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A Remote Sensing Approach in Detecting Landslide Susceptibility in Ngadas Village

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Abstract

This study explores the use of remote sensing techniques to assess landslide severity in Ngadas Village, a mountainous area prone to landslides due to its steep topography. Located in Poncokusumo District, Malang Regency, Ngadas Village serves a strategic role as a gateway to Bromo Tengger Semeru National Park (TNBTS). Its significance in tourism and agriculture underscores the importance of mitigating landslide risks that could disrupt accessibility and local livelihoods. By integrating remote sensing data such as Digital Elevation Models (DEM), satellite imagery, rainfall patterns, soil types, and geological characteristics, this study employs weighted overlay analysis to produce a comprehensive landslide vulnerability map. The findings reveal that landslide vulnerability in the Ngadas region varies but is predominantly moderate to low. This is largely due to the rainfall parameter, which holds the highest weight (30%), making it the dominant influencing factor. In years of high rainfall, landslide vulnerability in Ngadas is expected to increase significantly. Conversely, soil type contributes minimally to the vulnerability assessment, as the region's soil has inherently loose properties. This spatial analysis provides valuable insights for disaster mitigation planning, highlighting the need for adaptive land management strategies to enhance resilience and sustainability in the area.

Keywords: landslide susceptibility, remote sensing, disaster mitigation

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1. Introduction

Natural disasters are events that can occur anytime and anywhere, which have a detrimental impact in terms of material and immaterial for the lives of people affected by the disaster. Landslides are one of the most common disasters in Indonesia. Generally, landslides are often found in mountainous areas, especially where there is frequent rainfall. The occurrence of landslides causes many losses such as property and casualties and also causes damage to other facilities and infrastructure, for example in housing, companies or industries and agricultural land and plantations which have an impact on

reducing the economy in the community (Yuniarta et al., 2015).

The main factor in the occurrence of landslides is due to the process of changes in the structure on the earth's surface characterized by the disturbance of instability in the soil and the rocks that make up the slope which is influenced by geomorphological conditions, especially on the slope, the type of rock or soil on the slope, and hydrological conditions in the area (Nurjanah & Mursalin, 2021).

Ngadas Village is one of the villages in Poncokusumo District, Malang Regency, which has a strategic role as a link to the Bromo Tengger Semeru National Park (TNBTS). This area is not only the main route for tourists who want to enjoy the natural beauty of the TNBTS area, but also an integral part of the economic activities of the local community, such as tourism and agriculture, therefore, this village has high natural potential(Yurisma, 2021) . However, its location in a mountainous area with steep topography and high rainfall makes Ngadas Village vulnerable to landslides. This condition not only disrupts tourist accessibility, but also threatens the safety of the community and the continuity of agricultural activities as the main livelihood.

Landslide vulnerability in Ngadas Village can have a significant impact on economic and tourism activities, given that the connecting roads to TNBTS are at risk of being cut off by landslides. This condition not only disrupts tourist accessibility, but also threatens community safety and the continuity of agricultural activities as the main livelihood. Therefore, landslide mitigation in Ngadas Village is an important priority to ensure the sustainability of the village's strategic function.

The remote sensing approach is one of the effective methods to detect and analyze the level of landslide vulnerability in Ngadas Village. This technology allows mapping of landslide-prone areas by considering various factors such as slope, soil type, land cover, and rainfall patterns. In addition, remote sensing can also be integrated with Geographic Information Systems (GIS) to produce accurate landslide vulnerability maps that are easily understood by stakeholders. While remote sensing offers significant advantages in landslide detection and analysis, challenges remain, such as the need for high-quality data and potential model overload, which may affect the reliability of the assessment (Lv et al., 2024) .

Previous research in Poncokusumo sub-district shows that Poncokusumo sub-district has a moderate to high level of vulnerability. Poncokusumo sub-district has a moderate to very high level of vulnerability to landslide risk due to a combination of several environmental factors (Rif'ah et al., 2024) . The main factor causing landslides is rainfall. High rainfall will cause high ground motion (Goma et al., 2022) .

