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Research articles

Assessment of Landslide Susceptibility in the Pagentan Area, Banjarnegara Regency: A Spatial Multi-Criteria Evaluation Approach

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ABSTRACT

Landslides are widespread natural disasters that occur across various areas in Indonesia. Among these areas, Pagentan and its surroundings in Banjarnegara Regency are identified as having significant potential for large-scale landslides. Therefore, this research was conducted to determine the susceptibility of ground movements. The method used to examine the surface geological mapping and analyze the soil movement susceptibility was the Spatial Multi-Criteria Evaluation (SMCE). This method is an applied science approach that employs spatial analysis and multi-criteria evaluation to support decision-making processes. Geological mapping was used to describe rocks, make geomorphological observations, measure geological structures, take stratigraphic sections, and collect rock samples. Multiple parameters were used to determine soil susceptibilities in the research area, such as slope, lithology, rock mass, elevation, land cover, road buffer, river buffer, and aspects, which were transformed into raster data for analysis. The susceptibility analysis classified the research area into four categories: low, medium, high, and very high. The low susceptibility zone includes Pandansari and Karangtengah. The moderate susceptibility zone includes Wonosroyo, Aribaya, Karangtengah, Pandansari, and Bantar. Most of the high susceptibility zones are in Bantar and Karangtengah. Meanwhile, the very high susceptibility zones include Gumingsir, Plumbungan, Kalitlaga, Kayuares, Nagasari, Karangnangka and Mentawana.

INTRODUCTION

Indonesia is highly vulnerable to hydrometeorological disasters resulting from weather and climate changes (Susanti et al., 2017). Although landslides are localized events but widespread across almost all areas (Anwar, 2012). Since 2014, the National Disaster Management Agency (BNPB) has classified landslides as the deadliest disasters (Nugroho, 2018). The country faces many potential landslides, which pose risks of casualties, damages, losses, and disturbances to the environmental ecosystem (Mushinah et al., 2022).

A landslide is a natural occurrence characterized by the downward movement of soil material, regolith, and rock along a slope due to the force of gravity (Permanajati & Iswahyudi, 2018). Typically, erosion can be attributed to movement along a slip or shear plane (Sugito et al., 2010). According to data compiled by the National Disaster Management Agency (BNPB) in Indonesia, between January 1 and November 24, 2021, the country experienced 650 tornadoes, 511 landslides, and 263 forest fires. These disasters significantly impacted 7,522,866 individuals affected, including 584 fatalities, 76 individuals declared missing, and 13,087 injured. Additionally, 94,214 houses suffered minor damage, along with other public infrastructure such as offices, places of worship, healthcare facilities, educational institutions, and bridges (Utomo, 2021). Prevention steps can be carried out through research on the avalanche mechanism because a good understanding can minimize the associated impact (Permanajati et al., 2014).

Banjarnegara Regency is one of the areas in Indonesia susceptible to landslides. Its geographical composition comprises three distinct divisions. The first is the North Zone, encompassing steep and undulating terrains, such as the Dieng Plateau, the North Serayu Mountains, Mount Prau, and Mount Rogojembangan. The second division is the Serayu Depression Zone, located in the central part of the Regency. At the same time, the third is the southern part occupied by the Serayu Mountains, which exhibits steep relief. Given these geographical conditions, Banjarnegara faces a substantial risk of erosion (Setiadi, 2013).

The Banjarnegara area has experienced significant cases of landslides, such as the incident in the Mount Pawinihan area, resulting in the tragic loss of 80 lives (Permanajati et al., 2014). Geological factors, including rock stratigraphy, geological structures, and geomorphological conditions, can trigger landslides (Widagdo, 2009). The petrographic characteristics of the area change with primary minerals transitioning to secondary minerals, thereby contributing to rock weathering processes (Permanajati et al., 2018). The Gumingsir area and its surroundings in Banjarnegara Regency present a significant potential for further research on ground movement.

The research location is in the Gumingsir Area and its surroundings, with an area of 25 km^2 (5 km by 5 km), which is administratively included in the Pagentan District, Banjarnegara Regency, Central Java Province. It encompasses 15 villages, namely Suwidak Village, Pandansari, Karangtengah, Gumingsir, Karangnangka, Aribaya, Mentawana, Larangan, Talunamba, Clapar, Pakelen, Kayuares, Sokaraja, Jebeng Plampitan, and Nagasari, as shown in Figure 1.

