

Research article

Identification of Geophysical Conditions of Landslide Areas Ngargoyoso District, Karanganyar Regency

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Abstract

Landslides continue to pose a major threat to communities living in mountainous areas, such as Ngargoyoso District. Previous studies have shown that landslide points are scattered across several villages: Dukuh Village with 9 points, Nglegok with 2 points, Jatirejo with 1 point, Ngargoyoso with 6 points, Kemuning with 5 points, Segorogunung with 10 points, Girimulyo with 3 points, and Berjo with 5 points. The pattern of landslide events in the study area is clustered, with an average value of 0.65. This research aims to identify and analyze the geophysical characteristics of landslides in Ngargoyoso District. The initial step in the research involved a literature review on factors causing landslides, followed by creating a list of areas as location guides. Landslide identification was carried out descriptively, and various factors believed to contribute to landslides were identified and analyzed. The results of this study indicate that (a) geophysically, landslides in the area mostly occur in regions characterized by high rainfall (394.1 mm/hour), moderate to steep topography (slope $\geq 9\%$), geological formations consisting of Lawu volcanic rock, geomorphological features of faulted folding hills, and land use primarily involving buildings and settlements; and (b) the main type of landslide is predominantly the fall type, consisting of soil, gravel, and rock materials, totaling 24 points, along with creep-type landslides observed at 17 points. Fall-type landslides are dominantly found in Nglegok Village (2 points), Dukuh Village (5 points), Ngargoyoso Village (4 points), Kemuning Village (5 points), Puntukrejo Village (1 point), Girimulyo Village (1 point), Berjo Village (3 points), and Segorogunung Village (1 point). Meanwhile, creep-type landslides are spread across Segorogunung Village (8 points), Berjo Village (2 points), Girimulyo Village (2 points), Ngargoyoso Village (2 points), Dukuh Village (2 points), and Jatirejo Village (1 point).

Keywords: landslide point; landslide pattern; early warning system.

1. Introduction

Landslides are among the types of natural disasters that frequently affect various regions across the country. In 2019 alone, there were 1,483 recorded landslide incidents. The spatial distribution of these events is shown in Figure 1. Landslides, also known as mass movements of soil, rock, or a combination of these materials, often occur on natural or man-made slopes. They are essentially natural phenomena where the environment seeks a new equilibrium following disturbances or influencing factors that lead to a reduction in shear strength and an increase in soil shear stress.

One of the areas particularly vulnerable to landslides is Karanganyar Regency. The parts of Karanganyar Regency most prone to landslides are areas with steep topography, slopes greater than 30%, high rainfall intensity, and agricultural land use. Most of these areas are spread along the slopes and foothills of Mount Lawu. Although landslides frequently occur in Karanganyar Regency, not all incidents result in casualties. Detailed information on landslide occurrences in Karanganyar Regency from 2015 to 2019 is presented in Table 1.

Figure 1 illustrates that the highest number of disaster events occurred in Central Java Province, with a total of 733 incidents. Meanwhile, nearly all provinces experienced landslide disasters in 2019.

Table 1 shows that landslide disasters occurred almost every year in Karanganyar Regency. The highest number of incidents occurred in 2017, with 19 cases, followed by 16 cases in 2016. These disasters often lead to losses in terms of lives, property, and public facilities, highlighting the need for mitigation and prevention efforts to minimize the resulting impacts.

Vegetation cover has been recognized for its ability to mitigate landslide risk by stabilizing the soil, as highlighted by studies on the protective effects of plant roots in preventing soil erosion (Liu et al., 2019). Human activities, such as deforestation and improper land use, exacerbate the risk of landslides by disrupting natural water drainage systems and reducing soil cohesion (Siregar et al., 2015). Recent advances in GIS and remote sensing technologies have significantly enhanced the ability to assess landslide susceptibility through spatial analysis and the integration of various environmental data (Nuraeni et al., 2020).



