meninting Watershed in West Lombok had rainfall of 5 to 20 mm/day, which was included in the light rain category (Figure 2).

Rainfall is one of the trigger factors that have the most influence on floods, namely in terms of influencing river flow discharge. In general, floods occur when the soil's absorbent capacity is surpassed by a period of high rainfall, which leads to flooding. As one of the parameters for determining flood vulnerability areas, rainfall factors such as the amount of rainfall, rain intensity, and rainfall will determine how big the chance of a flood occurring and where the flood will occur (Karimah et al., 2022b; Suripto et al., 2022; Aju et al., 2024).

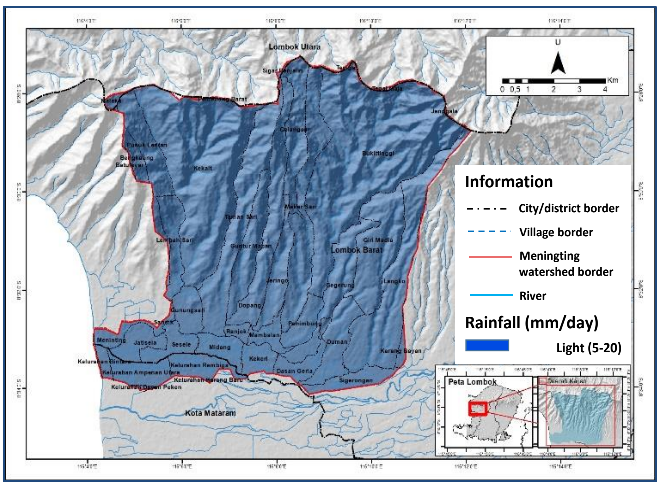

Figure 2. Map of rainfall in the Meninting watershed

The data obtained was estimated rainfall based on the results of direct measurements in the field and satellite observations, which is referred to as CHIRPS data. According to Abhishek et al. (2021) and Amen et al. (2023), CHIRPS data is the result of collaboration with scientists at the United States Geological Survey (USGS) and the Earth Resources Observation and Science (EROS) Center. CHIRPS aims to provide a complete, reliable, and up-to-date data set and can be utilized for several early warning purposes, such as trap analysis and seasonal drought monitoring. To predict future rain, rainfall data from previous times can be used, but other climate data also needs to be used such as air temperature and wind records.

Height of Land Surface

Information about the height of the land surface of the study area was obtained from SRTM DEM image extraction, namely the Meninting watershed area comprising intervals of 0–10, 10–50, 50–100, 100–200, and 200–1400 meters above sea level for altitude classes. Land surface height data from satellite imagery has been validated with data from direct measurements in the field. The Meninting watershed area was dominated by the altitude class 200-1400 meters above sea level (57.65%). The land elevation classes in the Meninting watershed can be seen in Table 3 and Figure 3.

Table 3. Composition of Land Area Based on Altitude Class in the Menininting Watershed

Altitude (m asl)	Areas (hectare)	(%)
0-10	370.31	3.02
10-50	1,866.16	15.20
50-100	1,272.74	10.36
100-200	1,690.96	13.77
200-1400	7,080.16	57.65
Total	12,280.33	100.00

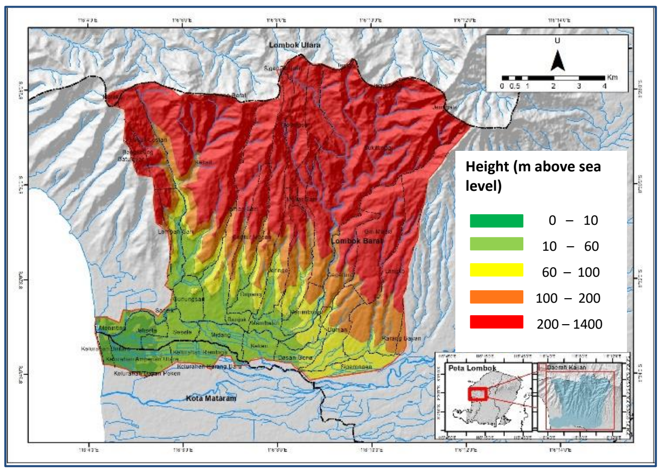

Figure 3. Map of land elevation in the Meninting watershed

The higher an area, the smaller the chance of flooding in that area. This strengthens the results of observations made by Virgota et al. (2023). In contrast to areas that have lower land elevations, they will have a greater chance of flooding (Suripto et al., 2022).