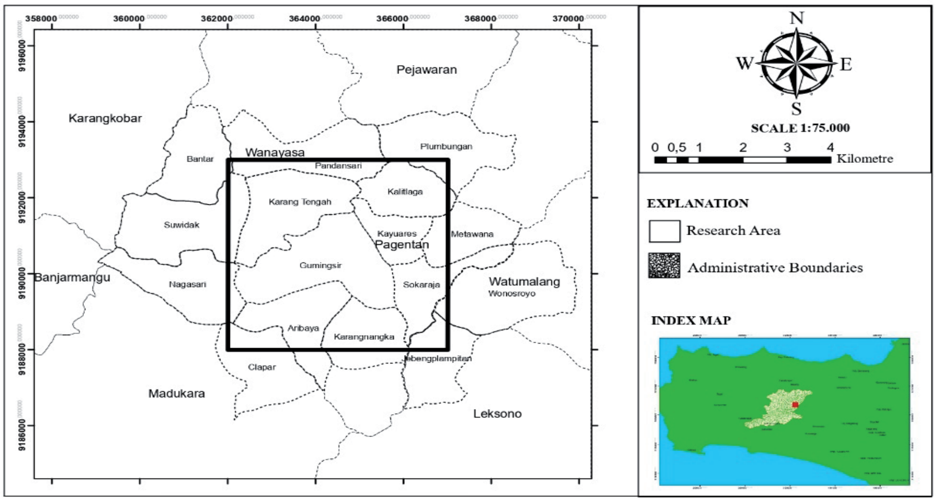

Figure 1. Research locations

RESEARCH METHODS

The method employed involved surface geological mapping, which encompassed collecting various data, including lithology information, natural features, stratigraphic sequences, geological structures, geological potentials, rock sampling, and documentation of field data. Additionally, ground movement analysis was conducted using the Spatial Multi-Criteria Evaluation (SMCE) method.

The research aimed to comprehensively review previous research on the area, encompassing various aspects, including regional physiography, geomorphological conditions, regional stratigraphy, regional structure, and specific research related to landslide disaster mitigation. This review aimed to gain an initial understanding of the area's characteristics and serve as a reference for problem formulation in the subsequent research implementation.

Data Collection Fields

Field data collection was conducted through geological mapping, which comprised various activities such as rock outcrop observations, geomorphological observations, field data collection, and rock sampling. The observation of rock outcrops was conducted using the daily trajectory method, which involved systematically recording and documenting the characteristics of exposed rocks in the field.

Studio Analysis and Data Processing

Studio analysis and field data processing were used to determine the geological conditions of the research area. The analysis included evaluating alignment and geological structure, stratigraphy, micropaleontology, and geological history. These analyses provided insights into the geological characteristics and history of the area (Zaenurrohman et al., 2023). The SMCE method, based on applied science principles, was used for the ground motion analysis. This method combined spatial analysis using Geographic Information Systems (GIS) and multi-criteria evaluation techniques to incorporate spatial and non-spatial inputs into decision-making processes. In the SMCE method, each parameter used in the analysis was converted into raster data, which enabled a comprehensive assessment of ground motion susceptibility in the research area.

RESULTS AND DISCUSSION

Geology of Research Area

Based on field observations, lithology descriptions, and the identification of fossils that can provide information about the age of rock units, an unofficial lithostratigraphic nomenclature is assigned to the geology of the research area (Martodjojo & Djuhaeni, 2006). The geology is classified into four rock units, and in chronological order from oldest to youngest, as follows:

1) Claystone-Sandstone Unit

The identified rock units exhibit a combination of brown and gray colors in the field, characterized by alternating claystone and sandstone lithologies in fresh and weathered conditions. Through micropaleontological analysis, benthic foraminifera fossils were discovered, namely *Robulus* sp, *Nodosaria* sp, *Amphistegina lessonii*, and *Dentalina* sp. These fossils provided insights into the depositional environment, which was interpreted as Middle-Upper Neritic paleobathymetry by Blow (1969). An analysis was conducted to determine the relative age of the rocks, using fossils from the phylum Foraminifera, focusing on the planktonic foraminifera group and their age zoning range. The result showed that the sandstone-claystone alternating units have ages ranging between N5-N14, with the discovery of the index fossil *Globigerina seminulina.*

2) Diorite Intrusion Unit (MA)

This vegetation-covered rock intrusion, which is field-gray in appearance, is formed from the rock material. It is an intrusion dyke with a sizable newly weathered structure found on regional geological maps as Late Miocene (Condon et al., 1996).

