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Original Research Paper

Implementation of a spatial model for developing a flood early warning system in the Kelep River Basin, Lombok, Indonesia

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Abstract

Indonesia, including in the Kelep Watershed, Lombok Island, flood disasters frequently occur. Land use changes and climate variability make this area more vulnerable to floods. This study aims to analyze the distribution and level of flood vulnerability and the dominant factors causing flood vulnerability in the Kelep Watershed. The method used was the weighting of six parameters, namely slope, landform, soil type, rainfall, land use, and river buffer, which were then overlaid using ArcGIS 10.8 software. The results showed that the highly flood-prone areas were spread across all sub-districts in the Kelep watershed, with the highest concentration in Sekotong, Lembar and Southwest Praya sub-districts. The three villages with the highest flood-prone areas are Candi Manik, Sekotong Tengah and Taman Baru. These areas require special attention as they often experience serious impacts due to flooding. Based on the validation test, the RMSE value of 5.95% indicates acceptable accuracy. The resulting flood vulnerability classification map can be used as a flood early warning system or basis for flood risk mitigation and is proposed to be implemented through cross-sector collaboration to improve preparedness and reduce disaster impacts.

Keywords: equitable development, implementation theory, pentahelix collaboration

INTRODUCTION

Floods are one of the hydrometeorological disasters that frequently occur in Indonesia (Maulana, 2024), including in the Kelep Watershed (DAS Kelep), Lombok Island. This region is vulnerable to floods due to various factors, such as topography, high rainfall, and land use changes. Human activities, such as deforestation and land conversion for residential and agricultural purposes, further increase the risk of flooding (Reza et al., 2025). Radar Lombok (2023) reported that a flood disaster occurred that affected four villages in Sekotong District, namely Sekotong Tengah Village, Taman Baru, Persiapan Empol and Persiapan Pengantap Villages. The floods that occur certainly cause several impacts such as damage to residences that force people to evacuate to safer areas. Furthermore, floods can also damage public facilities such as schools, shopping centers and agricultural areas, resulting in economic losses (Ihwan, 2023).

Flood vulnerability is related to the interaction between biophysical parameters such as slope, landform, soil type, rainfall, as well as anthropogenic activities such as land use changes and the presence of settlements near rivers (Pratama et al., 2021). The spatial approach that integrates Geographic Information Systems (GIS) and parameter weighting has been widely used in flood risk mitigation studies (Nuryanti et al., 2018). The spatial model that is built can provide visual information regarding vulnerable zones, while also supporting the decision-making process in spatial planning and early warning systems (Wisnawa et al., 2021).

Although several flood hazard mapping studies have been conducted, comprehensive studies on multivariate integration of spatial parameters in the Kelep Watershed remain limited. Furthermore, there has been no comprehensive utilization of actual seasonal rainfall data (rainy season and dry season) in flood hazard mapping in this region. This creates a gap in precise spatial validation and the determination of policy intervention priorities at the affected village level (Gao et al., 2018; Anugrah, 2020; Suni et al., 2023). This research will address these problems by developing a flood vulnerability model based on six main parameters and validation using RMSE.

The urgency of this research is to provide an accurate flood vulnerability map that can be applied as an early warning system, particularly in areas frequently affected by floods such as Sekotong, Lembar, and Southwest Praya. Therefore, this study aims to (1) map and analyze the spatial distribution of flood vulnerability in the Kelep Watershed, and (2) identify villages with the highest vulnerability levels to be prioritized for disaster mitigation and response planning. The results of this research are expected to be utilized by policymakers, local governments, and communities in enhancing preparedness and resilience against flooding. In addition, the output of this study is expected to support the optimization of land-use planning, infrastructure development, and community-based disaster risk reduction programs. Strengthening early warning systems through spatial modeling will contribute to minimizing economic losses, protecting public safety, and improving environmental sustainability in flood-prone areas.

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RESEARCH METHODS

Time and location of research

This research was conducted in the Kelep Watershed (DAS Kelep), Lombok Island. The research period took place during 2023, including data collection, processing, and spatial analysis processes.

Research design

This research type is descriptive exploratory with a spatial approach. The aim is to identify flood vulnerability potential and develop an early warning model using spatial and non-spatial data through weighting techniques and map overlay. Analysis was conducted using ArcGIS 10.8 software.

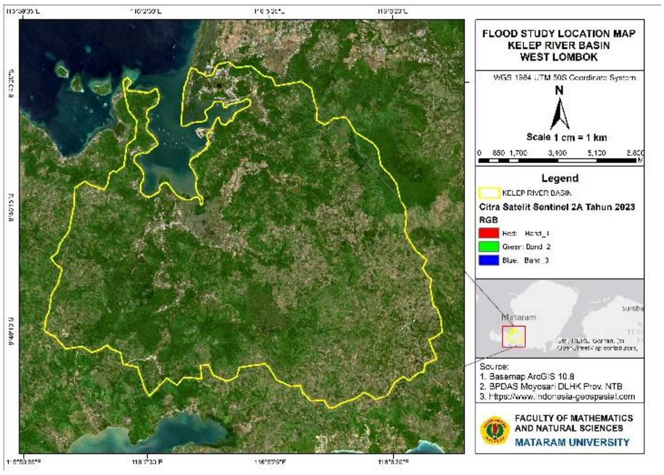

Figure 1. Peta lokasi studi

Population and sample

The research population includes the entire Kelep Watershed area on Lombok Island. The research sample consisted of parameters causing floods, including slope, landform, soil type, rainfall, land use, and river buffer. Spatial data were obtained from Indonesia's Basic Map (RBI), Digital Elevation Model (DEM) data, Sentinel 2A imagery, and other thematic maps. Non-spatial data consisted of daily rainfall in 2023 obtained from the Climate Hazards Group InfraRed Precipitation (CHIRPS). The sampling technique used purposive sampling based on data relevance to flood vulnerability (Pratama et al., 2021). Research variables included physical parameters consisting of slope, soil type, landform, rainfall, land use, and river buffer (Darmawan et al., 2017). Data were obtained through satellite image interpretation, secondary data from relevant agencies, and field accuracy testing. The tools used included computers, ArcGIS 10.8, RBI map data, and rainfall data.

Research procedure

The research procedure began with data collection consisting of spatial and non-spatial data. Spatial data included Digital Elevation Model (DEM) maps, land use maps, soil texture maps, and rainfall maps. Meanwhile, non-spatial data consisted of daily rainfall data obtained from official sources. After data collection, the next stage was pre-processing, which included image cropping, land use classification, and assigning weights to each parameter based on literature.

The next stage was spatial analysis using the overlay method to combine parameters that have been weighted and classified based on flood vulnerability levels. The overlay results were then tested for accuracy by comparing the resulting flood vulnerability map with flood event history data using the Root Mean Square Error (RMSE) method based on random community interviews. The RMSE value was used to assess the accuracy of the developed model. In the final stage, the flood vulnerability map results were interpreted to develop a flood early warning model in the Kelep Watershed.