Type of Soil

The soil in the Meninting watershed area consists of various types of soil, namely alluvial, andosol, litosol, gleisol, and cambisol. Alluvial soil is formed from the sedimentation of soil erosion with alluvial and colluvial materials. In general, the composition of the soil type is classified into the entisols subgroup, which is formed in areas with a floodplain physiographic form. The properties of the soil are then greatly influenced by the type of sediment material. If we refer to the soil sensitivity criteria proposed by Diharja et al. (2022) and Virgota et al. (2023), then the type of soil mentioned above is classified as very sensitive to flooding. The Meninting watershed area is dominated by andosol (34.04%) and lithosol (37.65%) soil types. Other types of soil that are also found but are not dominant in the Meninting watershed are gleisol and eutric combisol. Soil types in the Meninting watershed area can be seen in Table 4 and Figure 4.

Table 4. Composition of Land Area Based on Soil Type in the Meninting Watershed

Type of soil	Area (hectare)	(%)
Aluvial	436.19	3.54
Andosol	4189.89	34.04
Kambisol eutrik	1251.70	10.17
Gleisol	1795.72	14.59
Litosol	4634.26	37.65
Total (Ha)	12307.76	100.00

Source: BBSDLP (Processed), 2022.

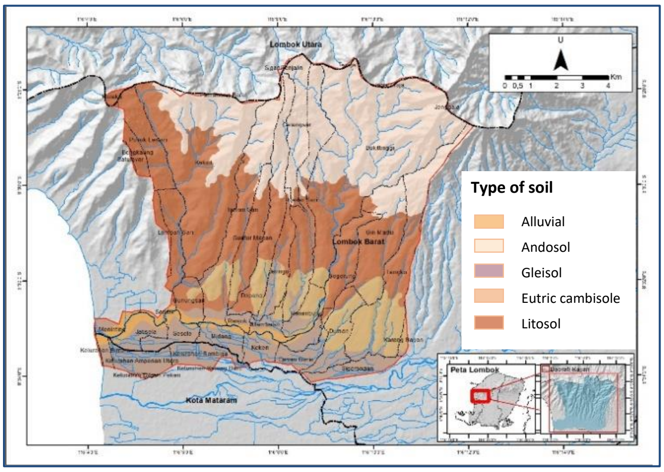

Figure 4. Map of soil type in the Meninting watershed

Andosol soil is found in flat, undulating, and hilly topography. This type of soil is generally black in color, has a developed cross-section, with a thick A-horizon, loose and rich in organic matter. The original rocks are andesite, andesite tuff, and dacite. Its physical properties are good, with moderate resistance and sensitivity to erosion. This type of soil is classified as less sensitive to flooding (Allen et al., 2017; Zech et al., 2022). Litosol soil, commonly called "laterite", is generally thick, the top containing several percent organic matter. The color is brown, yellow, to reddish. It is granular, firm, stable, contains kaolinite, is not plastic, and can be agriculturally processed throughout the year. This type of soil is draining, resistant to erosion, and is classified as somewhat sensitive to flooding (Zech et al., 2022). Glaisol soil is usually found in lowland areas or depressions, which are almost always flooded with water, the soil solum is medium, gray to yellowish in color. loam to clay texture, muddy to massive structure, sticky consistency, acidic (pH 4.5 - 6.0), and contains organic material (Zech et al., 2022). Based on the classification of soil types from the Bogor Soil Research Center (Virgota & Farista, 2023), gleisol soil is always saturated with water so it is gray in color or shows other hydromorphic properties. This type of land is classified as very sensitive to flooding. Eutric cambisol soil is a type of mineral soil that has the characteristics: acid pH, low CEC, low availability of Ca, Mg, Na, N, P, and K. Cambisol has deep to very deep soil solum, many micropores, dusty clayey clay texture, crumb structure, and sticky consistency (Allen at al., 2017; Zech et al., 2022).