3) Laharic Breccia Unit

This unit consists of reddish-brown soil along with fragments and a matrix of brownish-gray laharic breccia material that ranges in size from gravel fragments to boulders and coarse to medium-sized sand.

The fragments present in this unit are composed of andesite and possess specific physical characteristics such as a non-carbonate nature, dark gray hue, varying sizes from pebbles to cobbles, open packing, and poor grain selection. On the other hand, the matrix primarily consists of sandstones with brown physical properties, medium-sized sand grains, closed packing, and well-selected grains. According to the Regional Geological Map, the Laharic Breccia Unit is estimated to be of early Pliocene age (Condon et al., 1996).

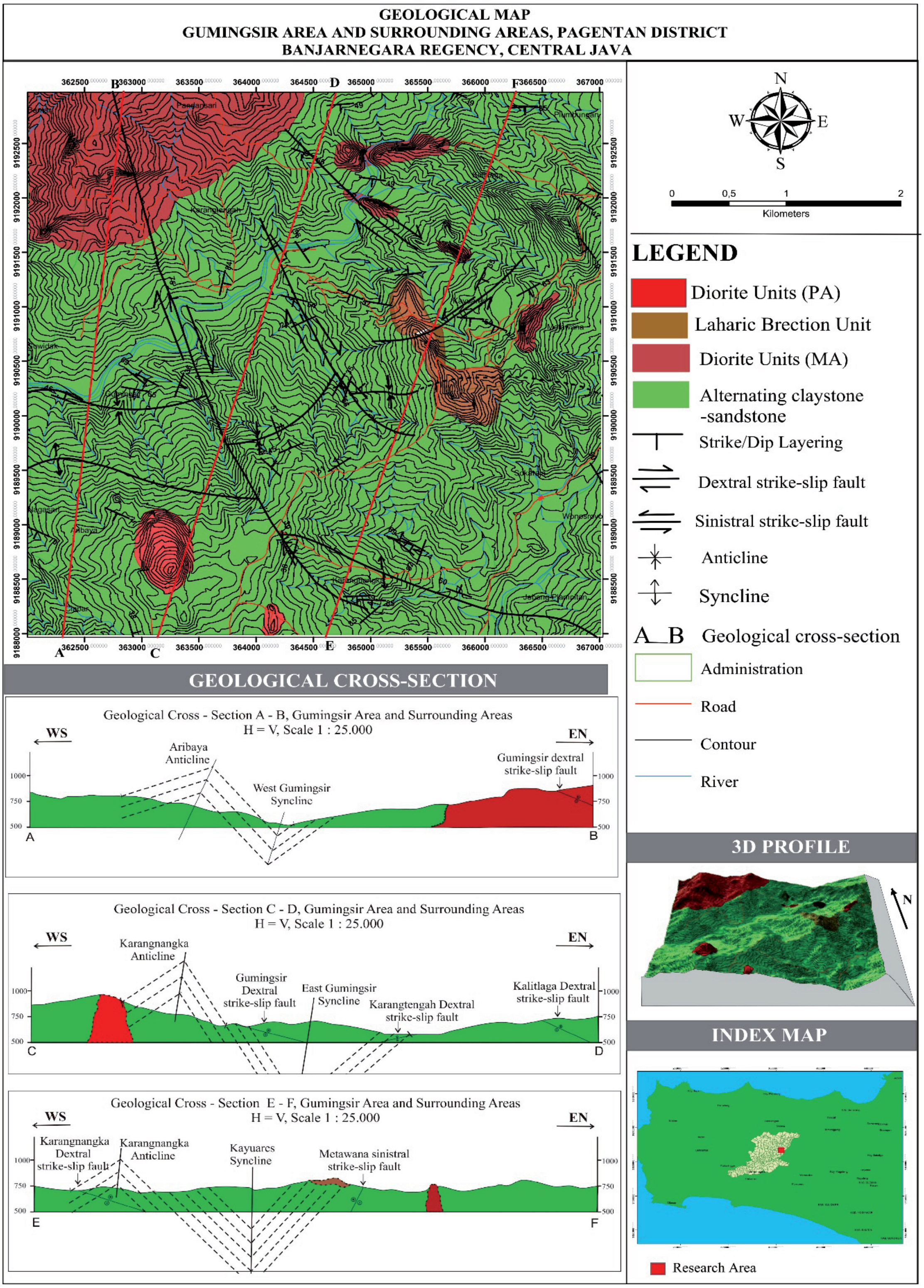

Figure 2. Geological Map of Research Area

4) Diorite Intrusion Unit (PA)

This unit is distinguished by diorite intrusions within the rock elements. Diorite is a gray-colored rock that has undergone weathering over time. In terms of regional conditions and age, based on the regional geological map, this unit is classified as Late Pliocene (Condon et al., 1996). Cross-cutting relationships are observed where the diorite intrusion intersects with the rock unit of claystone and sandstone. This situation indicated that the intrusion occurred after the deposition of the claystone-sandstone unit and resulted in structural changes such as uplifting, folding, and faulting.

Geological Structure