Data analysis

Land use maps were obtained from Sentinel 2A image data and analyzed using Unsupervised Classification. Before this, image data were cropped to reduce the area and facilitate the classification process, resulting in accurate map dimensions between model and field data. Accuracy testing was obtained through the Root Mean Square Error (RMSE) formula as follows:

$$\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \tag{1}$$

Where:
- yi = observed value
- ŷi = predicted value
- i = data sequence in dataset
- n = number of data

Subsequently, flood-prone area data were analyzed based on the total value of each area. The vulnerability value of each area can be determined with the following equation:

$$K = \sum_{i=1}^{n}(w_i \times x_i) \tag{2}$$

Where:
- K = Vulnerability Value
- $\sum$ = Sum of Parameters
- w_i = Weight for parameter i
- x_i = Class value for parameter i

The next stage after overlay was performed by summing the total score to obtain the flood vulnerability level score. According to Anggraini et al. (2021), the classification score for each flood vulnerability level class can be grouped into 4 class scores, using the equation:

$$K = \frac{(\sum_{i=1,2,3\ldots i}(\mathrm{B_t x\ t_t}) - (\mathrm{B_r x\ t_r})}{\mathrm{JK}} \tag{3}$$

Where:
- K = Class Interval
- $\sum$ = Sum of All Overlay Parameters
- $(\mathrm{Bt} \times \mathrm{t_t})$ = Highest Score Sum
- $(\mathrm{Br} \times \mathrm{t_r})$ = Lowest Score Sum
- JK = Number of Classes

Masing-masing peta diklasifikasikan berdasrakan tingkat kerawanan terbagi menjadi empat tingkat kerawanan. Kelas kerawanan bisa dilihat pada Tabel 1.

Table 1. Flood vulnerability level classification

Flood Vulnerability Level	Score
Safe	≤ 1,29
Low Risk	1,29 – 2,52
Vulnerable	2,52 – 3,76
Highly Vulnerable	>3,76

RESULTS

Distribution of flood-prone areas

Flood-prone areas are areas that, from a physical and climatological perspective, have the possibility of experiencing floods within a certain period and have the potential for environmental damage (Wisnawa et al., 2021).

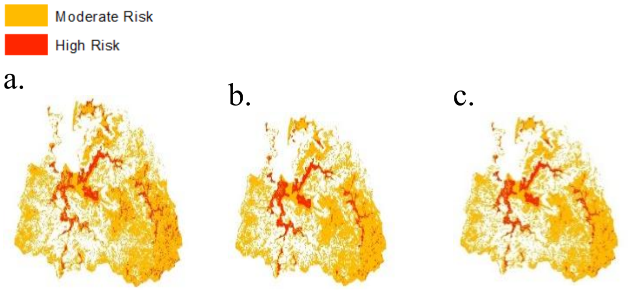

Figure 2. Flood vulnerability map where: (a) Average daily 2023 (b) Average daily February (c) Average daily August

Flood-prone areas are distributed throughout the Kelep Watershed. The area of flood-prone areas with three different rainfall data is presented in Table 2.

Table 2. Flood vulnerability area classification

Rainfall Data		vulnerability (Ha)		Total
		Vulnerable	Highly Vulnerable	
a.	Average daily 2023	8.511,15	1.164,76	9675.91
b.	Average daily February	8.607,80	1.161,48	9769.29
c.	Average daily August	8.308,35	1.084,60	9392.96

Profile of study area

Slope

Based on analysis, the Kelep Watershed in Lembar, Sekotong, and Southwest Praya sub-districts shows varying slope variations.

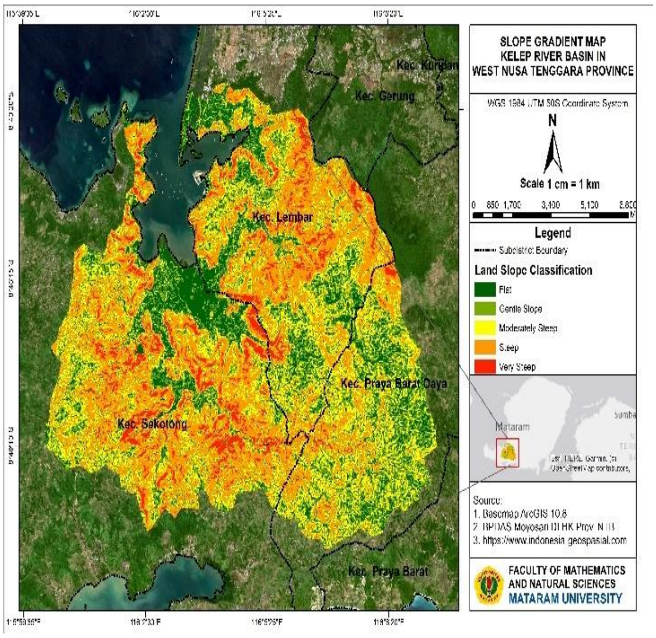

Figure 3. Slope classification results

Areas with flat slope category (0-8%) are distributed throughout the administrative region, with the flat category dominant in Sekotong District, Candi Manik Village (Table 3).

Table 3. Slope classification

Slope (%)	Description	Area Size (Ha)	%
0-8 %	Flat	2233.03	14%
8-15 %	Gentle	3111.63	19%
15-25 %	Slightly Steep	4261.45	26%
25-45 %	Steep	5670.23	35%
>45%	Very Steep	1075.65	6%
Total		16352.01	100%

Landform

The northern coast of the Kelep Watershed located in the administrative areas of Lembar and Sekotong Districts has mangrove plains, estuaries, and mudflats that are coastal areas.

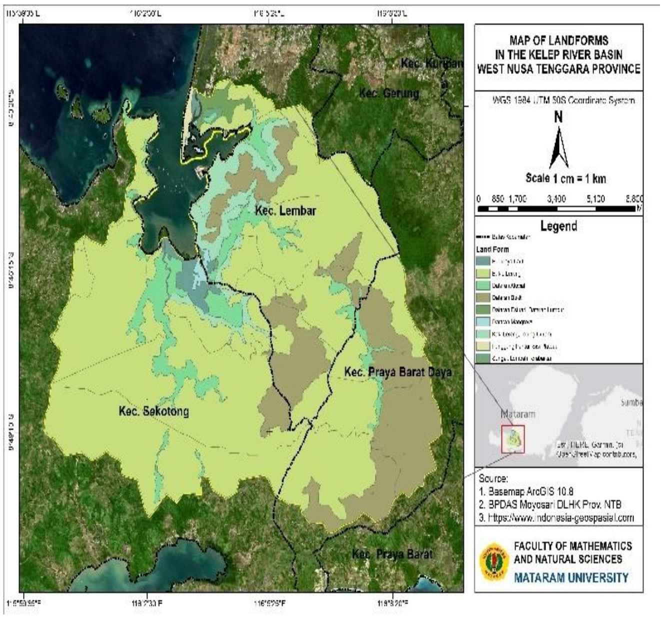

Figure 4. Klasifikasi bentuk lahan

Bentuk This landform has high potential for flooding due to several factors such as being located at low elevation and being affected by tidal movements. Limited water absorption capacity in mudflats and mangrove areas (Azevedo de Almeida & Mostafavi, 2016)

Table 4. Landform classification

Landform	Area Size (Ha)	%
Marine Aquaculture	195.63	1%
Slope Foot, Steep Cliff	735.02	5%
Hill, Slope	10982.67	67%
Beach Ridge, Plateau Side	52.59	<1%
Hill Plain	3015.60	18%
River, Neglected Valley	61.35	<1%
Alluvial Plain	1162.95	7%
Estuarine Plain, Mudflat	129.15	1%
Mangrove Plain	66.25	1%
Total	16401.22	100%

Soil texture

Hampir Almost the entire Kelep Watershed has Mediterranean soil type with medium soil porosity texture. However, in the northern part of the Watershed located in Lembar District administrative area, there are regosol and lithosol soil types with coarse to slightly coarse soil texture. These soil types have drainage resistant to erosion, and are classified as moderately sensitive to flooding (Zech et al., 2022). Meanwhile, alluvial soil type with slightly fine to fine soil texture is found at the boundary of Lembar and Sekotong Districts administrative areas.