Several reports have also stated that Lombok Island is one of the areas where andosol is distributed in Indonesia (Sukarman, 2014; Virgota & Farista, 2023; Suripto et al., 2022). Andosol soil with a clayey sand texture has fairly fast permeability, meaning it can seep into the soil easily. Andosol soil is soil that is not sensitive to flooding because it has good infiltration capabilities. High infiltration capacity due to the large permeability of a type of soil makes the possibility of flooding lower (Madani et al., 2022; Zech et al., 2022). Soil types that are very sensitive to flooding are Alluvial and Gleisol (Zech et al., 2022). The percentage of areas with soil types that are sensitive to flooding in the Meninting watershed is relatively small, namely around 18.13%. Therefore, based on soil type, it can be said that the Meninting watershed has a low potential for flooding.

Land Use

Based on the land use map presented by the Ministry of Environment and Forestry, Republic of Indonesia in 2019 with corrections to the latest data using Sentinel imagery in 2022, it was known that the type and percentage of land use in the Meninting watershed area is primarily composed of forests and rice fields. Details of the types and percentages of land use in the Meninting watershed area are presented in Table 5 and Figure 5.

Table 5. Area Size Based on Land Use Type in the Meninting Watershed

Land use type	Area (hectare)	(%)
Settlements/built-up land	1159.33	9.42
Forest	3444.55	27.99
Garden/Plantation	6146.76	49.94
Rice field	1454.38	11.82
Shrubs	102.73	0.83
Total (Ha)	12307.75	100.00

Source: Sentinel 2A Image (Processed), 2022.

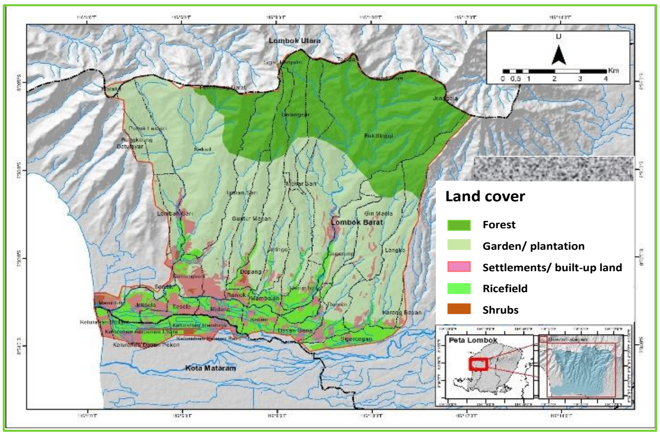

Figure 5. Map of land use in the Meninting watershed

Based on these data, it can be seen that the largest land use is forest (49.94%), and next in sequence is rice fields (27.99%), fields (11.82%), bushes (9.42%), and settlements (0.83%). The change in land use in an area will certainly influence or change the quality of the environment, including its resilience to the threat of flooding (Diharja et al., 2022). The land use has a substantial impact on hydrological processes, including surface runoff, infiltration, evapotranspiration, and evaporation (Bilskie et al., 2014). The influence of forests and vegetation results in a reduction in flood risks, as evidenced by the increased infiltration and consequent reduced runoff. Conversely, infiltration is minimal through the hard and impervious surfaces of desolate land, rivers, riverbanks, impermeable roads, and buildings, which contribute to a higher runoff rate (Aju et al., 2024).

Land Slope

The slope of the land in the Meninting watershed area varies from flat to very steep. In general, the Meniniting watershed area slopes towards the south. Rivers flow from the highland areas in the north to the south. Based on the results of the DEM (Digital Elevation Model) the Meninting watershed is classified into five slope classes according to the criteria previously used by Saputra et al. (2023), Dandapat et al. (2023), namely flat land (0-8% slope), sloping (8-15% slope), steep (slope 15-25%), steep (slope 25-45%) and very steep (slope > 45%). The area of each land slope class and its distribution map in the Meninting watershed can be seen in Table 6 and Figure 6.