The geological structure was analyzed using direct and indirect methods. The indirect method examined alignment patterns obtained from SRTM data, revealing a prevailing northwest-to-southeast (NW-SE) trend in the research area. Additionally, direct observations were made on features such as rivers with significant bends, brecciation data, shear fractures, streak lines, and other field data.

Analyzing these data patterns provided insights into the geological structures that influenced the research area. The DIPS 6.0 software was used to identify several notable structures, including the dextral faults Mentawana, Kayuares, Karangtengah, Karangnangka, Gumingsir, Kalitlagah, and Synclin Gumingsir. Furthermore, specific wing data folds, such as the anticlines Aribaya, Karangnangka, West, East, and Kayuares, were also discovered in the research area.

Analysis Susceptibility to Landslides

This research used the SMCE method with 8 parameters, namely:

1) Slope

The Digital Elevation Model (DEM) data are utilized to calculate the slope in the research area. The slope values are then categorized into five simplified classes, as shown in Table 1 (Chalkias et al., 2014). It is important to note that gravity plays a significant role in causing land to move downward. Therefore, steeper slopes result in increased surface flow and have the potential to trigger soil material movement downslope. As the slope value increases, the susceptibility to landslides also rises, as shown in Figure 3.

Table 1. Classification Slopes (Chalkias et al., 2014).

Parameter	**Information** (°)	**Class**	**Parameter Weight**	**Weight Value**
Slope	Gentle slope (0 - 5)	1	0.04	0.31
	Sloping slope (5 - 10)	2	0.08	
	Strongly sloping (10 -15)	3	0.15	
	Steep slope (15 - 20)	4	0.23	
	Very steep (> 20)	5	0.5	