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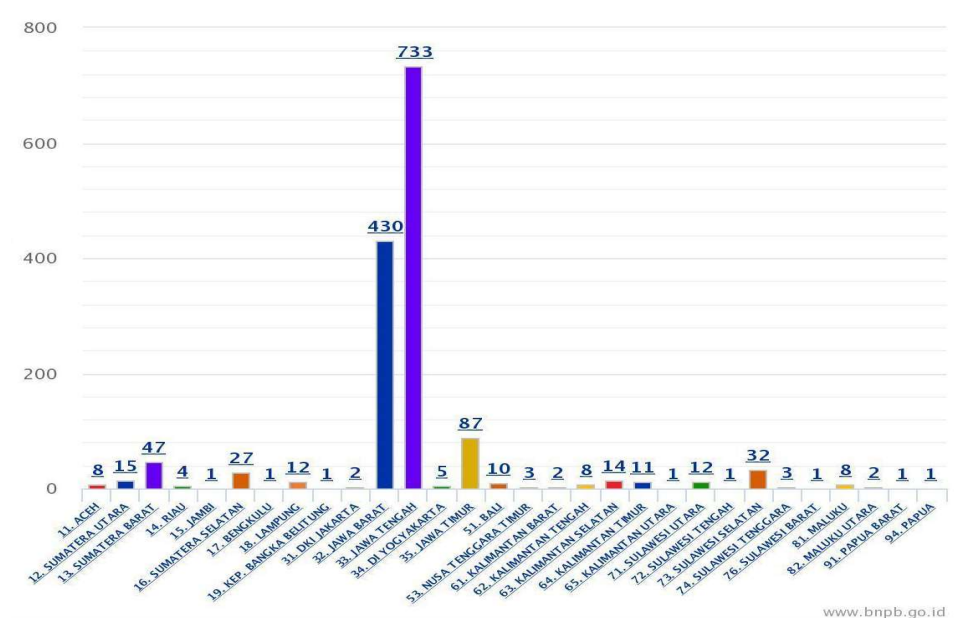


Figure 1. Landslide Disaster Events in Indonesia in 2019
Source: DIBI BNPB, 2020

Table 1. Landslide Disaster Incidents in 2015-2019 in Karanganyar Regency

No	Year	Amount	Impact
1.	2019	3	Damage : 1 house was moderately damaged and 1 house was slightly damaged
2.	2018	2	Damage 1 house was severely damaged, 3 moderate damage, and 18 lightly damaged
3.	2017	19	234 residents were displaced, 6 houses were severely damaged, 15 houses were moderately damaged, and 20 houses were slightly damaged.
4.	2016	17	3 residents died, 728 were displaced, 4 houses were severely damaged, 9 were moderately damaged, and 9 were slightly damaged, as well as 2 educational facilities were damaged.
5.	2015	7	2 residents died, 3 injured, 260 residents evacuated, 15 houses severely damaged, 5 moderately, 3 lightly

Source: DIBI BNPB, 2020

Given the still relatively high number of casualties, landslide mitigation is essential to reduce fatalities. Landslide mitigation is crucial because landslides have long-term negative impacts on both humans and the environment (Jen Chang et al., 2018). Pham et al. (2017) further emphasized that understanding the factors influencing landslide types is important in different geological conditions. The landslide type and the factors that influence it are essential for developing mitigation strategies. Different factors require different mitigation approaches, so understanding the primary factors for each landslide type is crucial. This study aims to identify the geophysical characteristics of areas and the types of landslides in Ngargoyoso Subdistrict.

The use of satellite data enables broader and deeper mapping, providing more comprehensive information about soil conditions, slope angles, and other factors that influence landslide susceptibility. Furthermore, integrating GIS with environmental monitoring tools has helped enhance early warning systems for landslide hazards (Wahyudi et al., 2021).

This technological approach has proven crucial in disaster risk reduction strategies in landslide-prone regions.