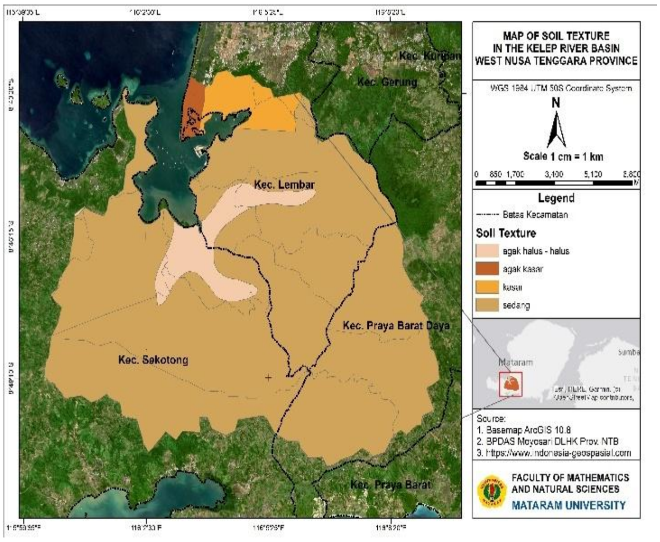

Figure 5. Klasifikasi tekstur tanah

Table 5. Soil texture classification

Texture Class	Area Size (Ha)	%
Slightly Fine	982.1069	6%
Medium	14686.5	89%
Slightly Coarse	182.3839	1%
Coarse	632.2748	4%
Total	16483.26	100%

Rainfall

The Kelep Watershed (DAS Kelep) is located in a tropical climate region that experiences two main seasons: the rainy season and the dry season. During 2023, the Kelep Watershed showed very low rainfall intensity, with average daily rainfall ranging from 3.61 to 3.97 mm per day, or below 5 mm per day. According to Virgota et al., (2024), rainfall ranging from 5-20 mm/day falls in the light category. The highest monthly rainfall was recorded in February, with an average intensity reaching 14 mm per day.

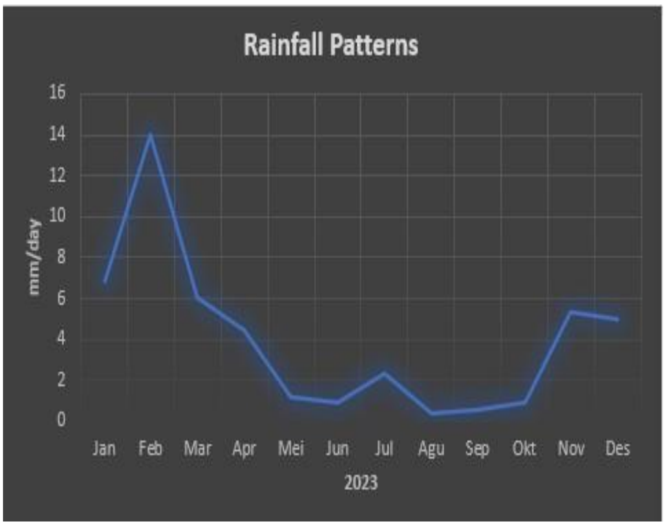

Figure 6. Rainfall pattern graph in 2023

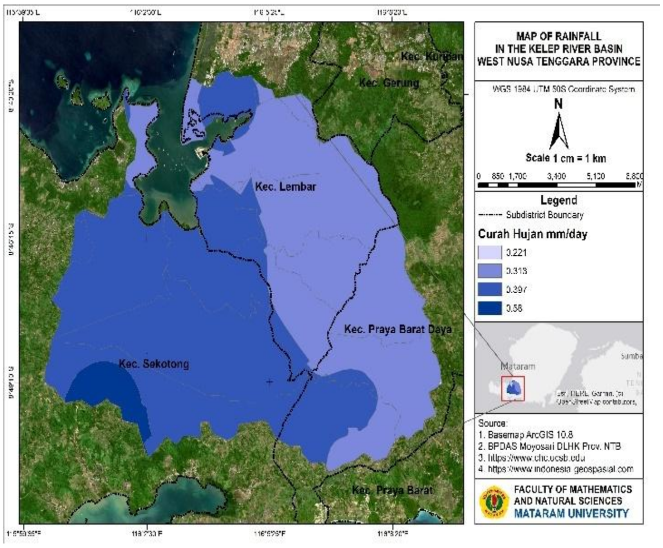

Figure 7. Classification of average daily rainfall for August 2023.

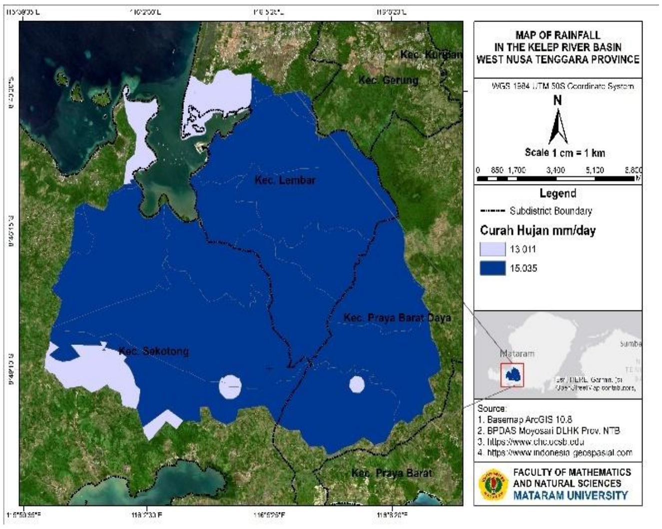

Figure 8. Classification of daily average rainfall for February 2023

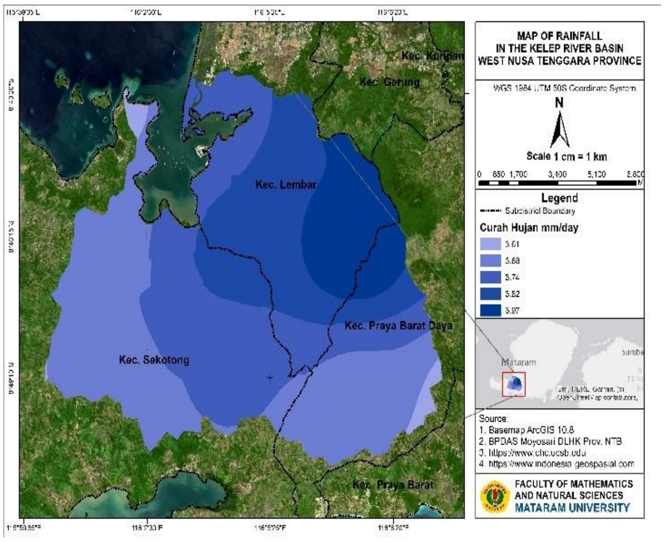

Figure 9. Classification of average daily rainfall in 2023

Climate change affecting small islands has the potential to cause increases or decreases in rainfall intensity in the coming years, as well as shift existing rainfall patterns (United Nations Caribbean, 2022).

Land use

Land use in the Kelep Watershed area is dominated by forests, scrubland, paddies/ponds, as well as fields and plantations. Settlements are scattered throughout the Watershed (Table 6), with higher concentration in Sekotong and Lembar Districts, especially around ports and certain residential areas.

