Spatial Analysis of Landslides in Kulon Progo Regency, Yogyakarta as a Basis for Disaster Mitigation

Isbandi[1], *Oktia Woro Kasmini* Handayani[2], *Intan* Zainafree[2], *Evi* Widowati[2]

[1]Doctoral student in Public Health study program, Unnes
[2]Lecturer, Public Health Universitas Negeri Semarang, Central Java

Abstract. Kulon Progo Regency, Yogyakarta, is a region with a high risk of landslides due to hilly topography and intense rainfall. This disaster routinely threatens life and infrastructure, so spatial analysis is needed as a basis for mitigation. This study aims to map the level of landslide vulnerability and identify the dominant factors that influence it in Kulon Progo Regency. The method used is spatial analysis with a tiered quantitative approach (scoring and weighting) using a Geographic Information System (GIS). The parameters analyzed include slope gradient, rainfall, soil type, geology, and land use overlaid *with* landslide point distribution data. The results of the study produced a landslide vulnerability zoning map divided into three classes: low, medium, and high. Areas with a high level of vulnerability are concentrated in the western part from the north to the south with dominant factors being steep slopes (>40%) and high rainfall intensity on dryland agricultural land. In conclusion, this zoning map is an important and strategic instrument for local governments to prepare disaster risk-based spatial plans, determine evacuation routes, and develop early warning systems for the community.
Keywords: landslide, spatial analysis, geographic information system, disaster mitigation, kulon progo.

1 Introduction

Indonesia is a country with a high level of vulnerability to natural disasters. Geographically, Indonesia is located at the confluence of three major tectonic plates and is located on the Pacific Ring of Fire. Furthermore, its tropical climate with two seasons leads to a high potential for hydrometeorological disasters. The National Disaster Management Agency (BNPB) consistently reports that hydrometeorological disasters, such as floods, extreme weather, and landslides, dominate disaster statistics in Indonesia each year and are the main cause of both material losses and casualties [1]. Landslides are one of the most destructive hydrometeorological disasters. This disaster is defined as the downward displacement of rock, soil, or debris material that makes up a slope due to the influence of gravity [2]. Landslides are the result of a complex interaction between controlling and triggering factors. Controlling factors are static and are the inherent conditions of an area, including geological conditions, slope gradient, soil type, and land use. Meanwhile, the main triggering factors in Indonesia are generally high-intensity, long-duration rainfall, or vibrations caused by earthquakes [3].

Kulon Progo Regency, located in the Special Region of Yogyakarta Province, is one of the areas with a significant level of landslide risk. Topographically, the western part of Kulon Progo, stretching from north to almost the south, is dominated by the Menoreh Hills, which are characterized by steep to very steep slopes. The geological formations in this region are largely composed of ancient volcanic rocks that have undergone intensive weathering, resulting in thick layers of soil that are prone to movement when saturated with water [4]. Data from the Regional Disaster Management Agency (BPBD) of Kulon Progo Regency shows that landslides occur almost every year during the rainy season, especially in sub-districts such as Girimulyo, Samigaluh, and Kalibawang, causing damage to homes and agricultural land and even cutting off road access [5].

Given the high frequency of landslide occurrences and the magnitude of their impacts, disaster mitigation efforts are crucial. One fundamental approach to mitigation is spatial analysis-based vulnerability mapping. Geographic Information Systems (GIS) technology offers the ability to simultaneously integrate, analyze, and visualize various spatial data on landslide-causing factors. Through overlay analysis *and* weighting of these parameters, an accurate vulnerability zoning map can be produced. This map is vital as a scientific basis for local governments in formulating risk-based spatial planning policies, designing early warning systems, and improving community preparedness. Therefore, this study, entitled **"Spatial Analysis of Landslide Occurrences in Kulon Progo Regency, Yogyakarta as a Basis for Disaster Mitigation,"** is considered crucial. This research is expected to produce a comprehensive and scientifically accountable landslide vulnerability map, thus serving as a practical reference in disaster risk reduction efforts in the region.

2 Methods

The research location administratively covers the entire Kulon Progo Regency, Yogyakarta Special Region Province. Geographically, the study area is located between 7°38'42" – 7°59'3" South Latitude and 110°1'37" – 110°16'26" East Longitude. The main focus of the analysis is on areas with hilly topography on the western side of the north to the south which have a history of the highest landslide events.

This research is a quantitative descriptive study using a spatial analysis approach. It is called descriptive because it aims to describe the distribution of landslide vulnerability levels in the study area. Quantitative aspects are used in the analysis process through scoring and weighting methods *for* landslide-causing parameters. All spatial analyses were conducted using Geographic Information Systems (GIS) technology.