The area with a land slope of 0-8% (flat) covers an area of 2714.60 ha (22.05%). Regions with a land slope of 8-15% (sloping) have the smallest area, namely 1372.59 ha (11.15%). The area occupied by areas with a land slope of 15–25% (quite steep) is 1571.88 ha (12.78%). Regions with a land slope of 25-45% (steep) have the largest area, namely 3520.85 ha (28.60%). Areas with a slope of > 45 (very steep) cover an area of 3127.83 ha (25.42%).

Table 6. Area Size Based on Land Slope in the Meninting Watershed

Land slope	Slope Class	Area (hectare)	(%)
0-8%	Flat	2714.60	22.06
8-15%	Sloping	1372.59	11.15
15-25%	Quite Steep	1571.88	12.77
25-45%	Steep	3520.85	28.61
>45%	Very Steep	3127.83	25.41
Total (Ha)		12307.75	100.00

Source: DEM SRTM (Processed), 2022.

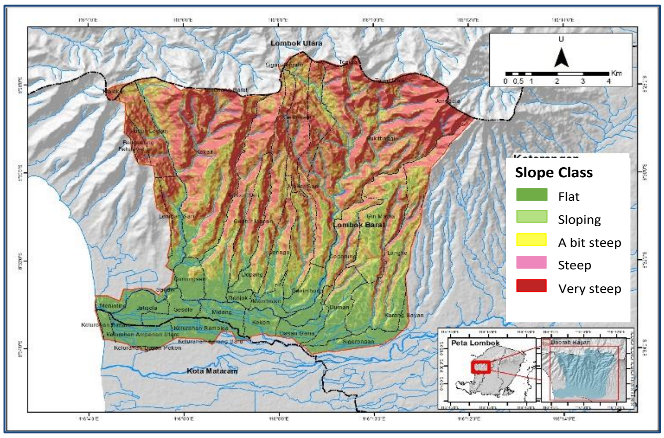

Figure 6. Map of the slope in the Meninting watershed

Flat and sloping areas have the potential for flooding. In flood disasters, the slope of the land is very influential. As the slope angle decreases, the likelihood of flooding increases and the area becomes more vulnerable to floods, as the flow of water is influenced by the slope angle. This is because areas that have a slope of 0–15% tend to have slow water flow, so the ground becomes saturated with water and becomes waterlogged. Besides that, the downstream, which is lower than the upstream, gets air runoff when it rains, considering the nature of water that flows from high areas to lower areas (Dandapat et al., 2023; Suripto et al., 2022; Virgota & Farista, 2023; Rana et al., 2024).

River Density

The river density in the Meninting watershed area was 1.94 km/km^2, which was classified as medium density. A map of river density in the Meninting watershed can be seen in Figure 7.

According to Utama et al. (2016), river density values of 0.25-10 km/km^2 are classified as medium river density class. River density is an important factor in determining the speed of running water. The higher the river density, the greater the speed of running water for the same rainfall. River densities less than 0.7 km/km^2 generally have poor drainage or frequently experience inundation and have the potential for flooding. Rivers with a density between 0.73 - 2.74 km/km^2 generally have good drainage conditions or rarely experience flooding, the level of flood vulnerability is relatively lower. Goyal (2023), Salman et al. (2023), and Pramudiya et al. (2023) have also stated that the variable river density or the distance of an area to a river or other body of water greatly determines whether an area has the potential for flooding or not. The closer the area is to the river, the higher the potential for flooding in that area.