Based on the existing problem background, the main objectives of this research are: (a) to analyze the geophysical characteristics of landslide points in Ngargoyoso Subdistrict, and (b) to analyze the types of landslides occurring at each landslide point in Ngargoyoso Subdistrict.

2. Research Methods

The research employs a secondary data analysis approach combined with field observations. All data processing and analysis were conducted using Geographic Information System (GIS) technology. The detailed methodology is illustrated in the research flowchart shown in Figure 2.

2.1. Research Location

The research was conducted in the Ngargoyoso Sub District of Karanganyar Regency, Central Java, selected due to the frequent occurrence of landslides and the diverse physical conditions present in the area.

2.2. Research Materials and Tools

The following materials and tools are required for conducting this research:

1. Materials:
 - a) Topographic maps as base maps
 - b) Geological maps
 - c) Land use maps
 - d) Road and river network maps
 - e) Previous research findings as references
 - f) Materials for map creation
 - g) Supporting thematic maps
2. Equipment:
 - a) Computer with Geographic Information System (GIS) software for data processing
 - b) Camera
 - c) Scanner

2.3. Data and Data Sources

The data used in this study are secondary data. Data collection was conducted through a compilation of previous research data. Detailed information on the data and data sources can be found in Table 2 below.

Table 2. Data and Data Sources

No	Data	Data source
1.	Landslide point	Previous research
2.	Administrative map	Previous research
3.	Land use map	Previous research
4.	Slope gradient map	Previous research
5.	Geological map	Previous research
6.	Soil type map	Previous research
7.	Rainfall map	Previous research
8.	Elevation map	Previous research
9.	Social, economic, population	Central Statistics Agency of Karanganyar Regency

Source: Researcher, 2020

2.4. Data Analysis

The data analysis in this study employs spatial pattern analysis, which primarily focuses on the distribution of "spatial elements." This analysis aims to address geographic questions, such as (what, when, where, why, who, and how) (Yunus, 2010). The analysis is conducted on the distribution patterns and the factors contributing to landslides in the study area.

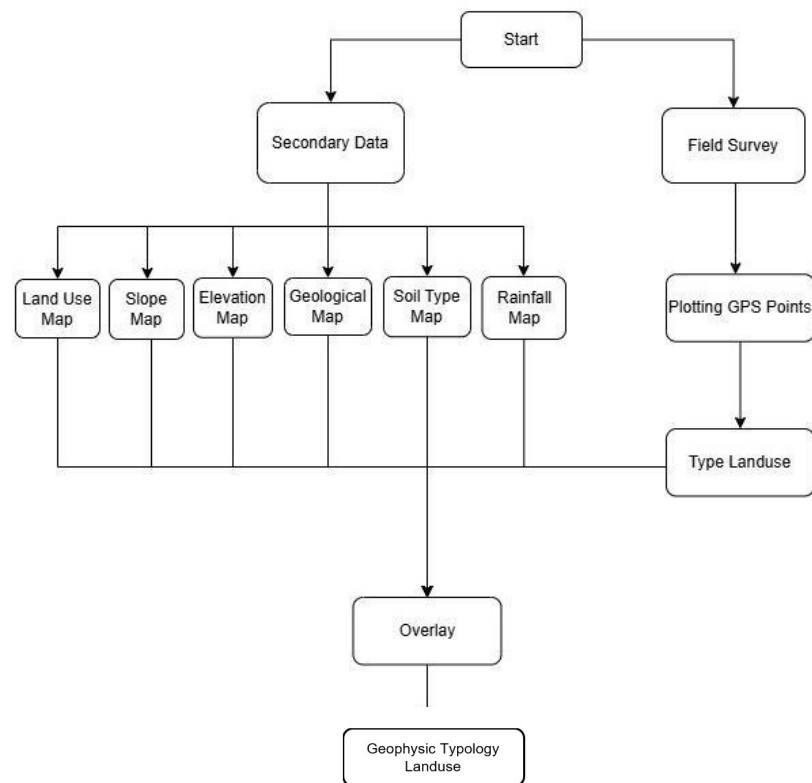


Figure 2. Research flow Diagram.