2.1 Research Tools

2.1.1 Hardware

- One computer unit (PC) with Core i7 processor specifications, 16 GB RAM for GIS data processing.
- Handheld GPS (Global Positioning System) for field verification coordinate point retrieval.
- Digital camera for field documentation.
- Stationery and field work maps.

2.1.2 Software

- ArcGIS Pro 3.02 for spatial analysis, including overlay, classification, and cartography and data processing.
- Google Earth Pro for initial visualization and validation of landslide points.
- Microsoft Excel 2021 for managing attribute data and score tabulation.

2.2 Research Materials and Data

The data used in this research consists of primary data and secondary data with the following details

2.2.1 Primary Data

- Coordinate data of landslide occurrence points from field verification (ground-truth) at several sample locations to validate secondary data.
- Photo documentation of field conditions in landslide-prone areas.

2.2.2 Secondary Data

- Administrative Boundary Map of Kulon Progo Regency, scale 1:25,000, obtained from the Geospatial Information Agency (BIG).

- Data on Landslide Event Points for the period 2020-2024, obtained from BPBD Kulon Progo Regency.
- Digital Elevation Model (DEMNAS) data with a resolution of 8 meters to derive the Slope Gradient Map, was obtained from BIG.
- Average Annual Rainfall Data from 5 rainfall stations around the study location (period 2015-2024), obtained from the BMKG Yogyakarta Climatology Station.
- Soil Type Map on a scale of 1:50,000, obtained from the Center for Agricultural Land Resources Research and Development (BBSDLP).
- Regional Geological Map of Yogyakarta Sheet scale 1:100,000, obtained from the Geological Survey Center (PSG), Bandung.
- Land Use Map for 2023, obtained from the Ministry of Environment and Forestry (KLHK).

2.3 Research Procedures

This research was carried out through several systematic stages as described in the following flow diagram:

1. Preparation Stage**:** Includes literature studies on factors causing landslides, determining parameters, and preparing base maps (administrative maps).
2. Data Collection Stage: Collect all required secondary data from relevant agencies.
3. Initial Data Processing Stage:
   - Perform geometric corrections and equalize the projection system (UTM Zone 49S) for all maps.
   - Derive slope data from DEMNAS data.
   - Perform interpolation (IDW method) on rainfall data to produce a rainfall distribution map.
   - Reclassify each parameter map according to the predetermined class.
4. Spatial Analysis Stage: Scoring and weighting each parameter, then overlaying *using* the *Weighted Overlay Tool* in ArcGIS.
5. Field Verification Stage: Conducting direct checks at several locations identified as having a high level of vulnerability to validate the analysis results.
6. Final Stage: Compiling the final landslide vulnerability zoning map, presenting the analysis results in the form of tables and graphs, and drawing conclusions.

2.4 Data Analysis Techniques

Data analysis to determine the level of landslide vulnerability was carried out using scoring and weighting techniques for five main parameters.

1. Scoring Each parameter is divided into several classes, and each class is given a score between 1 (low influence) and 5 (high influence) on landslide potential. Scoring criteria are based on literature studies and the biophysical conditions of the study area.
2. Weighting: Each parameter is assigned a different weight according to its level of influence on landslide occurrences. The weights are determined based on a literature review and are considered a multiplier for the score.
3. Overlay The final vulnerability score is calculated by adding up the results of multiplying the scores of each parameter by its weight using the formula in GIS analysis:
   Where: Final Score=∑i=1n(Weight1×Score1)
   - n= number of parameters
   - Weight1= Weight of the 1st parameter
   - Score1= Class score on the 1st parameter
4. Classification of Vulnerability Levels
   The continuous final score values were then classified into three vulnerability classes (Low, Medium, High) using the *Natural Breaks (Jenks) classification method*. This method groups data based on natural boundaries in the distribution of data values, so that variance within classes is minimal and variance between classes is maximal.

3 Results And Discussion

The final results provide an overview of the spatial analysis conducted and an in-depth discussion of the findings. The research findings include the characteristics of each parameter and a final landslide susceptibility zoning map. The discussion will examine the correlation between causal factors, validate the results, and their implications for disaster mitigation efforts.

3.1 Characteristics of Parameters Causing Landslides

The spatial analysis is based on five main parameters. The spatial distribution of each parameter in Kulon Progo Regency shows significant variation and serves as the basis for determining the level of vulnerability.