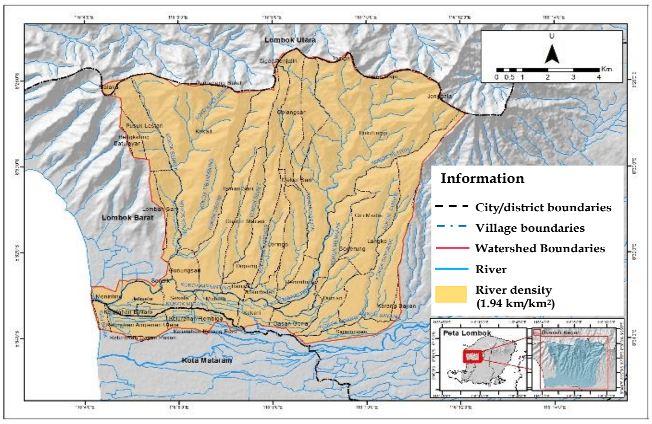

Figure 7. Map of river density in the Meninting watershed

Area Coverage and Flood Vulnerability Level in the Meninting Watershed

Around 35.55% of the area (4372.33 hectares from 41 villages/urban villages) of the Meninting watershed area was included in the not-vulnerable category, and around 64.45% of the area (6918.22 hectares from 41 villages/urban villages and 1009.98 hectares from 34 villages /urban villages) were included in the moderate or quite vulnerable and very vulnerable categories. The areas according to the level of flood vulnerability in the Meninting watershed in West Lombok Province of West Nusa Tenggara can be seen in Table 7 and Figure 8. The broad range of levels of flood vulnerability in the Meninting watershed was divided into three levels of vulnerability by the modified criteria from Cusser et al. (2021), Uca et al. (2023), Ginting & Tarmansyah (2023), and Anna et al. (2023), namely areas that fall into the categories of very vulnerable, quite vulnerable and not vulnerable.

The results of these observations indicate that more than half of the Meninting watershed area has the potential to experience flood disasters. Therefore, the Meninting watershed area must be paid attention to by the local government and the surrounding community. Furthermore, based on the results of the analysis of the level of flood vulnerability, it was known that there are 34 villages/sub-districts in the Meninting watershed that are highly vulnerable to flooding. The area vulnerable to flooding reaches 8.21% of the Meninting watershed area. The four villages/urban villages that have the largest flood vulnerability areas were North Ampenan (120.16 ha), Midang (87.43 ha), Dasan Griya (79.68 ha), and Sesela (77.32 ha). The part of the Meninting watershed which was classified as moderately vulnerable includes 41 villages/urban villages with an area of around 6,918.22 hectares. The areas based on the level of flood vulnerability in the Meninting watershed have been presented in Table 7, its map can be seen in Figure 9.

Table 7. Extent and Scope of Flood Vulnerability in the Meninting Watershed

Village/Urban Village	Flood vulnerability level		
	Not vulnerable	Quite vulnerable	Very vulnerable
Batulayar	4.32	0.45	0.00
Bengkaung	130.88	17.49	0.09
Bukittinggi	398.38	1994.67	6.02
Dasan Geria	5.10	75.25	79.68
Dopang	182.47	378.70	5.98
Duman	104.39	169.45	30.10
Gegerung	199.48	165.11	30.13
Gelangsar	18.01	340.94	0.01
Giri Madya	09.31	198.08	0.60
Guntur Macan	209.02	136.83	1.09
Gunungsari	6.07	127.99	5.31
Jatisela	1.89	107.33	69.09
Jenggala	1.24	2.39	0.00
Jeringo	122.50	130.93	15.97
Karang Bayan	5.24	14.25	1.58
Kekait	1035.64	784.42	15.54
Kekeri	1.40	61.95	75.87
Ampenan Utara	0.74	82.03	120.16
Bintaro	0.43	21.58	29.53
Dayan Peken	0.14	2.86	7.29
Karang Baru	0.37	1.44	0.27
Pejeruk	0.22	0.60	0.15
Rembiga	2.82	118.79	74.01
Langko	504.51	392.56	13.80
Lembah Sari	136.18	91.83	6.38
Malaka	23.24	3.90	0.00
Mambalan	1.45	83.66	29.98
Mekar Sari	226.72	431.01	11.28
Meninting	1.84	52.99	27.28
Midang	2.91	70.78	87.43
Pemenang Barat	1.67	2.38	0.00
Penimbung	22.90	105.65	35.11
Pusuk Lestari	294.36	26.59	0.01
Ranjok	0.15	30.16	21.98
Sandik	5.29	29.87	2.02
Sesela	1.83	87.05	77.32
Sigar Penjalin	3.38	3.12	0.00
Sigerongan	5.39	97.57	74.30
Taman Sari	273.57	462.43	24.62
Tegal Maja	4.25	7.55	0.00
Teniga	2.64	5.63	0.00
Total area (ha)	4372.33	6918.22	1009.98
%	35.55	56.24	8.21