Table 6. Land use classification

Land Cover	Area Size (Ha)	%
Forest	6170.27	38%
Scrubland	4911.89	30%
Paddy/Pond	3543.24	21%
Field/Tagelan/Plantation	1482.18	9%
Settlement	295.44	2%
Total	16403.03	100%

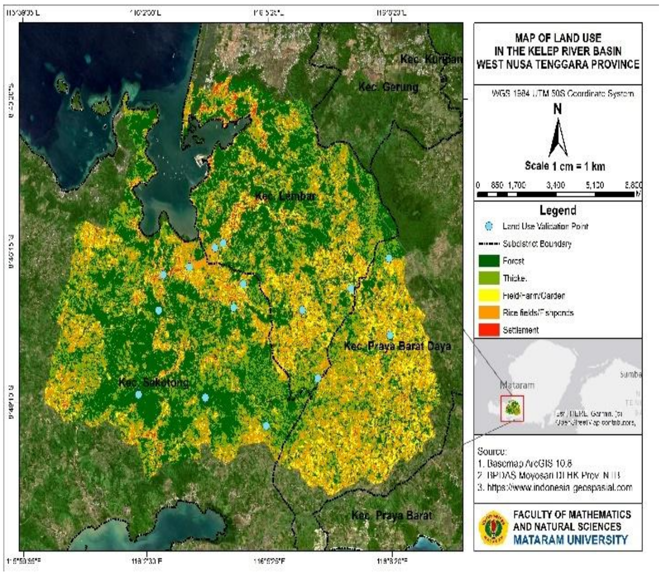

Figure 10. Land use classification

River buffer

Flood events are closely related to the river's capacity to discharge water. If the capacity is lower than the volume of water flowing through, overflow occurs and causes flooding (Wisnawa et al., 2021).

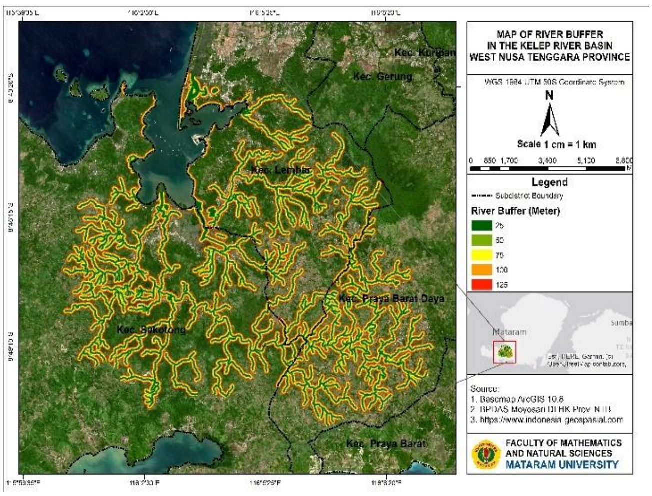

Figure 11. Classification of *river buffers*

The results of five-category river buffer classification show that some parts of the Kelep Watershed river buffer have varying levels of influence on floods, ranging from buffer distance of 0 to 100 meters (Table 7).

Table 7. River buffer classification

River Buffer	Area Size (Ha)	%
0 - 25 m	10748.64	65%
25 - 50 m	1566.42	10%
50 - 75 m	1477.54	9%
75 - 100 m	1370.68	8%
> 100 m	1260.10	8%
Total	16423.39	100%

Flood vulnerability level classification based on 2023 annual daily rainfall data

Flooding is an event where land that is normally dry becomes inundated with water (Nuryanti et al., 2018). Flood vulnerability analysis resulted in a flood vulnerability map of the Kelep Watershed based on average daily rainfall data throughout 2023.

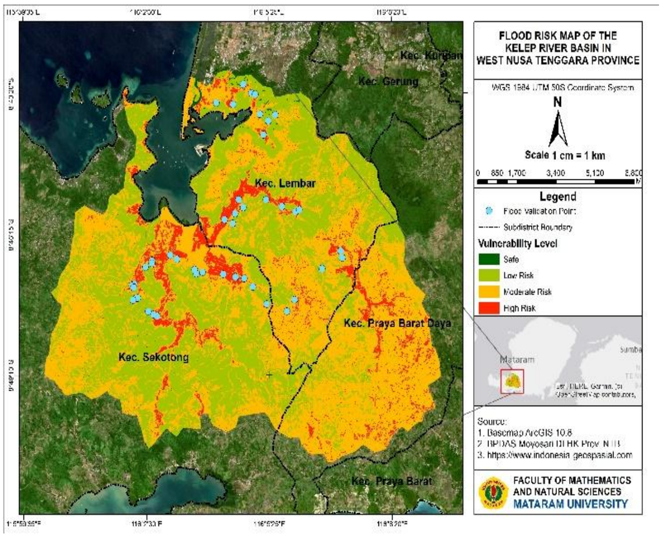

Figure 12. Classification of flood vulnerability levels with average daily rainfall in 2023

There are 4 areas classified as highly flood-prone in each sub-district (Table 8). Average daily rainfall for 2023 is classified as very light with a value of 1. The distribution of flood vulnerability classification using 2023 average daily rainfall data is dominated by the vulnerable class (52%).

Table 8. Number of villages with highly flood-prone areas

Sub-district	Safe	Low Risk	Vulnerable	Higly Vulnerable
Southwest Praya	4 Desa	4 Desa	4 Desa	4 Desa
Sekotong	6 Desa	6 Desa	6 Desa	6 Desa
Lembar	7 Desa	9 Desa	8 Desa	8 Desa
Gerung	1 Desa	1 Desa	1 Desa	-

In more detail, the distribution of highly flood-prone areas in each village is presented in Table 9. The three villages with the largest highly flood-prone areas are Candi Manik Village, Sekotong Tengah Village, and Taman Baru Village. These three villages have areas with flat to gentle slope levels and medium to fine soil texture that are quite extensive.

These physical characteristics, when combined with limited drainage infrastructure and increasing land-use change, intensify flood risk in these areas. In particular, the conversion of vegetated land into residential and agricultural built-up areas has reduced natural water absorption capacity and increased surface runoff volume. As a result, even moderate rainfall can lead to substantial flooding, affecting settlements, agricultural activities, and local transportation access. Therefore, stakeholders need to prioritize flood mitigation efforts in these villages through integrated watershed management, improvement of drainage networks, and the application of nature-based solutions such as vegetation buffer development and rainwater infiltration systems.

Table 9. The area is very prone to flooding in each village

District	Sub-district	Village	Area (hectares)
West Lombok	Lembar	Eyat Mayang	88,610
West Lombok	Lembar	Jembatan Gantung	0,060
West Lombok	Lembar	Jembatan Kembar Timur	0,802
West Lombok	Lembar	Labuan Tereng	36,655
West Lombok	Lembar	Lembar Selatan	47,905
West Lombok	Lembar	Mareje	47,861
West Lombok	Lembar	Mareje Timur	70,518
West Lombok	Sekotong	Sekotong Timur	98,183
West Lombok	Sekotong	Buwun Mas	34,815
West Lombok	Sekotong	Cendi Manik	193,855
West Lombok	Sekotong	Kedaro	0,698
West Lombok	Sekotong	Sekotong Barat	19,660
West Lombok	Sekotong	Sekotong Tengah	129,382
West Lombok	Sekotong	Taman Baru	122,720
Central Lombok	Southwest Praya	Batu Jangkih	104,087
Central Lombok	Southwest Praya	Montong Ajan	61,823
Central Lombok	Southwest Praya	Montong Sapah	107,125
Central Lombok	Southwest Praya	Serage	0,003

Flood vulnerability level classification based on dry season and rainy season

Flood vulnerability analysis resulted in flood vulnerability maps of the Kelep Watershed based on average daily rainfall data in February (representing the peak rainy season) and average daily rainfall data in August (representing the dry season). The use of rainfall data from two contrasting seasons enabled a comparative assessment of spatial variations in flood risk conditions throughout the year, reflecting both extreme and minimal precipitation scenarios. This approach is essential because rainfall intensity is one of the dominant factors influencing surface runoff, river discharge, and the capacity of the watershed to absorb and store water. By integrating hydrometeorological and geomorphological parameters, the resulting maps provide a detailed visualization of zones with different levels of vulnerability, ranging from low, moderate, high, to very high flood potential.

