

Use of Geographic Information Systems for Mapping Landslide Susceptibility in the Bangsal Sub-Watershed, Mojokerto

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Abstract

Landslides are natural phenomena that often occur in Indonesia, especially in areas with a humid tropical climate and varied topography. Mojokerto Regency is one of the areas prone to landslides, especially in the Bangsal Sub-Watershed. Landslides are triggered by a combination of factors such as high rainfall, steep slopes, unstable soil conditions, and lack of vegetation cover. This study aims to identify the main factors associated with landslide susceptibility and map the level of landslide susceptibility in the Bangsal Sub-Watershed of Mojokerto using a Geographic Information System (GIS). This study includes secondary data covering annual rainfall, soil type, geology, land cover, and slope inclination, which were analysed using ArcGIS software. The methods used were overlay, weighting, and scoring of each parameter to produce a landslide susceptibility map. The results of this study show that there are three classifications of landslide susceptibility in the Bangsal Sub-Watershed, namely moderate class with an area of 3.1 ha or 0.07%, high class with an area of 4,708.32 ha or 98.85%, and very high class with an area of 51.49 ha or 1.08%. Rainfall received the highest weight in the scoring model used in this study.

Keywords: geographic information system, land cover, landslide susceptibility, rainfall, slope

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1. Introduction

A landslide is the natural movement of soil, rock, and water in a short period of time with a relatively large volume (Kunu and Luhukay, 2018). Landslides can occur due to natural faults and weather conditions that affect soil and rock, especially in areas with a humid and hot climate (Kurniawan, 2019). According to Yassar et al. (2020), a landslide disaster can be defined as a process of erosion accompanied by soil movement, causing the displacement of soil and rock layers in an area. The Centre for Volcanology and Geological Disaster Mitigation (PVMBG) and the Ministry of Energy and Mineral Resources (ESDM) stated that the results of mapping in East Java Province showed that 29 districts/cities experienced soil movement, which caused frequent landslides in the East Java region, one of which was Mojokerto District.

Mojokerto Regency Regulation No. 9 of 2012 states that there are several subdistricts classified as landslide-prone areas in Mojokerto Regency. One of the areas located in Mojokerto Regency is the Bangsal Sub-Watershed. The Bangsal Sub-Watershed is part of Mojokerto Regency, which is included in the upper reaches of the Brantas Watershed. The Bangsal Sub-Watershed is classified as a landslide-prone area with slopes varying from gentle to very steep (steep). In general, in Indonesia, landslides frequently occur in

almost every watershed, especially in the upper reaches (Darwis et al., 2021).

Landslides can occur due to high rainfall combined with steep slopes, eroded soil, vibrations, and lack of vegetation cover. This is in line with the research by Kurniawati et al. (2022), which states that high-intensity rainfall can cause landslides when combined with steep slopes. Steep slope inclination is a key component in determining the level of landslide hazard. Steep slopes have a higher potential for landslides, especially if the slope conditions are unstable (Susanti and Miardini, 2019).

The analysis that can be carried out is by utilising Geographic Information Systems (GIS) using various parameters that cause landslides (Taufik et al., 2016). Complex disaster modelling can use GIS methods that support disaster analysis, identify and determine areas that are prone to disasters, and conduct extensive regional mapping. In addition, this method is also effective in identifying landslides over a wide area (Mulyasari et al., 2023). The potential for landslide hazards can also be identified easily, quickly, and accurately using GIS (Thamsi et al., 2019). This study aims to identify the main potential causes of landslides and map landslide-prone areas in the Bangsal Sub-Watershed.

2. Materials and Methods

Study site

The research was conducted from April to August 2025 in the Bangsal Sub-Watershed located in Mojokerto Regency. The research was carried out in several stages, starting from the collection of secondary data, data processing, weighting and scoring of each indicator to determine the landslide susceptibility class. The research was conducted in Mojokerto Regency due to the large number of community activities around the river that convert forests into activities such as housing, agriculture or industry, which can affect water quality and cause landslides (Sulomo, 2015).

Materials and Methods

The study used a quantitative approach by examining landslide indicators used to analyse the level of landslide susceptibility in the Bangsal Sub-Watershed. The research was conducted using ArcGIS software to generate maps of these parameters. Furthermore, the overlay method was used by assigning scores to each indicator and determining weights using the scoring scheme presented in Table 1. The resulting weighted

scores were then used to determine landslide susceptibility classes as presented in Table 2.

Tools required for the research were ArcGIS software, which was used to create maps, and a GPS (Global Positioning System) receiver. This study utilized secondary data. The secondary data included annual rainfall data for the last five years in the Bangsal Sub-Watershed obtained from NASA, soil type data, geological data, land-use data, and slope data obtained from Indonesian geospatial and DEMNAS data sources. Sampling points consisted of five land uses, namely forest, moorland, plantation, rainfed rice fields, and scrubland, which were overlaid with a slope map. Three samples were taken from each land-use area based on three different slope categories : 8–15%, 15–30%, and 30–45%.