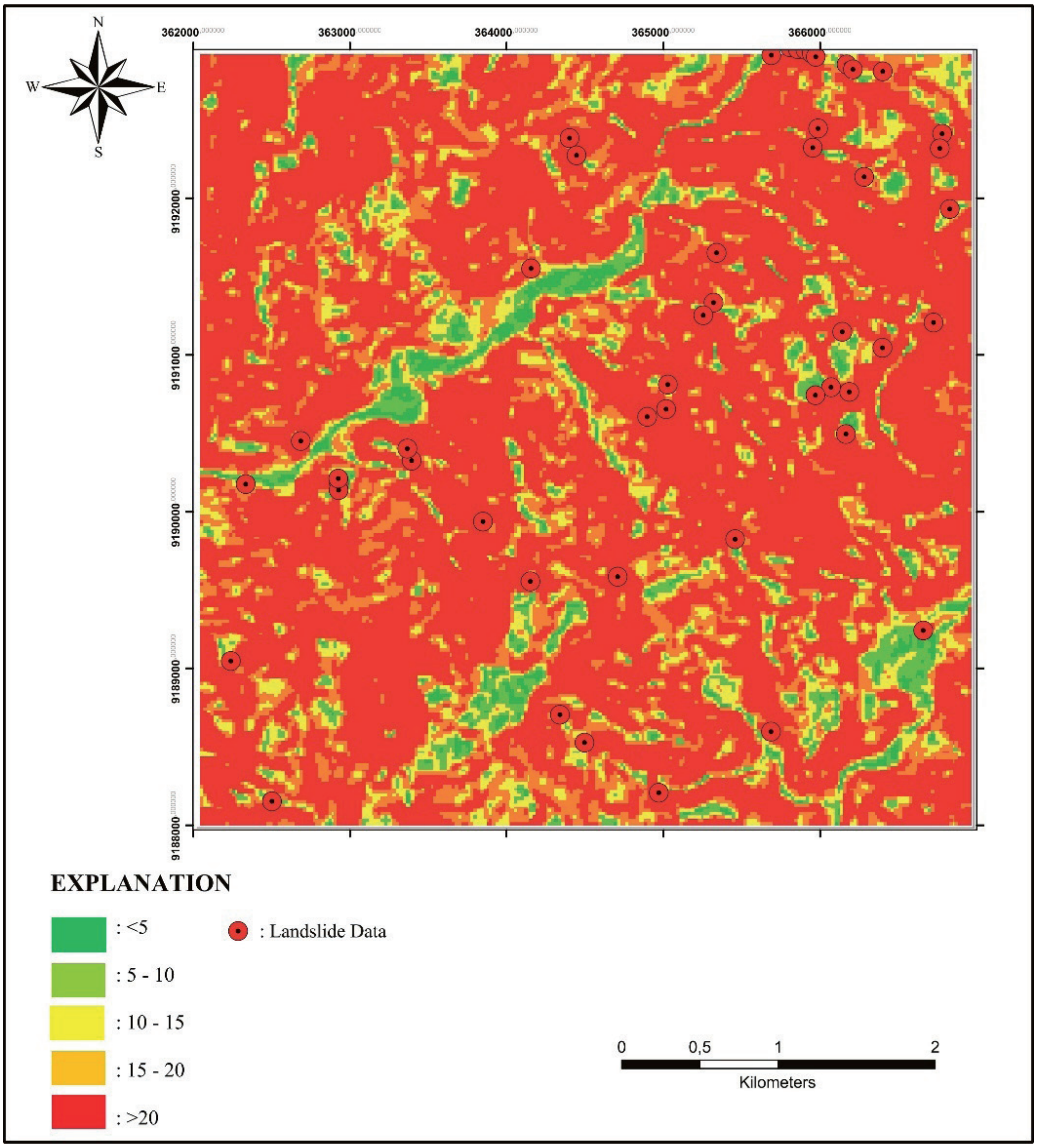

Figure 3. Slope Map of Research Area

2) Lithology

Based on field observations, the four units (Table 2) of the area around Gumingsir and its surroundings are known as the diorite intrusion (PA), diorite intrusion (MA), breccia laharic, and claystone-sandstone, as shown in Figure 4. The combination of sand, clay, and gravel within the volcanic and sedimentary rocks may not possess solid and cohesive properties. Moreover, when these rocks are situated on steep slopes, their momentary weathering and the force of gravity leads to landslides (Permanajati et al., 2023).

Table 2. Classification Rock Lithology (Feizizadeh *et al*., 2013)

Parameter	Information	Class	Parameter Weight	Weight Value
Lithology	Diorite Intrusion (PA)	1	0.07	0.2
	Diorite Intrusion (MA)	2	0.12	
	Breccia Laharic	3	0.26	
	Claystone-Sandstone	4	0.55	