3. Results and Discussions

3.1. Physical Description of The Study Area

Ngargoyoso District is one of the districts in Karanganyar Regency, Central Java Province. Geographically, Ngargoyoso District is located between 111° 3' 58" E - 111° 9' 55" E and 7° 38' 11" S - 7° 34' 13" S. The area of Ngargoyoso District is 6,533.942 hectares and includes 9 villages: Puntukrejo, Berjo, Girimulyo, Segoro Gunung, Ngargoyoso, Jatirejo, Dukuh, Kemuning, and Nglegok. The administrative boundaries of Ngargoyoso District are as follows:

- a. North: Jenawi District and Kerjo District
- b. South: Tawangmangu District
- c. West: Karangpandan District
- d. East: Magetan Regency, East Java

Ngargoyoso District consists of Quaternary volcanic deposits dating from the Pleistocene to the Holocene epochs. The volcanic formation during the Pleistocene period resulted in the ancient Lawu Volcano, while the volcanic formation in the Holocene period produced the younger Lawu Volcano. Based on the types of rocks, the study area consists of two different geological units, each with specific lithological characteristics. These lithological characteristics significantly influence physical properties such as soil development, slope stability, and soil productivity.

The study area is part of the Solo Zone Sensutricito, as its central zone is a volcanic area, specifically the Lawu Volcano Group (Pannekoek, 1949 in Budio Basri, 1989). This stratovolcano consists of andesite rocks. The materials are categorized into three types: unweathered volcanic materials, young volcanic materials, and old volcanic materials. The differences in volcanic products influence the weathering processes. The Lawu Volcano region is generally fertile due to the availability of water sources, as there are spring lines in stratovolcanic areas.

The topography of the study area varies; some areas have rugged topography, with steep slopes (10% - 75%) in certain places. The further east, the sharper the terrain, as the area lies on the slopes of Lawu Volcano. The flat land is between 10% and 40% in slope, with undulating to hilly terrain (75%), while hilly to mountainous land accounts for 25%.

Soil types are influenced by climate, parent rock, topography, and vegetation. The formation process is also affected by organisms and time. Based on soil mapping in Ngargoyoso District, the area is classified as having Andosol and Latosol soils. Hydrology of Ngargoyoso District Water resources in Ngargoyoso District are abundant and readily available, consisting of both surface water and groundwater. Surface water can be observed in rivers such as Kali Samin, which is used for agricultural irrigation and livestock maintenance. River flow conditions are relatively unstable (fluctuating), with high water flow during the rainy season and low flow during the dry season. Groundwater conditions are highly influenced by the local topography. The study area has various water sources due to its location at the foot of Lawu Mountain, where the terrain becomes flatter to the west, with many water sources originating from Lawu Mountain. Areas at the foot of Lawu Mountain are rich in water sources.

3.2. Geophysical Characteristic of Landslide Points

The geophysical characteristics of the landslide locations in the study area were determined through field surveys, where the coordinates of the landslide points were plotted. The necessary data for analyzing the spatial patterns of landslide events include the coordinates of the landslide points, which were obtained through surveys using GPS (Global Positioning System). Spatial pattern analysis of landslide data was processed using GIS technology (ArcGIS 10.3 software).

The analysis of the geophysical characteristics at the landslide points was conducted using a descriptive qualitative analysis. The parameters used for the analysis include the landslide points and the factors influencing them. Various factors that affect landslide events in Ngargoyoso District include rainfall, slope steepness, geology, geomorphology, and land use. The analysis of rainfall in the study area shows that most of the areas that experienced landslide events had high rainfall intensity, approximately 394.1 mm/hour, with 23 landslide points recorded. Meanwhile, areas with rainfall of approximately 332.9 mm/hour had 18 landslide points. The higher the rainfall in a region, the greater the potential for landslides, and vice versa.