1. Slope Gradient: The distribution of slope gradients contrasts sharply between the northern and southern regions. The northern region, which is part of the Menoreh Hills (covering the districts of Girimulyo, Samigaluh, Kalibawang, and Nanggulan), is dominated by steep (25-40%) to very steep (>40%) slopes. This class covers approximately 28% of the total area of the district. In contrast, the southern region towards the coast is dominated by flat (0-8%) and gentle slopes (8-15%), which cover more than 60% of the total area.
2. Rainfall: Rainfall distribution patterns show a gradient from north to south. Due to the orographic influence of the Menoreh Hills, the northern region has the highest average annual rainfall, reaching over 3,000 mm/year. This intensity decreases significantly in the flatter southern region, where average rainfall is below 2,500 mm/year.
3. Soil Types: Kulon Progo Regency has several dominant soil types. Andosol and Latosol soils, which have a crumbly, loose structure and high permeability, are commonly found in the northern hilly areas. Although fertile, this type of soil is highly susceptible to erosion and landslides when saturated with water. Meanwhile, the southern part is dominated by alluvial and grumosol soils, which are more stable in flat topography.
4. Geology: The most influential geological structure is the Old Andesite Formation in the north. This rock has undergone very advanced weathering, resulting in a thick and unstable layer of regolith (soil left over from weathering), making it prone to landslides. On the other hand, the Sentolo Formation, composed of limestone, is more stable, and the alluvial deposits on the south coast present a very low risk of mass movement.
5. Land Use: Land use in hilly areas (high risk) is dominated by dryland or dryland agriculture (approximately 25% of the total area). These agricultural practices often lack conservation measures and reduce permanent vegetation cover, increasing slope vulnerability. Conversely, community forests and denser settlements are located on gentler slopes, while rice paddies are concentrated in the lowlands.

3.2 Analysis of Landslide Vulnerability Level

The overlay of the five scored and weighted parameters produces a Landslide Susceptibility Zoning Map for Kulon Progo Regency. This map is classified into three classes: low, medium, and high.

Table 2. Area and Distribution of Landslide Susceptibility Classes

Vulnerability Class	Area (Ha)	Percentage (%)	Dominant Distribution (District)
Tall	15,120	26	Girimulyo, Samigaluh, Kalibawang, Kokap (northern part)
Currently	18,040	31	Nanggulan, Sentolo, Pengasih, Lendah (transition zone)
Low	25,040	43	Temon, Wates, Panjatan, Galur (lowlands & coast)

The spatial distribution shows a very clear pattern (see Figure 1 - Hazard Zoning Map).

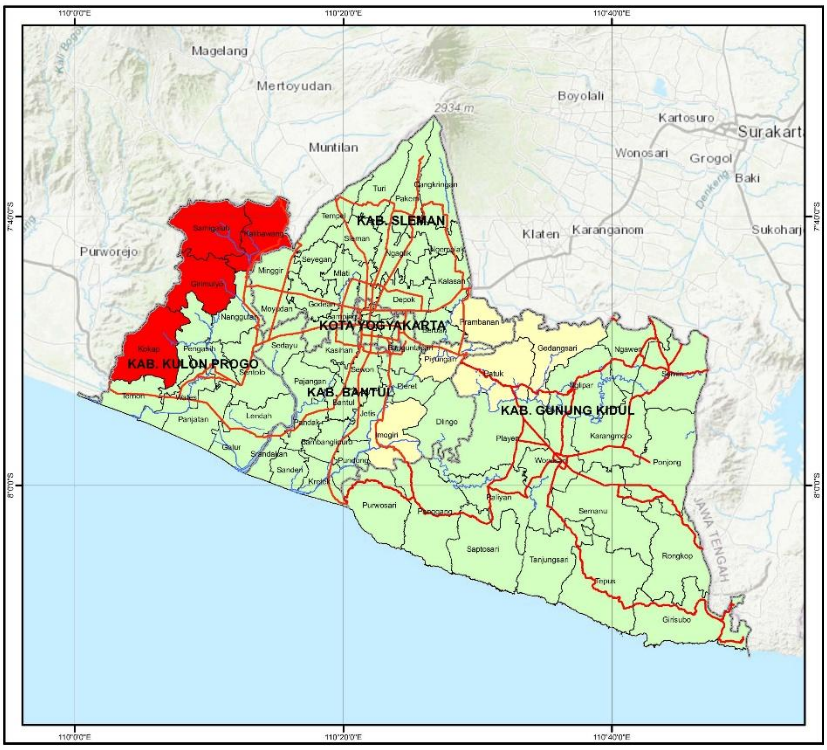

Fig 1. Hazard Zoning Map Kulon Progo Regency.