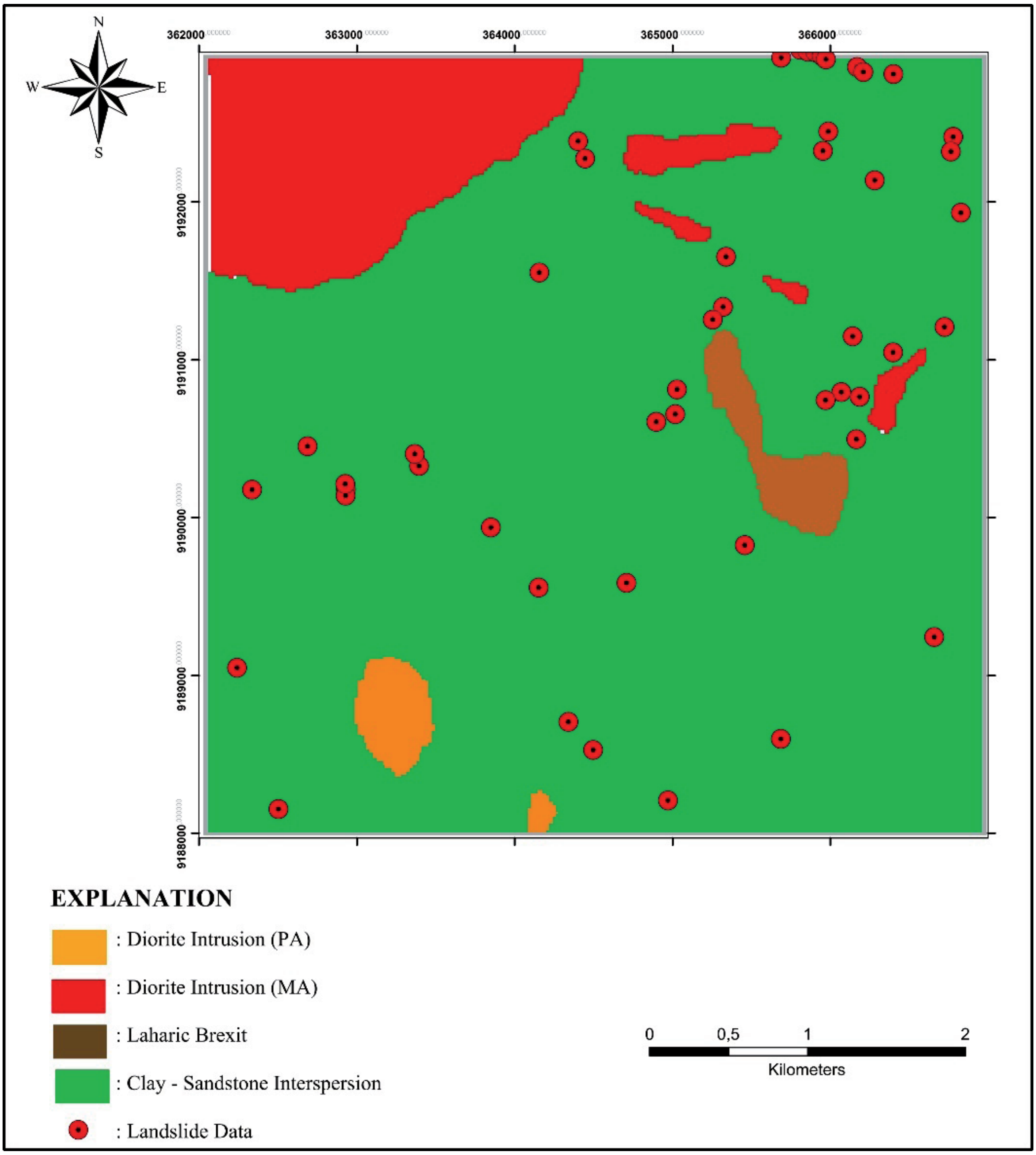

Figure 4. Lithology Map of Research Area

3) Rock Mass

The Geological Strength Index (GSI), based on visual observations, research, and condition data, such as structure ranking (SR) and surface discontinuity (SCR), was used to classify the rock mass in the research area (Zaenurrohman & Permanajati, 2019). Each rock mass type was classified considering various influencing factors, including rock type, general appearance based on structural geology (density, solidity, and presence of fractures), and weathering level obtained from field mapping, as shown in Figure 5 (Bieniawski, 1989).