Furthermore, the maps generated through the flood vulnerability analysis serve as a crucial reference for identifying priority areas requiring mitigation actions. Areas classified as highly vulnerable demonstrate a strong correlation with regions characterized by low slope gradients, clay-dominated soil textures, and dense settlement patterns adjacent to the river channels. In contrast, regions categorized as low vulnerability are typically located in upland zones with higher slopes and better vegetation cover, which enhance infiltration and reduce runoff accumulation. Therefore, the spatial distribution of flood vulnerability across the watershed highlights the need for targeted planning interventions and disaster mitigation strategies.

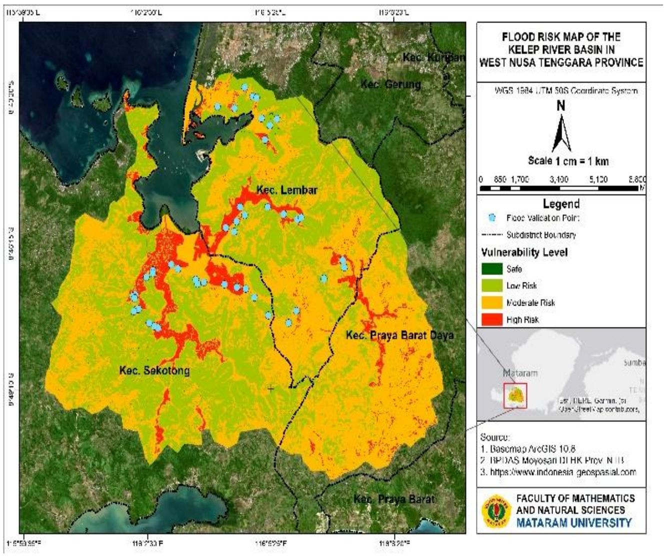

Figure 13. Classification of flood vulnerability levels by average daily rainfall for February

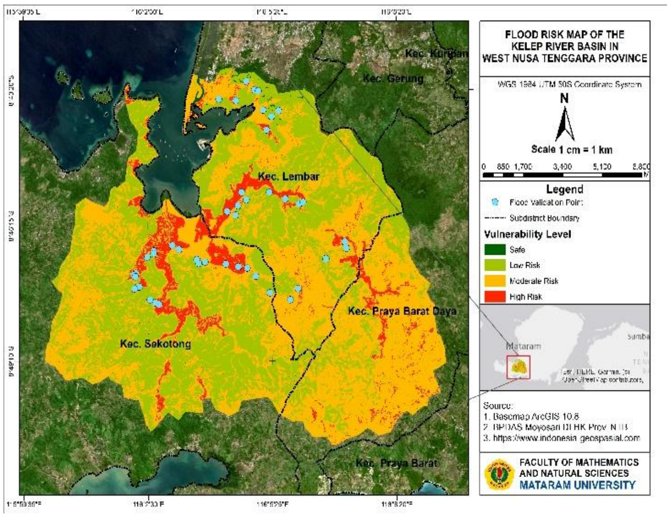

Figure 14. Classification of flood vulnerability level by average daily rainfall in August

February rainfall is classified as light with a value of 2 (Table 10). The distribution of flood vulnerability classification using February rainfall data is dominated by the vulnerable class (53%). For the low-risk and highly vulnerable classes, their respective areas comprise approximately 40% and 7%. The remainder falls into the safe class (< 1%).

Table 10. Flood vulnerability classification with August rainfall

	Classification			
	Safe	Low Risk	Vulnerable	Highly Vulnerable
Area (Hectares)	7.29	8607.80	1161.48	6633.34
%	<1%	53%	7%	40%

DISCUSSION

Distribution of flood-prone areas

Areas with highly flood-prone status are more dominant in the downstream part of the Kelep Watershed. Based on the flood classification area table using three different rainfall data, it is known that the resulting flood vulnerability differs slightly. Flood-prone areas using February rainfall data show the highest vulnerability area of 9,769.29 hectares, 9,392.96 hectares with August rainfall data, and 9,675.91 hectares with 2023 average daily rainfall data.

Flood vulnerability mapping in Watersheds (DAS) is obtained through the application of values and weighting to 6 (six) flood parameters (Suni et al., 2023). These parameters include meteorological aspects such as rainfall intensity and distribution, as well as frequency and duration of rainfall. This research uses three different rainfall data. In addition to meteorological aspects, the characteristics of the watershed also play an important role, including slope, landform, soil type, and land use (Kaya & Derin, 2023).

Study area profil

Slope

According to Darmawan et al., (2017), this condition increases the potential for flooding because relatively flat areas tend to become water accumulation areas during rainfall. Conversely, areas with steep slope categories (25-45%) are also distributed in Lembar, Sekotong, and Southwest Praya Districts. Areas with steep slopes have lower flood risk compared to flat areas because water in steep areas tends to flow faster, reducing the possibility of waterlogging. Lower areas often receive incoming floods from higher areas (Aziza et al., 2021).

Landform

Bentuk Other landforms with high flood risk are river channels related to increased river discharge due to water volume exceeding the channel capacity of the river (Wiweka & Suwarsono, 2011). Flood potential is not limited to coastal areas. Each administrative area of Lembar, Sekotong, and Southwest Praya Districts contains alluvial plains that are often water flow routes, thus also at risk of experiencing flooding due to increased river discharge. According to Wiweka & Suwarsono (2011), flooding is closely related especially to alluvial plains of river channels (river flow activities) and marine (tidal activity).

On the other hand, areas with hill and steep cliff landforms that dominate the Kelep Watershed, particularly in Lembar and Sekotong Districts, have relatively lower flood risk. The topographic character of these regions supports rapid water runoff, preventing excessive surface water accumulation. According to Suni et al. (2023), areas with steep slopes and high drainage capacity tend to channel rainwater more quickly into river systems, thereby reducing the possibility of waterlogging and minimizing the development of standing floodwater. In addition, vegetated hill regions with preserved forest cover also contribute to increasing infiltration capacity and stabilizing soil structure, further lowering the likelihood of flood events. These findings emphasize the importance of maintaining vegetation and preventing land-use changes in upland zones as part of watershed-based flood mitigation strategies..

Soil Texture

Almost the entire Kelep Watershed has Mediterranean soil type with medium soil porosity texture. However, in the northern part of the Watershed located in Lembar District administrative area, there are regosol and lithosol soil types with slightly coarse to coarse soil texture. These soil types are resistant to erosion and moderately sensitive to flooding (Zech et al., 2022). Alluvial soils form from erosion sedimentation with alluvial and colluvial material (Virgota et al., 2024). Fine-textured alluvial soil is very susceptible to flooding due to its difficulty in absorbing water. This limitation increases the risk of water waterlogging, especially during the rainy season or when there is increased discharge and rainfall intensity (Badwi et al., 2020).