- The High Hazard Zone is densely concentrated in the northern region of Kulon Progo Regency. This zone is characterized by a combination of all the triggering factors: very steep slopes, very high rainfall, loose Andosol soils, weathered volcanic rocks, and intensive dryland use.
- The Moderate Hazard Zone acts as a transition or buffer zone between hilly and lowland areas. This zone generally has gentle to moderately steep slopes, but with rainfall and soil conditions that are not as extreme as those in the highland zone.
- The Low Hazard Zone dominates the entire southern region. The main factor is the flat to gently sloping topography, resulting in very little potential energy for mass movement despite relatively high rainfall.

3.3 Discussion

Mapping results indicate that approximately 26% of Kulon Progo Regency falls into the high-risk category. This finding confirms that the Menoreh Hills are the most critical area for landslides. The high level of vulnerability in this zone is not caused by a single factor, but rather by the accumulation of various controlling factors. Weighted analysis of the methodology indicates that slope gradient (30%) and rainfall (25%) are the two most dominant factors. This is in line with research by Nugroho & Raharjo (2022), which states that in tropical volcanic landscapes, the interaction between steep topography and high-intensity rainfall is the primary trigger for shallow landslides (debris flow).

The role of land use as an anthropogenic factor cannot be ignored. Although its weight is only 10%, land use is a determining factor on naturally critical slopes. Conversion from forest or dense vegetation to seasonal dryland has been shown to reduce soil shear strength due to the loss of anchoring root systems. This aligns with findings by Rahman & Lestari (2019), which showed an increase in landslide frequency in areas deforested for agriculture. In Kulon Progo, steep slopes that should be protected areas are instead being extensively used for agriculture, exacerbating the existing risks.

Validation of the map results was carried out by overlaying landslide occurrence point data from the Kulon Progo Regional Disaster Management Agency (BPBD) for the 2020-2024 period. The results indicate that approximately **88% of the total landslide occurrences occurred within the zones mapped as high and medium vulnerability classes.** This high level of accuracy indicates that the analytical model used is sufficiently reliable and relevant to describe vulnerability conditions in the field.

Implications for Disaster Mitigation This hazard zoning map is not a final product, but rather a strategic tool for formulating effective and targeted mitigation policies.

1. **Structural Mitigation:** For high-risk zones, local governments can prioritize the construction of slope protection infrastructure such as retaining walls (TPT), gabions, or other civil engineering techniques, especially along vital roads and around dense settlements.
2. **Non-Structural Mitigation:**
    - **Spatial Planning:** This map should serve as the primary reference for revising the Regional Spatial Plan (RTRW). High-risk zones should be designated as Disaster-Prone Areas (KRB) with very strict development regulations. New residential development in these areas should be prohibited.
    - **Early Warning System:** Based on rainfall data, the BMKG and BPBD can collaborate to develop an early warning system based on rainfall thresholds . If rainfall in red zone sub-districts exceeds the critical threshold (for example, >80 mm/day), a warning can be issued to the public to increase vigilance or conduct independent evacuations (BMKG, 2021).
    - **Community Education and Empowerment:** Disseminating disaster-prone maps in an easy-to-understand format (participatory mapping) can raise public awareness. Additionally, community-based conservation programs, such as planting deep-rooted plants (vetiver, bamboo) on critical slopes, can provide a sustainable vegetative solution.

4 Conclusion

This

References

1. National Disaster Management Agency (BNPB). (2023). Annual Report and Statistics on Indonesian Disasters 2023. Jakarta: BNPB Press.
2. Karnawati, D. (2007). Mechanics of Rock Mass Movement: Application in Landslide Susceptibility Zoning . Yogyakarta: Gadjah Mada University Press.
3. Putra, AD, & Setiawan, B. (2021). Analysis of Landslide-Causing Factors Using Scoring and Weighting Methods in Tropical Regions. Indonesian Journal of Geography , 15(2), 112-125.
4. Sari, VP, & Hidayat, R. (2020). Identification of Geological and Morphological Characteristics as Controlling Factors of Landslide Disasters in the Menoreh Hills, Yogyakarta. Journal of Earth Sciences , 8(1), 45-56.
5. BPBD Kulon Progo Regency. (2024). Landslide Disaster Incident Report for the 2023-2024 Period . Wates: BPBD Kulon Progo.
6. Nugroho, A., & Raharjo, P. (2022). The Role of Topography and Rainfall Intensity on Shallow Landslide Initiation in Tropical Volcanic Terrains. Indonesian Journal of Geosciences , 9(3), 215-228
7. Rahman, F., & Lestari, P. (2019). Analysis of the Impact of Land Use Changes on Landslides in the Upper Ciliwung Sub-watershed. Geography Forum Journal , 33(1), 1-12.
8. Meteorology, Climatology, and Geophysics Agency (BMKG). (2021). Technical Guidelines for Early Warning of Hydrometeorological Disasters . Jakarta: BMKG.