The analysis based on topography in the study area shows that areas with steep topography (slope >16%) had 13 landslide points, areas with moderate topography (slope 9-15%) had 21 landslide points, and areas with flat topography (slope 0-8%) had 7 landslide points. The analysis based on geological conditions (parent rock) in the study area shows that areas with the Lawu volcanic lahar formation had 14 landslide points, while areas with the Lawu volcanic rock formation had 27 landslide points.

The analysis based on the geomorphological conditions of the region (landforms) in the study area shows that areas with an anticlinal valley geomorphological condition had 14 landslide points, while areas with a faulted fold hill geomorphological condition had 27 landslide points. The analysis based on land use in the study area shows that areas with buildings and settlements had 32 landslide points, areas with forested land had 2 landslide points, and areas with plantations had 7 landslide points.

3.3. Landslide Types

The majority of the landslide types in Ngargoyoso District are fall and creep. The materials involved in these landslides consist of sandy and clayey soil, as well as rocks of various sizes. The distribution of landslide types in Ngargoyoso District is detailed in Table 3.

Table 3. Landslide Types in the Research Area

No	Location Point	X Coordinate	Y Coordinate	Landslide Type
1.	Location 1	512.011	9.161.811	Rock Falls
2.	Location 2	511.948	9.161.716	Creep
3.	Location 3	511.726	9.161.724	Rock Falls
4.	Location 4	511.521	9.161.510	Rock Falls
5.	Location 5	511.434	9.161.400	Creep
6.	Location 6	510.715	9.161.068	Creep
7.	Location 7	509.679	9.160.175	Creep
8.	Location 8	511.505	9.159.661	Rock Falls
9.	Location 9	512.011	9.159.598	Rock Falls
10.	Location 10	512.082	9.159.479	Rock Falls
11.	Location 11	512.825	9.159.677	Rock Falls

No	Location Point	X Coordinate	Y Coordinate	Landslide Type
12.	Location 12	513.078	9.160.032	Rock Falls
13.	Location 13	514.501	9.160.222	Rock Falls
14.	Location 14	513.939	9.159.408	Creep
15.	Location 15	514.011	9.159.218	Creep
16.	Location 16	514.832	9.159.108	Creep
17.	Location 17	514.935	9.159.037	Rock Falls
18.	Location 18	515.046	9.158.681	Creep
19.	Location 19	514.919	9.158.665	Creep
20.	Location 20	516.595	9.160.348	Creep
21.	Location 21	516.547	9.160.373	Creep
22.	Location 22	514.579	9.155.665	Rock Falls
23.	Location 23	514.239	9.155.404	Rock Falls
24.	Location 24	513.686	9.156.020	Rock Falls
25.	Location 25	514.524	9.156.526	Creep
26.	Location 26	514.429	9.156.574	Creep
27.	Location 27	514.366	9.157.451	Rock Falls
28.	Location 28	514.382	9.157.854	Rock Falls
29.	Location 29	514.555	9.157.980	Rock Falls
30.	Location 30	511.066	9.157.937	Rock Falls
31.	Location 31	508.866	9.159.658	Rock Falls
32.	Location 32	508.415	9.160.759	Rock Falls
33.	Location 33	507.983	9.161.265	Rock Falls
34.	Location 34	508.046	9.161.372	Rock Falls
35.	Location 35	508.112	9.161.542	Rock Falls
36.	Location 36	508.062	9.161.557	Creep
37.	Location 37	508.068	9.161.592	Creep
38.	Location 38	508.059	9.161.603	Rock Falls
39.	Location 39	508.068	9.161.612	Creep
40.	Location 40	507.944	9.162.525	Rock Falls
41.	Location 41	508.891	9.162.959	Creep

Source: Field Survey Results, 2021

Based on Table 3, it is shown that there are 41 landslide points in the study area. The majority of the landslides are of the fall type, with materials consisting of soil, gravel, and rocks, totaling 24 points, while the creep type accounts for 17 points. The fall-type landslides are predominantly distributed across the following villages: Nglegok (2 points), Dukuh (5 points), Ngargoyoso (4 points), Kemuning (5 points), Puntukrejo (1 point), Girimulyo (1 point), Berjo (3 points), and Segoro Gunung (1 point). On the other hand, the creep-type landslides are distributed as follows: Segoro Gunung (8 points), Berjo (2 points), Girimulyo (2 points), Ngargoyoso (2 points), Dukuh (2 points), and Jatirejo (1 point).