Rainfall

This research utilized average daily rainfall data in August as a representation of dry months or dry season, as well as the highest daily rainfall data in February reflecting peak rainy season conditions. Additionally, average daily rainfall data for one year (2023) was also used. This is consistent with research conducted by Yasa et al., (2021), which shows that high rainfall on Lombok Island occurs in early months, particularly January, February, March, and late months November and December. The lowest rainfall occurs in August, indicating a dry period where surface water sources decline significantly.

Lombok tends to have lighter rainfall compared to the central or northern parts (Nandini & Narendra, 2011). This rainfall pattern is influenced by topography and monsoon winds (Yasa et al., 2021). A Watershed surrounded by hills will have high rainfall because humid air movement is blocked and driven upward by the presence of mountains and hills, thus causing orographic rainfall (Virgota & Farista, 2023). The Kelep Watershed is located in the western and southern parts of Lombok Island and tends to have lighter rainfall compared to the central or northern parts (Nandini & Narendra, 2011). This rainfall pattern is influenced by topography and monsoon winds (Yasa et al., 2021). In the flood vulnerability map, it appears that as rainfall increases, the area of flood-prone zones also increases (Wisnawa et al., 2021). The range between the highest rainfall value (February) and the lowest rainfall (August) is not far different, thus resulting in a slight increase in the area of each vulnerability classification.

Climate change affecting small islands has the potential to cause increases or decreases in rainfall intensity in the coming years, as well as shifting existing rainfall patterns (United Nations Caribbean, 2022). Climatological changes in Indonesia have occurred over a 19-year period, between 2001 and 2019. During the rainy season, rainfall intensity tends to increase extremely, while in the dry season, extreme rainfall becomes more frequent, particularly in East Java, West Nusa Tenggara, and East Nusa Tenggara (Sutrisno & Sari, 2023).

Through this approach, it is expected to obtain a deeper understanding of the relationship between rainfall patterns and flood potential in the Kelep Watershed. This analysis provides a higher ability to predict flood distribution in the future, especially when rainfall conditions approach similar intensity patterns. Since climate change makes future rainfall prediction increasingly difficult to perform accurately, therefore, in flood-prone area mapping, it is very important to determine appropriate weights for the rainfall parameter and use the most recent and accurate rainfall data to represent the rainfall pattern that may occur in the future.

Land Use

According to Suripto et al., (2023), land cover changes occur due to conditions or events that affect the use or activity in a land. From 15 validation data conducted, an RMSE result of 0.365 was obtained with details of 13 valid data (86.67%) and 2 invalid data (13.33%). Thus, the validity level of the validation process is sufficiently accurate and this spatial analysis result can be used in the parameter of flood vulnerability mapping in the Kelep Watershed (Darmawan et al., 2017).

The land use parameter greatly influences the mechanism of surface water runoff formation. Land with vegetation cover such as grass, herbs, or trees can provide resistance to rainfall water flow, whereas this does not occur in areas without vegetation such as dry land and built-up land. Initially, tree canopies and leaves play a role in intercepting rainfall, converting it into smaller water droplets. A similar process occurs in lower vegetation such as herbs and grasses. This mechanism provides an opportunity for water to seep into the soil slowly, thus reducing the potential for runoff (Mekuriaw, 2019). This is difficult to occur in built-up areas or residential areas, thus increasing runoff activity and the formation of flood water volume accumulation.

River Buffer

Rivers have an important role in their function as water discharge pathways. Flood events are closely related to the river's capacity to discharge water. If the capacity is lower than the volume of water flowing, overflow occurs and causes flooding (Wisnawa et al., 2021). The results of five-category river buffer classification show that some parts of the Kelep Watershed river buffer have varying levels of influence on floods, ranging from buffer distance 0 to 100 meters. The closer a region is to a river, the higher the probability of flooding occurring. According to Aziza et al., (2021), poor drainage systems also have the potential to increase flood risk.

Some tributaries in the Kelep Watershed are classified as dry during the dry season, but will flow during the rainy season and often overflow when rainfall is high with sufficient duration. Settlements located near these dry riverbeds are at risk of experiencing waterlogging due to river overflow, especially during intense rainfall conditions and with high sediment deposition (Zakipour et al., 2023). The rare structure of river flow is also one of the main factors supporting the occurrence of flooding, because the natural drainage system is unable to accommodate and discharge water optimally when there is an increase in water discharge due to high rainfall (Purnomo et al., 2019).

Flood vulnerability level classification based on 2023 annual daily rainfall data

The highly flood-prone classification on the map is marked with red color, indicating that this area has very high flood risk. This area is located on flat slopes, medium to fine soil texture and hill foot landforms, alluvial plains, mangrove plains, and mudflats with a very close distance to rivers (river buffer) of 0 to 25 meters. Areas classified as vulnerable on the map are marked with orange color, indicating moderate flood risk that often occurs during heavy rain. The very high rainfall factor, soil texture, and vegetation density still play important roles. Soil with medium texture, which is neither too dense nor too porous, can limit water absorption capacity, worsen surface runoff and increase flood risk even in hilly areas (Myers et al., 2024). The flood characteristics in this area are classified as runoff due to being located on hill and slope landforms, relatively steep slope with dominant medium soil texture. According to Fauza (2022), conditions in such areas have relatively small flood potential.

Average daily rainfall for 2023 is classified as very light with a value of 1. The distribution of flood vulnerability classification using 2023 average daily rainfall data is dominated by the vulnerable class (52%). For the low-risk and highly vulnerable classes, their areas are approximately 41% and 7%, respectively. The remainder falls into the safe class (< 1%). The area classified as highly flood-prone on the three vulnerability maps is not very large compared to the vulnerable and low-risk classes, but is distributed in every sub-district. Based on validation testing results, an RMSE value of 5.95% was obtained, which is below the threshold of 10%. According to Padron (2012), RMSE values in the range of 10-20% can still be accepted as valid results.

The three villages with the largest highly flood-prone areas are Candi Manik Village, Sekotong Tengah Village, and Taman Baru Village. These three villages have areas with flat to gentle slope levels and medium to fine soil texture that are quite extensive. Additionally, these villages have areas with alluvial plain landforms related to water flow routes with river buffer distances of 0 to 25 meters. These three villages require special attention from communities, government, and related stakeholders because flooding in these areas often causes serious impacts such as health disturbances, agricultural and livestock sector losses, building damage, and damage to land and public facilities (Aldiansyah & Wardani, 2023). Therefore, assistance is often channeled to these areas, including dredging and renovation of drainage systems. These measures are expected to reduce the negative impacts of flooding and increase community preparedness in facing flood disasters in the future.

Flood vulnerability level classification based on dry season and rainy season

According to Nazmelia (2018), waterlogging in highly flood-prone areas persists longer compared to areas classified as flood-vulnerable, with water depth exceeding 50 cm. This water depth is classified as high waterlogging with inundation duration of less than 48 hours, flood frequency occurring more than 3 times within one year. This phenomenon causes communities in highly flood-prone areas to often take adaptation measures against flooding, such as raising building foundations and conducting channel normalization.