This research aims to apply a remote sensing approach to detect the level of landslide vulnerability in Ngadas Village. With comprehensive spatial data-based information, it is expected to support disaster mitigation planning, maintain the sustainability of the village's strategic function as a link to the TNBTS, and improve the safety of the community and tourists in the area.

2. Method

This research was conducted in Ngadas village, Ponco Kusumo sub-district, Malang district. The altitude of Ngadas village is 2,175 meters above sea level. The eastern part of Ngadas village borders Ngadisari village, the eastern part of Ngadas village borders Gubug Klakah village, the northern part borders Mojo Rejo village and the southern part borders Ranu Pani village. Ngadas village has an area that is mostly used for agricultural land and plantations.

Remote sensing approach is an effective method to detect and map landslide vulnerability zones, especially in areas that are difficult to reach directly. In the context of Ngadas Village, this method can be applied by utilizing satellite image data and spatial analysis to produce an accurate landslide vulnerability map. GIS combined with remote sensing allows timely updates on landslide vulnerability, especially after extreme weather events (Nefros et al., 2024) .

A. Data Collection

1) Digital Elevation Model (DEM)

Elevation data is used to analyze the slope, which is one of the main factors in the occurrence of landslides. Steep slopes increase the risk of landslides. Slope analysis from DEM is essential to determine the level of susceptibility to landslides as steep slopes have a higher risk. Slope steepness is a major determinant of landslide occurrence, with steeper areas showing higher vulnerability (Mohammednur et al., 2024) .

2) Satellite Images from Google Earth

Image data from Google Earth is used to analyze land use. Satellite images from Google Earth were used for land cover identification, land cover classification using *Maximum Likelihood* Classification (MLC) algorithm. The high resolution of Google Earth imagery helps in analyzing land use change in more detail, so that it can be linked to human activities that affect slope stability. Landsat 8 multitemporal imagery enables detailed land use/land cover (LULC) mapping, improving understanding of changes over time, such as urban expansion and agricultural development (Pande et al., 2024) .

3) Rainfall Data from CHIRPS

Rainfall data is obtained from CHIRPS imagery that integrates satellite data with observation station data. This data provides information on historical rainfall distribution patterns in Ngadas Village. High rainfall is one of the main factors that trigger landslides, especially when the soil is saturated with water. This data analysis is used to understand the correlation between rainfall intensity and landslide frequency. CHIRPS combines satellite and ground-based data, improving spatial coverage and temporal resolution for rainfall analysis (Peiro et al., 2024) .

4) Soil Type and Rock Type Data

Information on soil type is obtained from maps or official documents, from FAO. This data includes a classification of soil types. Soil types with high clay content or those with high water absorption will be identified as areas more prone to landslides. Geographic Information Systems (GIS) are used to integrate soil data with other environmental factors, increasing the accuracy of landslide susceptibility maps (Baral et al., 2021) .

B. Analysis Method

Overlay and Weighting were used in this study. *Weighted overlay* technique is used to combine various parameters by assigning weights according to their respective contributions to landslide risk. For example, slope may be given a higher weight compared to soil type. *Weighted overlay* technique was used to model potential rainfall areas by integrating land use, landscape and soil texture parameters, where weighting was applied to those parameters based on previous research, thus enabling a nuanced

understanding of water absorption capability in different regions (Awanda et al., 2017) .