The level of landslide susceptibility was determined using a Geographic Information System (GIS)-based weighted overlay approach. This method uses indicators that influence landslide susceptibility, including rainfall, geology (rocks), soil type, slope inclination, and land use. Each indicator was weighted based on its relative influence on landslide susceptibility. The weighting scheme used in this study follows the Puspitanak (2004) model, with modifications to the soil-order classes used in the study area, as shown in Table 1.

Table 1. Landslide Susceptibility Score Indicators

Indicator	Parameters	Score	Weight
Annual Rainfall (mm/year)	Very Dry (<1500)	1	30%
	Dry (1501 - 2000)	2	
	Moderate (2001 - 2500)	3	
	Wet (2501 - 3000)	4	
	Very Wet (>3000)	5	
Geology (Rocks)	Alluvial Rocks	1	20%
	Sedimentary Rocks	2	
	Volcanic Rocks	3	
Slope	<8%	1	20%
	8% - 15%	2	
	15% - 30%	3	
	30% - 45%	4	
	>45%	5	
Land Cover	Ponds, reservoirs, waterways	1	20%
	Cities / Settlements	2	
	Forests and Plantations	3	
	Scrubland	4	
	Dry fields, rice fields	5	
Soil Orders	Aluvial, planosol, hidromoft	1	10%
	Latosol	2	
	Brown forest soil, mediteran	3	
	Andosol, literit, grumusol	4	
	Regosol, litosol, organosol	5	

Source: Modified from Pustitanak, (2004)

The weighting was then applied to determine the total landslide susceptibility index score. The formula used to calculate the landslide susceptibility index score was:

$$\text{Total Index Score} = (30\% \times \text{SCH}) + (20\% \times \text{SG}) + (20\% \times \text{SKL}) + (20\% \times \text{STL}) + (10\% \times \text{SJT}).$$

Explanation:

SCH = Rainfall Score SG = Geological Score

SKL = Slope Gradient Score SJT = Soil Type Score

STL = Land Cover Score

Table 2. Landslide Susceptibility Index Class Scores

Landslide Indicators	Score
Index Class	Low
	1.00 – 1.90
	Medium
	1.91 – 2.80
High	2.81 – 3.70
	Very High
3.71 – 4.60	
Total Weight	100%

Source: Derived from the weighted score range used in this study

3. Results and Discussion

Rainfall

Rainfall is a primary factor associated with landslides. In the weighting scheme employed in this study (Table 1), rainfall carries the highest weight at 30%. Rainfall data for the Bangsal Sub-Watershed were obtained from NASA POWER, covering the last fifteen years across three districts—Pacet, Padusan, and Sumberbrantas—and were averaged at a spatial resolution of $0.5^\circ \times 0.625^\circ$.

The Bangsal Sub-Watershed has an average annual rainfall of 2,361.444 mm/year. This rainfall is classified as moderate according to Table 1. Rainfall is evenly distributed in the Bangsal Sub-Watershed area. Rainfall is influenced by the topography of the slopes of Mount Arjuna-Welirang. Areas with steep slopes and evenly distributed rainfall can result in high soil moisture.

These conditions mean that the Bangsal Sub-Watershed area has a high potential for landslides.

Geology (Rocks)

The Bangsal Sub-Watershed consists of two geological formations: Mount Arjuna-Welirang and Mount Muda Anjasmara. Based on the rock types distributed throughout the Bangsal Sub-Watershed, volcanic rocks are found in the area. Volcanic rocks are difficult to weather and are at high risk of landslides (Rubarkah et al., 2024). In geology, lithology is also a component. The lithology classes in the Bangsal Sub-Watershed are Extrusive: Intermediate: Polymict.

Based on the geological structure, the study area covers an area of 4,762.91 hectares (ha), where the geological structure of Mount Muda Anjasmara covers

1,226.15 ha and the geological structure of Mount Arjuna – Welirang covers 3,536.76 ha. Mount Arjuna-Welirang itself has surface rocks consisting of volcanic breccia, tuff breccia with additional tuff and agglomerate rocks, and lava (Rahmawan, 2015). These volcanic breccia rocks have mild to moderate weathering with components of andesite, volcanic glass, and pumice. Mount Muda Anjasmara has a pyroclastic deposit rock structure consisting of pyroxene andesite and olivine basalt, which has a fairly dense and compact rock density, predicted to originate from the Middle Pleistocene (Firdaus and Sukojo, 2015).

The Bangsal Sub-Watershed is influenced by both mountains, which are quaternary mountains formed by the collision of the Eurasian plate. There is little variation in the geological conditions and landforms of the Bangsal Sub-Watershed, as the area was formed from volcanic activity, making it prone to landslides and soil movement.