Flood vulnerability analysis resulted in flood vulnerability maps of the Kelep Watershed based on average daily rainfall data in February (rainy season) and average daily rainfall data in August (dry season). From the two vulnerability levels resulting from using rainfall data in the dry and rainy seasons, there are five villages with the largest highly flood-prone area classifications, including Candi Manik Village, Sekotong Tengah Village, Taman Baru Village, Sekotong Timur Village, and Eyat Mayang Village. Average daily rainfall in August is classified as very light with a value of 1. The distribution of flood vulnerability classification using August rainfall data is dominated by the vulnerable class (51%). For the low-risk and highly vulnerable classes, their areas are approximately 43% and 6%, respectively. The remainder falls into the safe class (< 1%).

CONCLUSION

From the research results, it can be concluded that the flood vulnerability level in the study area shows variation influenced by differences in the rainfall data used. Analysis of flood classification area with three types of rainfall data resulted in slightly different vulnerability values. Using February rainfall data, the flood vulnerability area was recorded as the largest at 9,769.29 hectares, followed by 9,675.91 hectares for 2023 average daily rainfall data, and 9,392.96 hectares for August rainfall data. Based on the flood vulnerability map using 2023 average daily rainfall data, Sekotong District was identified as the area with the largest highly flood-prone area, followed by Lembar District and Southwest Praya District. Furthermore, in the vulnerability analysis resulting from rainy and dry season rainfall data, five villages consistently showed the largest highly flood-prone area classifications: Candi Manik Village, Sekotong Tengah Village, Taman Baru Village, Sekotong Timur Village, and Eyat Mayang Village. These findings emphasize the need for more specific flood mitigation strategies based on hydrological conditions and spatial characteristics of each region.

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REFERENCES

Aldiansyah, S., & Wardani, F. (2023). Evaluation of flood susceptibility prediction based on a resampling method using machine learning. *Journal of Water and Climate Change*, *14*(3), 937-961. DOI: https://doi.org/10.2166/wcc.2023.494

Anggraini, N., Pangaribuan, B., Siregar, A. P., Sintampalam, G., Muhammad, A., Damanik, M. R. S., & Rahmadi, M. T. (2021). Analisis pemetaan daerah rawan banjir di kota medan Tahun 2020. *Jurnal Samudra Geografi*, 4(2), 27-33. DOI: https://doi.org/10.33059/jsg.v4i2.3851

Anugrah, A. R. S. (2020). Analisis Peran Pemerintah dalam Penanganan Banjir di Kota Pontianak: Implementasi Kebijakan dan Koordinasi Lintas Sektor. *Jurnal Ilmu Administrasi Publik UMA*, 8(1), 163-71. DOI: https://doi.org/10.31289/publika.v11i2.10504

Arif, D. A., Mardiatno, D., & Giyarsih, S. R. (2017). Kerentanan Masyarakat Perkotaan Terhadap Bahaya Banjir Di Kelurahan Legok Kecamatan Telanipura Kota Jambi. *Jurnal Majalah Geografi Indonesa,* 31(1), 1-11. DOI: https://doi.org/10.22146/mgi.25493

Asdak, C. (2023). *Hidrologi dan pengelolaan daerah aliran sungai*. UGM PRESS.

Azevedo de Almeida, B., & Mostafavi, A. (2016). Resilience of infrastructure systems to sea-level rise in coastal areas: Impacts, adaptation measures, and implementation challenges. Sustainability, 8(11), 1115. DOI: https://doi.org/10.3390/su8111115

Aziza, S. N., Somantri, L., & Setiawan, I. (2021). Analisis pemetaan tingkat rawan banjir di Kecamatan Bontang Barat Kota Bontang berbasis sistem informasi geografis. Jurnal Pendidikan Geografi Undiksha, 9(2), 109-120. DOI: https://doi.org/10.23887/jjpg.v9i2.35173

Badwi, N., Invanni, I., & Abbas, I. (2020). Pemetaan Tingkat Rawan Bencana Banjir di Daerah Aliran Sungai Maros Provinsi Sulawesi Selatan. *Jurnal LaGeografia,* 18(3), 309-322. DOI: https://doi.org/10.35580/lageografia.v18i3.13930

Bintoro, A., Widjajanto, D., & Isrun, I. (2017). Karakteristik fisik tanah pada beberapa penggunaan lahan di Desa Beka Kecamatan Marawola Kabupaten Sigi. Agrotekbis: *Jurnal Ilmu Pertanian* (e-journal), 5(4), 423-430. http://jurnal.untad.ac.id/jurnal/index.php/agrotekbis/index

Diharja, R., Fahlevi, M. R., Rahayu, E. S., & Handini, W. (2022). Prototype-Design of Soil Movement Detector Using IoT Hands-on Application. *Jurnal Penelitian Pendidikan IPA*, 8(4), 1951-1960. DOI: https://doi.org/10.29303/jppipa.v8i4.1709

Darmawan, K., Hani'ah., & Suprayogi, A. (2017). Analisis tingkat kerawanan banjir di kabupaten sampang menggunakan metode *overlay* dengan scoring berbasis sistem informasi geografis. *Jurnal Geodesi Undip*, 6(1), 31-40. DOI: https://doi.org/10.14710/jgundip.2017.15024

Prima, S., Castellini, M., Rodrigo-Comino, J., & Cerdà, A. (2020). Soil hydrology for a sustainable land management: Theory and practice. Water, 12(4), 1109. DOI: https://doi.org/10.3390/w12041109

Gao, H., Cai, H., & Duan, Z. (2018). Understanding the impacts of catchment characteristics on the shape of the storage capacity curve and its influence on flood flows. Hydrology Research, 49(1), 90-106. DOI:10.2166/nh.2017.245

Hengkelare, S. H., & Rogi, O. H. (2021). Mitigasi Risiko Bencana Banjir di Manado. Spasial, 8(2), 267-274. ISSN 2442-3262.

Ihwan, A. S. (2023). Memperkuat Ekososial Untuk Mencegah Dampak Banjir Di Malang. Waskita: *Jurnal Pendidikan Nilai dan Pembangunan Karakter,* 7(2), 221-237. DOI: https://doi.org/10.21776/ub.waskita.2023.007.02.8

Kasenda, R. Y., Rantung, B., Lande, A., Warawarin, K., Posumah, M., Laurens, D., & Rompis, A. (2023). Analisis Penyebab Terjadinya Banjir Di Desa Papakelan Yang Mengakibatkan Trauma Pada Penduduk Sekitar. *JISIP Jurnal Ilmu Sosial dan Pendidikan*, 7(1), 441-449. DOI: http://dx.doi.org/10.58258/jisip.v7i1.4311

Kaya, C. M., & Derin, L. (2023). Parameters and methods used in flood susceptibility mapping: a review. *Journal of Water and Climate Change*, 14(6), 1935-1960. DOI: https://doi.org/10.2166/wcc.2023.035

Kodoatie, R. J. (2021). *Rekayasa dan manajemen banjir kota.* Penerbit Andi.