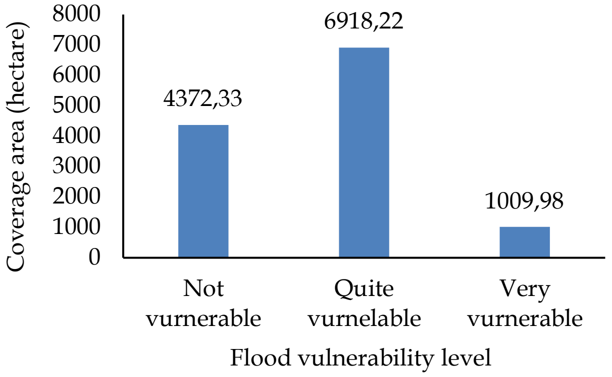

Figure 8. The area based on the level of flood vulnerability in the Meninting watershed

These villages and urban villages are located in the downstream part of the Meninting watershed. Flooding in these places most likely occurred due to overflowing water from the Meninting River. This possibility is in accordance with the opinion of Damanik et al. (2019), Maroeto et al. (2023), and Alia et al. (2023), who stated that water overflow downstream of the river basin could occur due to increased water discharge upstream due to high rainfall over a long duration. Nguyen et al. (2023) and Uca et al. (2023) also stated that large and small floods can occur, especially in areas close to rivers, that have low vegetation cover and gentle land slopes. Floods can occur when there is high-intensity rainfall for a long duration. The villages with the largest areas at the moderately vulnerable level were Bukittinggi Village (1,994.67 ha) and Kekait Village (784.42 ha).

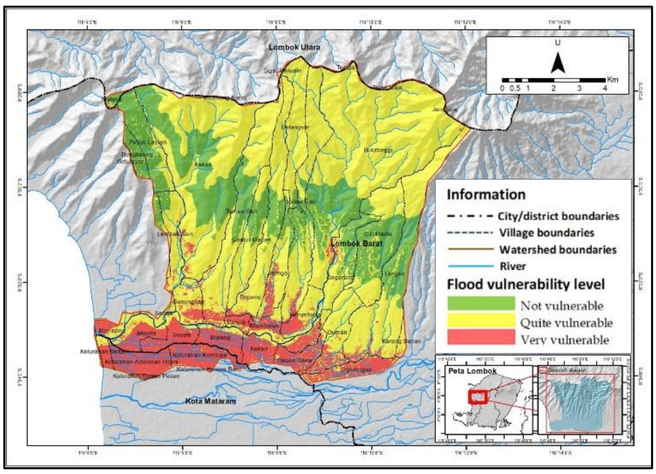

Figure 9. Map of the level of flood vulnerability in the Meninting watershed

Apart from natural factors, human activities are factors that can be controlled and greatly determine the level of flood vulnerability in this area. Activities that support efforts to increase the catchment area, manage drainage systems, and waste management, and reduce constructions and use of agricultural land that is not environmentally friendly, especially in upstream areas need to be carried out to reduce the area's vulnerability to flood disasters. A study in Jiangsu Province, China, found that different types of land, including cultivated land, forest land, water area, construction land, unused land, and grassland, have varying impacts on flood vulnerability. The study found that construction land has the most significant impact on flood vulnerability, followed by cultivated land, water, and woodland (Du & Zhang, 2021).

Conclusion

Of the entire Meninting watershed area, those categorized as not vulnerable to flooding are around 35.55%, moderately vulnerable to flooding around 56.24%, and very vulnerable to flooding around 8.21%, covering 34 villages/districts. The four villages that have the largest flood-vulnerable areas were the villages of North Ampenan (120.16 hectares), Midang (87.43 hectares), Dasan Griya (79.68 hectares), and Sesela (77.32 hectares).

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Author Contributions

Conceptualization, A.V., B.F., E., S. and L.A.G.; methodology, A.V., B.F., and S.; software, A.V., and E; validation, A.V., and S.; formal analysis, S.; investigation, B.F. and E.; resources, A.V. and S.; data curation, B.F. and S.; writing—original draft preparation, A.V.; writing—review and editing, S.; visualization, E. and B.F.; supervision, A.V., and S.; project administration, B.F.; funding acquisition, A.V. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest, either internally between the authors or between each author and external parties, both in carrying out the research and in the publication.

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