Soil Type

Another factor that influences landslide susceptibility is soil type. Soil type affects soil stability, including the soil's capacity to retain water and the resistance of its structure. Soil with good aggregates has the ability to drain water well and has large pore spaces (Kurniawati et al., 2022). There are two types of soil in the Bangsal Sub-Watershed, namely Inceptisol and Andisol. These soils have subgroups, namely Typic Dystrudepts and Typic Hapludands.

In the Bangsal Sub-Watershed, Andisol soil types are more widespread than Inceptisol soil types. Inceptisol is soil that has not undergone significant development, or young soil that is still developing and still closely resembles the properties of its parent material. Inceptisol soil is formed under conditions of evenly distributed rainfall over 90 days with a humid climate. Inceptisol is classified as soil that is prone to landslides with a low sensitivity level. On steep slopes, this type of soil is susceptible to erosion or landslides (Suprpto et al., 2017). Therefore, suitable land use for Inceptisol soil on steep slopes is forestry.

Andisol is dark brown to black in color and is classified as fertile soil. However, intensive land use on steep slopes increases the potential for erosion and landslides. Andisol has andic properties from volcanic material. Andisol has high organic matter and water content, as well as a crumbly soil structure (loose consistency) and a predominantly high dust texture, which also has the potential for landslides (Juarti, 2016).

Slope

Slope is one of the factors that influence landslides. The steeper the slope, the weaker the soil stability in that area, causing landslides. Slope gradients are obtained from DEMNAS (National Digital Elevation Model) data in raster form and extracted into slopes in the study area using ArcGIS 10.8 software. In the Bangsal Sub-Watershed, five slope classes were obtained from DEMNAS (National Digital Elevation Model), namely 0–8%, 8–15%, 15–25%, 25–45%, and >45%.

Slope class 3 (15–30%) is coloured yellow and dominates the Bangsal Sub-Watershed area with a land area of 1,420.44 hectares. Slope class 1 (0–8%) has the smallest land area of 2.87 hectares and is marked in dark green. Slope class 2 (8–15%) has an area of 1,009.90 hectares and is marked in light green on the map. Slope class 4 (30–45%) has an area of 649.76 hectares and is marked in orange, while slope class 5 (>45%) has an area of 240.46 hectares. Slope classes 4 and 5, which are steep and very steep slopes, are prone to landslides. This is in line with the research by Nursia et al. (2023), which states that areas with slopes of 25–45% and >45% have a high potential for landslides.

Land use in the Bangsal Sub-Watershed includes agricultural activities on slopes greater than 15%. In reality, there is still a lot of land used for dry fields and mixed gardens for farmers' businesses. On slopes with a gradient >15%, agricultural use is not recommended because it exceeds the safe slope gradient limit. Additionally, steep slopes make the soil unstable and highly susceptible to erosion during heavy rainfall (Safitry et al., 2023). The steeper a slope, the greater the portion of soil eroded due to the speed of water flow on the soil surface. As a result, the soil's holding force decreases, triggering soil movement that leads to large-scale landslides.

Land Cover

Land cover is an important factor to consider when analysing areas prone to landslides (Agustina et al., 2020). Land cover will continue to change over time due to activities occurring in a particular area (Yufahri and Widjajanti, 2022). Land cover that continuously undergoes land-use conversion can cause slope instability and landslides. Land cover in the Bangsal Sub-Watershed consists of forests and agricultural land. Land cover includes forests, mixed gardens, rain-fed rice fields, shrubs, and moorland.

The distribution of land cover in the Bangsal Sub-Watershed is dominated by forest land. Forest land cover covers an area of 3,590.31 hectares (75.38%), grassland covers 30.36 hectares (0.64%), settlements cover 37.62 hectares (0.79%), scrubland covers 436.05 hectares (9.16%), mixed gardens cover 142.35 hectares (2.99%), dry fields cover 483.78 hectares (10.16%), and rain-fed rice fields cover 42.44 hectares (0.89%). The land cover area in the Bangsal Sub-Watershed is dominated by forests that are part of the Raden Soerjo Grand Forest Park (Tahura), which has annual tree commodities such as mahogany and pine. Trees with wide and extensive roots and dense canopies, such as mahogany and pine, can prevent erosion and landslides. This is in line with the research by David Raj et al. (2024), which states that wide canopy cover in various places can reduce erosion caused by rain and act as a barrier to prevent soil from being directly exposed to rainwater falling on the ground.