C. Parameter Classification

Parameter Classification to analyze the landslide vulnerability, it is divided into several parameters, with the parameters of rainfall, slope, rock type, land cover, and soil type. This classification aims to make it easier to analyze the scoring of each parameter level. The following is the classification of landslide vulnerability parameters:

Table 1. Classification of Rainfall Parameters (mm/year) (Puslittanak, 2004)

Parameters	Weight	Score
Very wet (>3,000)	30%	5
Wet (2,500-2,300)		4
Medium/Currently (2,000-2,500)		3
Dry (1,500-2,000)		2
Very Dry (<1,500)		1

Table 2. Classification of Slope Parameters (Puslittanak, 2004)

Parameters	Weight	Score
<45%	20%	5
30-45%		4
15-30%		3
8-15%		2
<8%		1

Table 3. Classification of Rock Type Parameters (Puslittanak, 2004)

Parameters	Weight	Score
Volcanic Rocks	20%	3
Sedimentary Rocks		2
Alluvial Rocks		1

Table 4. Classification of Land Cover Parameters (Puslittanak, 2004)

Parameters	Weight	Score
Paddy Field, Rice Field	20%	5
Shrubs		4
Forest and Plantation		3
City/Settlement		2
Ponds, Reservoirs, Waters		1

Table 5. Classification of Soil Type Parameters (Puslittanak, 2004)

Parameters	Weight	Score
Regosol	10%	5
Andosol, Podzolic		4
Brown Latosol		3
Yellowish Brown Latosol Association		2
Alluvial		1

Therefore, a formula for analyzing landslide vulnerability in this study can be drawn as follows (Puslittanak, 2004) :

$$Total\ Score = 0{,}3\ RP + 0{,}2SP + 0{,}2RTP + 0{,}2LCP + 0{,}1STP \quad (1)$$

Description:
RP= Rainfall Parameter
SP= Slope Parameters
RTP= Rock Type Parameter
LCP= Land Cover Parameter
STP= Soil Type Parameter

D. Mapping and Interpretation of Results

The result of this analysis is a landslide vulnerability map that shows various levels of vulnerability, ranging from very low to very high. This map is not only useful for identification of vulnerable areas, but also as a tool in disaster mitigation planning in Ngadas Village. The interpretation results are laid out with vulnerability mapping levels, namely High, Medium and Low. Understanding the level of vulnerability helps the efficient distribution of resources, ensuring that high-risk areas receive immediate attention (Fatkhullah et al., 2022) .

3. Results and Discussion

A. Rainfall Map Results

Annual rainfall in Ngadas Village was mostly moderate, with extended dry periods throughout 2023. The results of interviews with the surrounding community revealed that rainfall in the Ngadas area was infrequent, forcing farmers to rely more on manual watering techniques to sustain their crops. Due to the lack of sufficient precipitation, agricultural activities in the region faced challenges, requiring additional labor and resources to maintain soil moisture levels.

Field observations further confirmed that the soil in Ngadas Village appeared dry, with visible cracks and reduced water retention capacity. The persistent dry conditions may also contribute to declining groundwater levels, which could impact long-term water availability for irrigation and household use. If these patterns continue, local farmers may need to adopt improved water conservation strategies, such as rainwater harvesting or drip irrigation, to mitigate the effects of reduced rainfall and sustain agricultural productivity in the region. Dry soils often indicate a lack of rainfall, especially in areas where soil moisture dynamics are closely linked to climatic conditions. The presence of a dry soil layer (DSL) is a significant indicator of water scarcity, which can affect vegetation and agricultural practices. DSL formation is positively correlated with average annual rainfall, suggesting that lower rainfall leads to thicker DSL (Yan et al., 2015) . The rainfall map can be seen in the following figure:

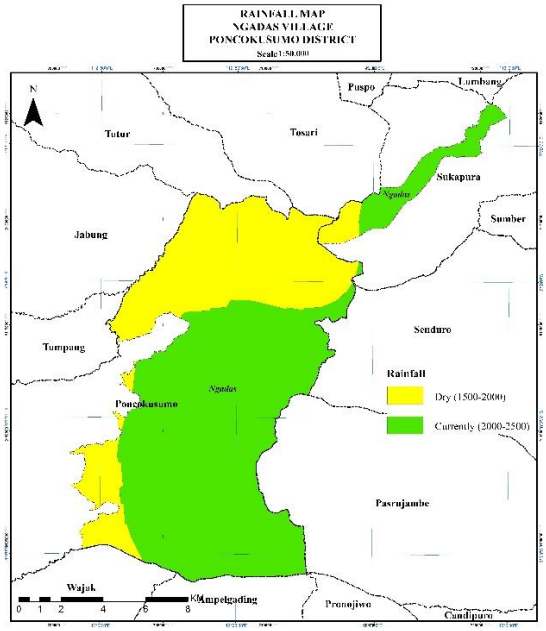

Figure 1. Rainfall Map

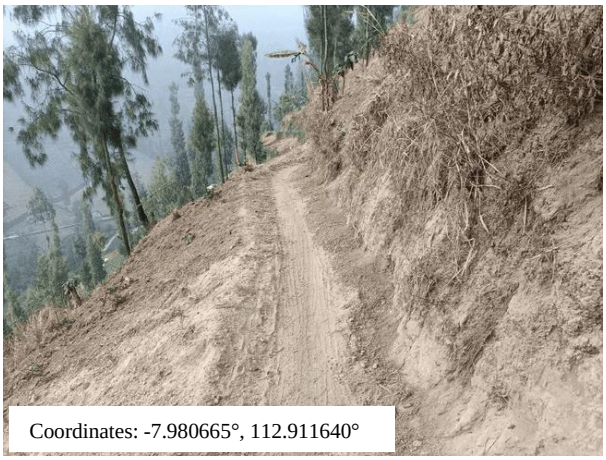

Figure 2. Photo documentation of dry soil in Ngadas region

B. Slope Map Results

The slope in the Ngadas area varies. The slope in the Ngadas area is more dominated by slopes >15%. The results of the field check show that the slope in the Ngadas area varies, but is more dominated by slopes >15%. The Ngadas region is characterized by diverse topography, with a significant dominance of slopes exceeding 15%. This steep terrain presents challenges for agricultural practices, especially in dryland management. The dominance of steep slopes requires specific agricultural practices, such as the cultivation of drought-resistant crops and the application of soil conservation techniques (Noywuli et al., 2024) . The slope map can be seen in the following figure:

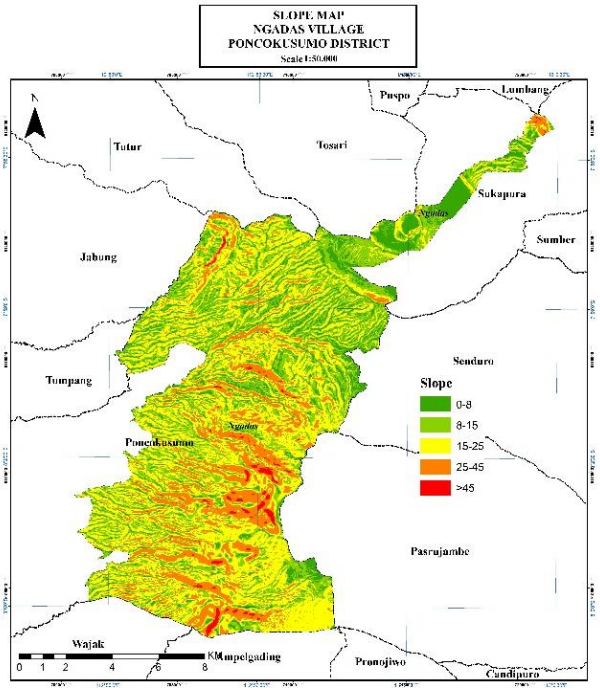

Figure 2. Slope Map

C. Rock Type Map Results

The rock types in the Ngadas area are all volcanic rocks. This is because the Ngadas region is close to a volcano. The Ngadas region is characterized mainly by volcanic rocks due to its proximity to active volcanic systems. This geological setting is influenced by the presence of several volcanoes, which contribute to the formation and distribution of various volcanic rock types. The volcanic dominance of rock types is mainly influenced by their proximity to volcanic activity, which shapes their characteristics and distribution. Classification of volcanic rocks reveals various types, including lava, pyroclastics and sub-volcanic reservoirs, each with different properties that affect the potential for resource exploration. A map of rock types can be seen in the following figure:

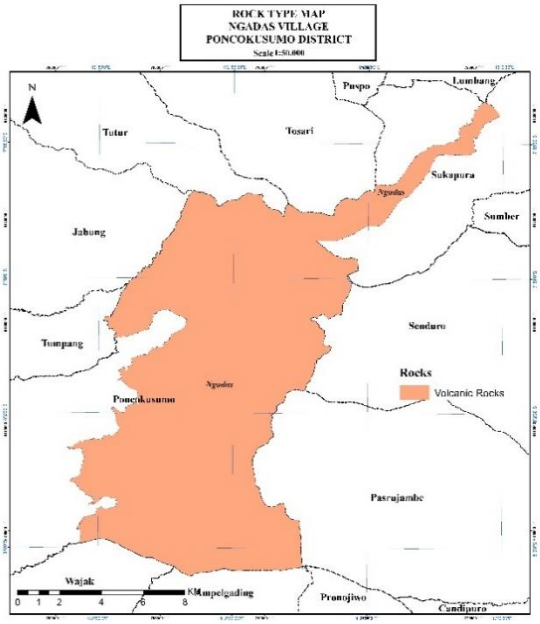

Figure 3. Rock Type Map

D. Land Cover Map Results

Land cover in the Ngadas region is predominantly characterized by the presence of dry forest, which serves as the most extensive vegetation type in the area. The dominance of dry forest is directly influenced by the region's relatively low annual rainfall, as the climatic conditions limit the growth of more water-dependent vegetation types. The prevalence of dry forest suggests that the ecosystem has adapted to arid conditions, with plant species that exhibit drought-resistant characteristics, such as deep root systems and reduced leaf surface area to minimize water loss.

Another significant land cover type in the Ngadas region is dryland agriculture, which also correlates with the area's limited rainfall patterns. Farmers in the region primarily cultivate crops that are more tolerant to dry conditions, such as maize, cassava, and certain legumes, as these plants require less water compared to paddy fields or other high-moisture crops. The dominance of dryland agriculture aligns with rainfall distribution patterns observed in the area, as reflected in rainfall map data, further reinforcing the influence of climate on land use practices. Dry forests in the Ngadas region show a functional response to rainfall variability, with vegetation productivity significantly influenced by annual rainfall levels (Ratzmann et al., 2016) . Below is the land use map:

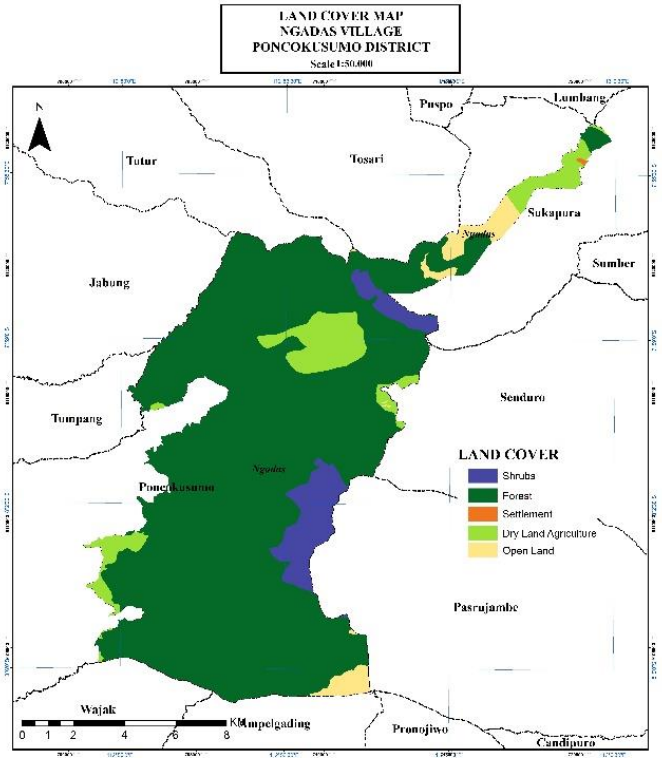

Figure 4. Land Use Map

Figure 5. Dryland Agriculture in the Ngadas Region

Figure 6. Dryland Farming in the Ngadas Region

E. Soil Type Map Results

The soil type in the Ngadas region is dominated by the Andosol soil type. Andosols are a unique soil type found mainly in volcanic areas, characterized by their high nutrient content and distinctive physical properties. These soils are formed from volcanic ejecta and are prevalent in areas near volcanoes. Andosol soils have very distinctive physical properties, namely a fine and porous texture, with a highwater holding capacity. This makes them very fertile and suitable for agriculture, especially for horticultural crops such as vegetables, potatoes and carrots that require soils with good aeration and water retention. The color of these soils tends to be dark due to the high organic matter content, which is the result of the weathering process of mineral-rich volcanic materials. Andosol soils also have their own challenges. Since they are often found on the slopes of volcanoes, they are prone to erosion, especially if the ground cover vegetation is damaged. Andosols develop from volcanic ash and tephra, resulting in a fine texture and high humus content (Takata et al., 2021) . The soil type map can be seen in the following figure:

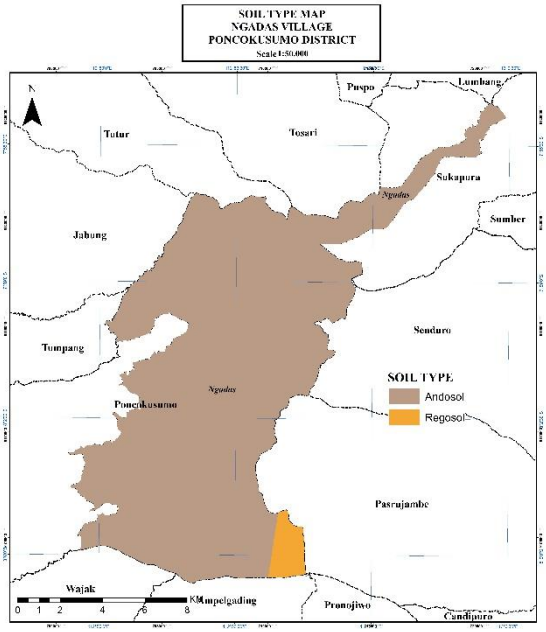

Figure 7. Soil Type Map

Figure 8. Soils in the Ngadas Region

F. Results of Landslide Vulnerability Overlay Map

The results of the overlay map of landslide vulnerability in Ngadas are dominated by moderate vulnerability. This moderate vulnerability is due to the rainfall parameter which has the highest weight than other parameters. This rainfall parameter is the highest base because previous researches have made the rainfall parameter has a strong influence. Rainfall in Ngadas region is from moderate to low, giving a moderate to low landslide vulnerability dominates. Another parameter that makes landslide vulnerability in some areas high in the Ngadas region, because the slope is more than 25%. The soil type parameter has the lowest weight of the other parameters also gives an impact of landslide proneness in the Ngadas area, because in fact the Ngadas area has a majority of andosol soil which has physical properties that are easily loose. Landslide vulnerability map can be seen in the following figure:

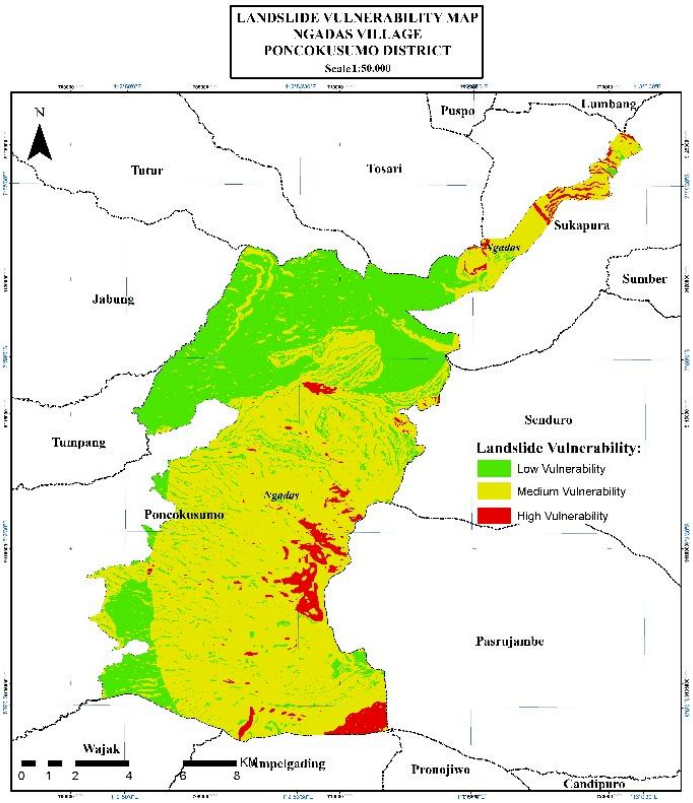

Figure 9. Landslide Vulnerability Map

Landslide vulnerability in Ngadas village is dominated by moderate vulnerability with an area of 7.653,08 Ha followed by medium vulnerability of 7.609,05 Ha and high vulnerability of 708,60 Ha. The results of the vulnerability chart are presented in the following chart:

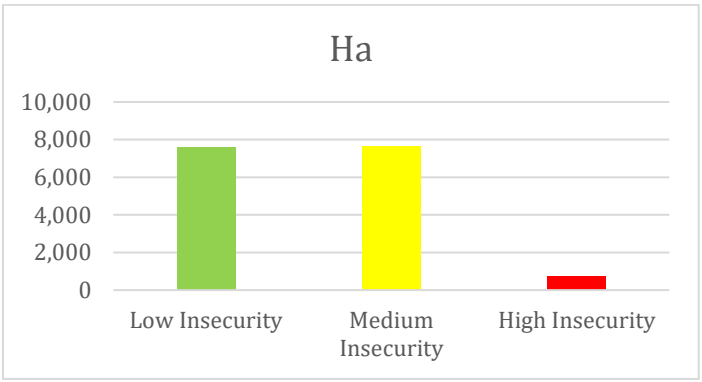

Figure 11. Landslide vulnerability area (Ha)

Landslide vulnerability in the Ngadas area is dominated by medium and low vulnerability. In this study, rainfall has the largest weight with a weight of 30%, but in the research area, rainfall is dominated by medium and low rainfall, this causes a lot of low and medium vulnerabilities in the area, suggestions for further researchers can consider weighting with the conditions of the research area. Rainfall ranges from moderate to low, resulting in moderate to low landslide vulnerability (Anees et al., 2024). Andosol soil types dominate the research area, but in this study this type of soil has the

smallest weight with a weight of 10%, with field results it can be seen in the previous discussion that the soil at the research location is loose and easily released even though there is no high rainfall in the research area, suggestions for further researchers to consider the weight of the soil type from the results of field checks. The presence of andosol soil, which is characterized by loose physical properties, contributes to landslide vulnerability, although it has the lowest weight in the vulnerability assessment (Dyah Susanti et al., 2017).

4. Conclusion

Landslide vulnerability in Ngadas region varies, but is dominated by moderate and low vulnerability. This vulnerability is dominated by medium and low because the rainfall parameter has a weight of 30% making the superiority of the rainfall parameter. Ngadas area if it has high rainfall year it will cause landslide vulnerability in this area to be high vulnerability. The parameter of soil type in this study is also less weighted, because actually the soil in the Ngadas region has a loose nature.

Suggestions for future researchers try to weight each parameter more tailored to the research area. Rainfall is an external factor, but in some places it affects the cause of landslides. Soil type and land cover are also considered to have internal influences that affect landslide vulnerability. Therefore, the next researcher can consider those 3 things as the main parameters in the next research.

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