Mekuriaw, T. (2019). Evaluating impact of land-use/land-cover change on surface runoff using Arc SWAT model in sore and Geba Watershed, Ethiopia. *Journal of Environment and Earth Science*, 9(10), 6-17. ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)

Mualimin, M. (2017). Manajemen Dakwah melalui Bantuan Kemanusiaan Korban Banjir di Kabupaten Sambas. Ilmu Dakwah: Academic *Journal for Homiletic Studies,* 11(1), 111-132. DOI: https://doi.org/10.15575/idajhs.v11i1.1104

Myers, B. R., Boland, J., & Peters, S. (2024). Predicting suspended sediment transport in urbanised streams: A case study of dry creek, South Australia. *Hydrology,* 11(11), 196. DOI: https://doi.org/10.3390/hydrology11110196

Negari, C.A.S., Imam, T., dan Faik, K., 2017, Analisis Spasial Daerah Penangkapan Ikan dengan Alat Tangkap Gillnet di Perairan Pasir, Kabupaten Kebumen, Jawa Tengah, Indonesian *Journal of Capture Fisheries* 1 (03) : 1-7. e-ISSN 2613-9766

Nuryanti, N., Tanesib, J. L., & Warsito, A. (2018). Pemetaan Daerah Rawan Banjir dengan Penginderaan Jauh dan Sistem Informasi Geografis di Kecamatan Kupang Timur Kabupaten Kupang Provinsi Nusa Tenggara Timur. *Jurnal Fisika: Fisika Sains Dan Aplikasinya*, 3(1), 73-79. DOI: https://doi.org/10.35508/fisa.v3i1.604

Ouma, Y. O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. Water, 6(6), 1515-1545. DOI: https://doi.org/10.3390/w6061515

Parmadi, U. N., Arifin, M., & Ali, M. (2022). Arahan Pencegahan Bencana Banjir Pada Perumahan Di Kawasan Sub Urban Kota Makassar. Jurnal Wilayah & Kota Maritim, *Journal of Regional and Maritime City Studies*, 10(2). DOI: https://doi.org/10.20956/jwkm.v10i2.1605

Pratama, I. A., Hariyadi, H., Wirasatriya, A., Maslukah, L., & Yusuf, M. (2021). Validasi Pengukuran Turbiditas dan Material Padatan Tersuspensi di Banjir Kanal Barat, Semarang dengan Menggunakan Smartphone. Indonesian *Journal of Oceanography*, 3(2), 149-156. DOI: https://doi.org/10.14710/ijoce.v3i2.11158

Purnomo, S., Mulki, G. Z., & Firdaus, H. (2019). Pemetaan Rawan Banjir Di Kecamatan Pontianak Barat Dan Pontianak Kota Berbasis Sistem Informasi Geografis. JeLAST: *Jurnal PWK, Laut, Sipil, Tambang,* 6(2), 1-7. DOI: https://doi.org/10.26418/jelast.v6i2.34829

Putra, M. A. R. (2017). *Pemetaan kawasan rawan banjir berbasis sistem informasi geografis (sig) untuk menentukan titik dan rute evakuasi*. UIN Alauddin Makassar.

Qodriyatun, S. N. (2020). Bencana banjir: pengawasan dan pengendalian pemanfaatan ruang berdasarkan UU penataan ruang dan RUU Cipta Kerja. Aspirasi: *Jurnal Masalah-Masalah Sosial,* 11(1), 29-42. DOI: https://doi.org/10.46807/aspirasi.v11i1.1590

Rubaiyn, A., Okto, A., & Asfar, S. (2023). Analysis of Groundwater Quality In Areas Surrounding Mining Sites In Kolaka Regency. *Jurnal Rekayasa Geofisika Indonesia,* 5(01), 1-13. DOI: https://doi.org/10.56099/jrgi.v5i01.1

Rudi, R., & Avianto, D. (2019). Implementasi ekstraksi ciri histogram dan k-nearest neighbor untuk klasifikasi jenis tanah di Kota Banjar, Jawa Barat. *Jurnal Buana Informatika,* 10(2), 85-98. DOI: https://doi.org/10.24002/jbi.v10i2.2141

Reza, M., Surya, B., Akil, A., Nasution, M. A., Muhibuddin, A., Saleh, H., ... & Barkey, R. A. (2025). Analisis Alih Fungsi Lahan Pertanian pada Kawasan Rawan Bencana di Kota Batu. *Geodika: Jurnal Kajian Ilmu dan Pendidikan Geografi*, *9*(2), 235-244. DOI:

Sihombing, Y. H., Muskananfola, M. R., & A'in, C. (2018). Pengaruh kerapatan mangrove terhadap laju sedimentasi di desa bedono demak (The Effect of Mangrove Density on Sedimentation Rate in Bedono Village, Demak). *Management of Aquatic Resources Journal* (MAQUARES), 6(4), 536-545. DOI: https://doi.org/10.14710/marj.v6i4.21346

Suni, M. A., Nurulaeni, M., & Kurniawan, A. D. (2023). Analisis tingkat kerawanan banjir menggunakan sistem informasi geografi di Sub DAS Toili Kabupaten Banggai. *Nusantara Hasana Journal*, 2(9), 100-108. https://ejournal.nusantarahasanajournal.com/index.php/nhj/article/view/670

Sugiarta, L. A., & Anggraeni, J. D. (2023). Study of Land Use Change Map in the Irrigation Areas of Gebong and Sesaot, West Lombok Regency. *Jurnal Pengabdian Magister Pendidikan IPA,* 6(4), 1132-1142. DOI: https://doi.org/10.29303/jpmpi.v6i4.6259

Taufik, M., & Rahman, I. W. (2020). Pemetaan daerah rawan banjir (studi kasus: banjir pacitan desember 2017). *Geoid*, 15(1), 12-19. DOI: http://dx.doi.org/10.12962%2Fj2442

. Virgota, A., & Farista, B. (2023). Identification and Mapping of Landslide-Prone Areas in the Meninting Watershed Area, West of Lombok. *Jurnal Biologi Tropis,* 23(1), 382-391. DOI:10.29303/jbt.v23i1.4493

Virgota, A., Farista, B., & Gunawan, L. A. (2024). Identification and Mapping of Flood Vulnerability in the Meninting Watershed, West Lombok. *Jurnal Penelitian Pendidikan IPA*, 10(7), 3759-3769. DOI**:** 10.29303/jppipa.v10i7.8201

Wisnawa, I. G. Y., Jayantara, I. G. N. Y., & Putra, D. G. D. (2021). Pemetaan lokasi rawan banjir berbasis sistem informasi geografis di Kecamatan Denpasar Barat. *Jurnal ENMAP (Environment and Mapping)*, *2*(2), 51-61. DOI: https://doi.org/10.23887/em.v2i2.39841

Wiweka, W., & Suwarsono, S. (2011). Pengkajian Relasional Risiko Banjir Dengan Bentuk Lahan Berdasarkan Citra Satelit Penginderaan Jauh Di Daerah Aliran Sungai Bengawan Solo Bagian Hilir. *Jurnal Teknik Hidraulik*, 2(2), 125-140. DOI: https://doi.org/10.32679/jth.v2i2.250

Yasa, I. W., Saadi, Y., Sulistyono, H., Setiawan, E., Hartana, H., & Negara, I. D. G. J. (2021). Analisis Karakteristik Kedalaman Hujan Dan Iklim di Pulau Lombok. GANEC SWARA, 15(2), 1067-1074. DOI:10.35327/gara.v15i2.219

Zakipour, M., Yazdandoost, F., Alizad, K., Izadi, A., & Farhangmehr, A. (2023). An Integrated Resilient Sediment Transport RIsk Management (IRSTRIM) Approach for Estuaries. Journal of Marine Science and Engineering, 11(7), 1471. DOI: https://doi.org/10.3390/jmse11071471

Zech, W., Schad, P., & Hintermaier-Erhard, G. (2022). *Soils of the World*. Berlin: Springer

Zhou, Z., Smith, J. A., Baeck, M. L., Wright, D. B., Smith, B. K., & Liu, S. (2021). The impact of the spatiotemporal structure of rainfall on flood frequency over a small urban watershed: An approach coupling stochastic storm transposition and hydrologic modeling. Hydrology and Earth System Sciences, 25(9), 4701-4717. DOI:10.5194/hess-25-4701-2021