Another type of land cover is mixed gardens consisting of banana, avocado, coffee, petai trees, pine trees, and durian trees. Plants with taproots such as petai, pine, and durian trees have deep and extensive

root systems that can stabilise slopes against landslides. Shrubland cover consists of wild grasses, *Ageratum conyzoides*, *Pouzolzia* grass, and insulin plants. Other cover includes rain-fed rice fields, which are considered highly prone to landslides because they lack irrigation channels that can stabilise the land. The field cover consists of field crops, corn, and carrots. These commodities do not have dense cover plants such as grasses or deep root systems that can stabilise the soil, thereby increasing susceptibility to erosion or landslides.

Landslide Susceptibility

Landslide susceptibility is obtained from landslide parameters that undergo a weighting and scoring process (Table 1). After the weighting and scoring process, landslide susceptibility classes are obtained (Table 2). The next process is the overlay of these landslide parameters, resulting in a landslide susceptibility map (Figure 1).

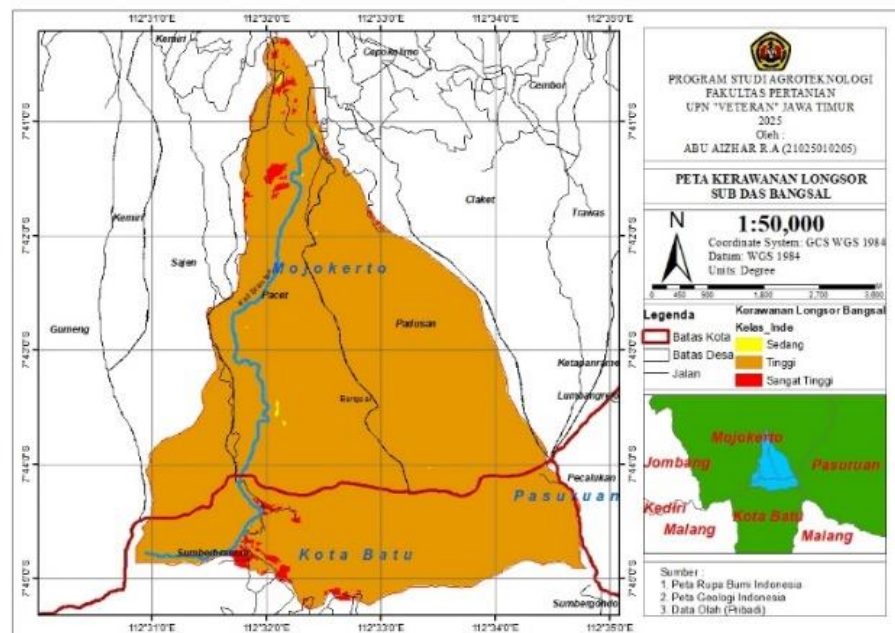


Figure 1. Landslide Susceptibility Map of the Bangsal Sub-Watershed

The overlay results of five parameters (geology, rainfall, land cover, slope, and soil type) yielded three classifications of landslide susceptibility in the Bangsal Sub-Watershed, namely moderate, high, and very high. High landslide susceptibility dominated the Bangsal Sub-Watershed area with an area of 4,708.32 ha marked in orange. The very high class, covering an area of 51.49 ha or 1.08%, is marked in red, and the moderate class, covering an area of 3.1 ha or 0.07%, is marked in yellow.

The Bangsal Sub-Watershed area where the sampling points were taken has a high landslide susceptibility class. Data processing in ArcGIS produced a landslide susceptibility value for the Bangsal Sub-Watershed of 2.90–3.70, which is classified as high (Table 2). This condition is associated with the combined effects of rainfall and other physical parameters in the model. The average annual rainfall in the Bangsal Sub-Watershed is 2,361.444 mm/year,

4. Conclusions

The combination of five parameters, namely geology, rainfall, land cover, slope, and soil type, resulted in three landslide susceptibility classes in the Bangsal Sub-Watershed, ranging from moderate to very high. Rainfall had the highest weight in the scoring model used in this study. These susceptibility classes consist of moderate with an area of 3.1 ha or 0.07%, high with an

area of 4,708.32 ha or 98.85%, and very high with an area of 51.49 ha or 1.08%. The results of landslide susceptibility classification in the Bangsal Sub-Watershed can be used to support further mitigation and minimize potential hazards.

which is classified as moderate. Areas with annual rainfall in the range of 2,000 to 2,500 mm are categorized as having moderate rainfall-related susceptibility, while the potential for landslides can increase during high-intensity rainfall or intensive human activities that disturb slope stability (Kapitan et al., 2025).

Additionally, the presence of volcanic rock geology and Andisol soils that are prone to landslides contributes to the high landslide susceptibility class in the Bangsal Sub-Watershed. Steep slopes are one of the factors causing soil movement and landslides. The steeper the slope, the higher the potential for landslides. This statement is consistent with the research by Saputra et al. (2022), which states that steep slopes cause significant soil displacement due to gravitational forces, thereby disrupting slope stability and increasing the risk of landslides.

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