The areas in the study region dominated by fall-type landslides have an average rainfall of 394.1 mm/hour, with a geological condition of Lawu lava deposits, a geomorphological condition of an anticlinal valley, moderate to gentle slopes, and land use characterized by built-up areas (residential, buildings, etc.). Meanwhile, areas dominated by creep-type landslides have an average rainfall of 332.9 mm/hour, a geological condition consisting of Lawu volcanic rocks, geomorphology with fault-fold hills, moderate to gentle slopes, and land use that includes built-up areas. The spatial distribution of the landslide types in the study area can be seen in Figure 3.

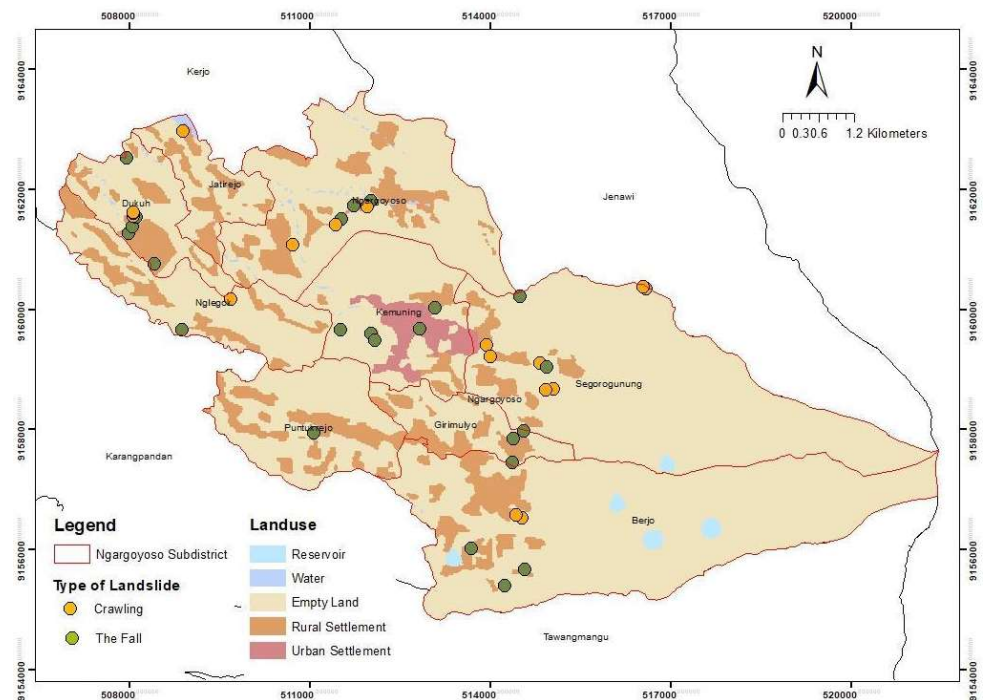


Figure 3. Map of Landslide Types in Ngargoyoso District, Karanganyar Regency, 2021

Based on the analysis results, the landslide-prone area demonstrates specific geophysical and land-use characteristics that require a comprehensive and integrated management approach. High rainfall intensity (394.1 mm/hour), combined with moderate to steep slopes ($\geq 9\%$), geological features of volcanic rocks (Lawu volcanic formations), and faulted hill geomorphology, significantly increase susceptibility to landslides. Additionally, land use dominated by buildings and settlements exacerbates the risk, particularly by altering natural drainage patterns and increasing the load on unstable slopes. These factors necessitate targeted interventions to reduce future disaster risks and ensure the safety of the local population.

The distribution of landslides further highlights the need for location-specific management strategies. Falling landslides, primarily composed of soil, gravel, and rocks, were mostly recorded in villages such as Nglegok, Duku, Ngargoyoso, Kemuning, Punturejo, Girimulyo, Berjo, and Segoro Gunung, with a total of 24 incidents. Meanwhile, sliding landslides, which were less frequent with 17 points, were concentrated in Segoro Gunung, Berjo, Girimulyo, Ngargoyoso, Duku, and Jatirejo. The spatial clustering of these events indicates that local factors such as slope gradients, vegetation cover, and land-use practices may influence landslide dynamics, necessitating tailored solutions for each location.

To effectively manage landslides in this area, a multi-faceted approach is required. Engineering measures such as slope stabilization using retaining walls and bioengineering techniques (e.g., planting deep-rooted vegetation) should be prioritized in villages with frequent falling landslides. Developing efficient drainage systems is crucial to control surface runoff and reduce water infiltration into vulnerable slopes. Additionally, terracing and contour farming should be promoted in agricultural areas to minimize erosion and stabilize the land. Research has shown that heavy rainfall significantly contributes to landslide occurrences, which aligns with previous findings indicating that high rainfall intensity increases the likelihood of landslides (Chang et al., 2018; Pham et al., 2017).

Community-based initiatives are equally essential. Public education programs should be designed to raise awareness about landslide risks, early warning signs, and evacuation procedures. Sustainable land-use planning, which restricts construction in high-risk zones and encourages reforestation, can significantly reduce pressure on unstable terrains. Moreover, local communities in the most affected areas, such as Segoro Gunung and Berjo, should be equipped with emergency response training and provided access to safe evacuation routes and shelters. Slopes steeper than 30% are a key factor in triggering landslides, which is supported by prior studies that have stated that steeper slopes are more vulnerable to landslides (Jen Chang et al., 2018).

At the policy level, the government must enforce strict zoning regulations and building codes in landslide-prone areas. Collaborative efforts involving geologists, engineers, and local

stakeholders can facilitate the design of effective mitigation strategies tailored to the unique needs of each village. Furthermore, consistent funding for landslide monitoring systems, including rainfall gauges and slope stability sensors, will enable the early detection of potential risks and timely interventions. The lithosphere, composed of both old and young volcanic rocks, significantly contributes to slope stability, as described by Basri (1989), who discussed the influence of geology on land stability in volcanic areas.

By integrating engineering solutions, community involvement, and policy enforcement, landslide-prone areas within the study region can achieve greater resilience. This holistic approach not only mitigates short-term risks but also fosters long-term sustainability and safety for local communities.

The Influence of Geological Structure and Human Activities: Unstable geological structures, such as the presence of active faults, and human activities, such as deforestation and inappropriate farming practices, increase the susceptibility to landslides (Sutrisno & Prasetyo, 2018). For example, areas around active faults in Karanganyar frequently experience landslides, especially during the rainy season with heavy rainfall. Meanwhile, land cover changes carried out by the local community further worsen soil stability (Subekti & Santosa, 2017).

The Application of Technology for Landslide Mapping: By utilizing GIS and remote sensing technology, various studies have shown improvements in the accuracy of landslide-prone area mapping, including the hilly areas in Karanganyar (Nugroho et al., 2020). The use of satellite data enables broader and deeper mapping, providing more comprehensive information about soil conditions, slope angles, and other factors that influence landslide susceptibility.

4. Conclusions

Based on the findings and discussions, and referring to the research objectives, the following conclusions can be drawn:

- a. The landslides in the study area predominantly occurred in regions characterized by high rainfall (394.1 mm/hour), moderate to steep topography (slopes $\geq 9\%$), volcanic rock formations (Lawu volcanic rocks), faulted hill geomorphology, and land use primarily consisting of buildings and settlements.
- b. The types of landslides that occurred were predominantly falling landslides, with materials such as soil, gravel, and rocks, occurring at 24 points, and sliding landslides at 17 points. The falling landslides were mostly distributed in the following villages: 2 points in Nglegok, 5 points in Dukuh, 4 points in Ngargoyoso, 5 points in Kemuning, 1 point in Puntukrejo, 1 point in Girimulyo, 3 points in Berjo, and 1 point in Segoro Gunung. Meanwhile, the sliding landslides were scattered across Segoro Gunung with 8 points, Berjo with 2 points, Girimulyo with 2 points, Ngargoyoso with 2 points, Dukuh with 2 points, and Jatirejo with 1 point.
- c. Future research should focus on developing an integrated landslide susceptibility mapping system that incorporates key environmental factors such as rainfall intensity, slope characteristics, geological formations, and land use patterns. This mapping should prioritize high-risk villages like Segoro Gunung, Berjo, and Ngargoyoso to provide detailed risk assessments. Additionally, studies on the impact of land use changes, particularly the conversion of natural landscapes into settlements, should be conducted to understand their role in exacerbating landslide occurrences. Hydrological and geotechnical analyses are also critical, particularly in villages experiencing frequent falling and sliding landslides, to examine soil stability and drainage conditions. Furthermore, exploring the relationship between climate change and landslide frequency is essential to anticipate risks associated with increasing rainfall intensities. Implementing real-time monitoring and early warning systems using IoT-enabled sensors can enhance disaster preparedness, especially in high-risk areas. Lastly, community-based mitigation strategies that combine structural interventions with public education and participatory planning can significantly improve resilience and reduce landslide impacts.

Future studies related to this research can focus on developing a more accurate landslide prediction model in high-risk areas already identified, such as Segoro Gunung, Berjo, and Ngargoyoso, by considering additional factors like soil type and climate change. The use of monitoring technologies, such as drones, to map and monitor geological conditions can enhance detection and mapping of landslide-prone areas. Research on the social and economic impacts of landslides in these villages is also important to design more effective mitigation policies, including protection programs for affected communities. Additionally, environmentally based mitigation techniques, such as land rehabilitation in areas affected by falling and sliding landslides, should be prioritized. Lastly, studies on land use planning based on landslide risk can

ensure that development in these areas remains safe and aligned with disaster mitigation principles.

This article has several significant strengths. First, it provides an in-depth analysis of the spatial distribution of landslides and the key environmental factors influencing them, such as rainfall, slope gradients, geological formations, and land use. Second, the classification of landslide types—falling and sliding—accompanied by data on locations and frequencies enhances the understanding of landslide dynamics in the study area.

Third, the article successfully identifies high-risk villages, such as Segoro Gunung, Berjo, and Ngargoyoso, facilitating targeted mitigation efforts. Moreover, its recommendations for future research, such as landslide susceptibility mapping and analyses of land use changes and climate change impacts, offer clear directions for further studies.

The environmentally-based approach, including land rehabilitation, reflects a commitment to sustainability, while the proposed use of technologies like drones underscores the potential for innovation in disaster mitigation. This article makes a valuable contribution to landslide research and is highly relevant for practical applications and the development of disaster mitigation policies.

The article has several weaknesses. First, the study primarily focuses on identifying landslide occurrences and their distribution without providing in-depth analysis on the underlying causes or factors that contribute to these landslides, such as soil properties, hydrological factors, or human activities. Second, the research lacks a comprehensive exploration of the long-term impacts of landslides on the affected communities, including the socio-economic consequences and the effectiveness of existing mitigation measures. Additionally, while the study recommends future research, it does not provide specific methodologies or tools for implementing the suggested improvements, such as the development of a landslide prediction model or the use of drones for monitoring. Lastly, the article could benefit from a more detailed discussion on how the findings can be integrated into local policies or land-use planning to ensure practical applications and real-world impact.

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Conflict of interest

All authors declare that they have no conflicts of interest..

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