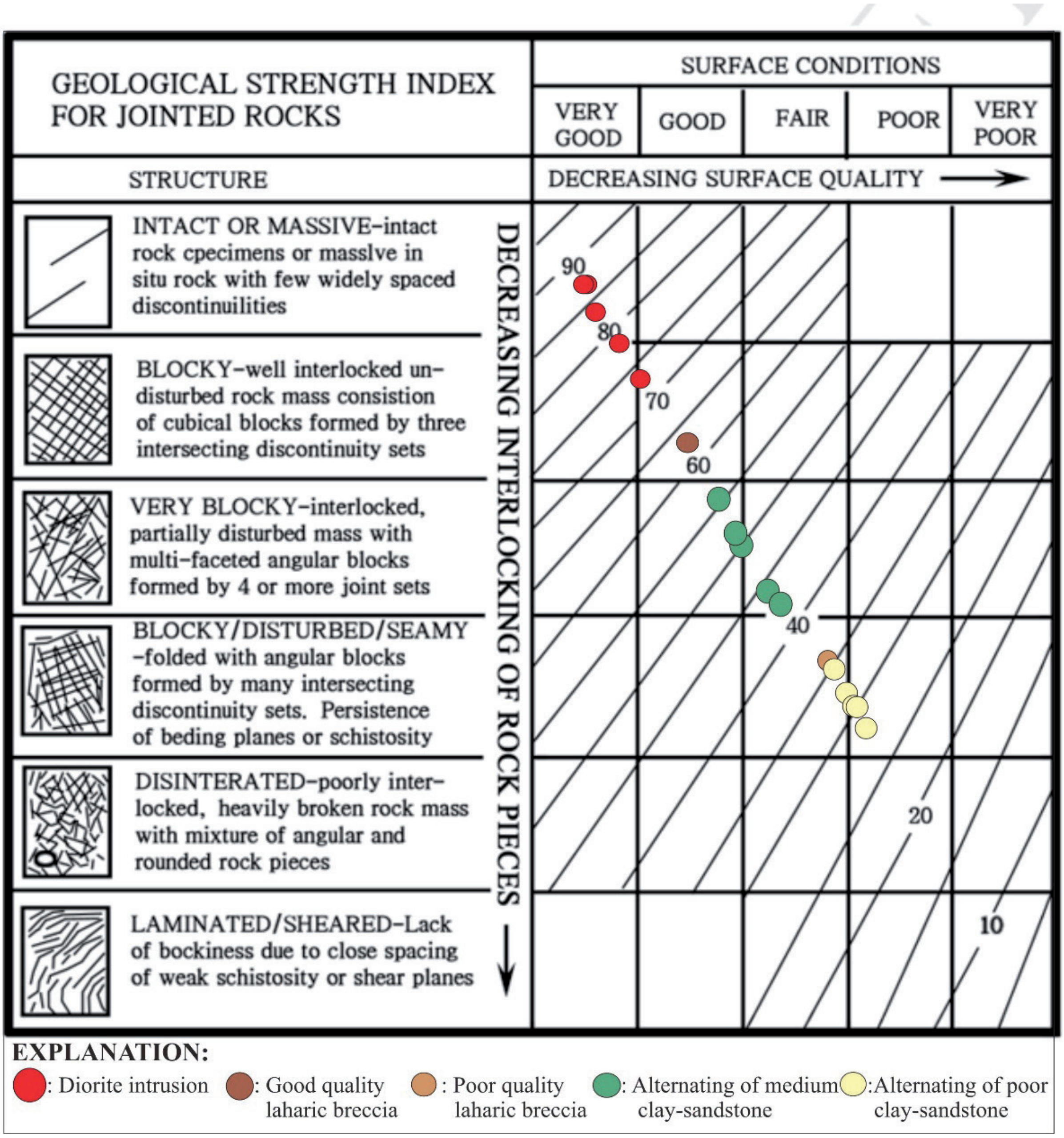

Figure 5. GSI estimation chart in the research area

Table 3. GSI quality estimates of the rock mass in the research area

Sample Code	Lithology	GSI Value	Average	Rock Mass Quality
SS 8.8	Diorite Intrusion	79		Very Good
SS 3.8	Diorite Intrusion	82		Very Good
FM 5.9	Diorite Intrusion	88	82.2	Very Good
FM 6.9	Diorite Intrusion	74		Very Good
AN 3.7	Diorite Intrusion	88		Very Good

Sample Code	Lithology	GSI Value	Average	Rock Mass Quality
SS 6.10	Claystone-Sandstone	56		Fair
SS 7.3	Claystone-Sandstone	43		Fair
AN 2.4	Claystone-Sandstone	54	49.4	Fair
SS 5.6	Claystone-Sandstone	42		Fair
FM 7.14	Claystone-Sandstone	52		Fair
AN 1.3	Claystone-Sandstone	33	34	Bad
AN 1.11	Claystone-Sandstone	35		Bad
AN 3.22	Breccia Laharic	61	61	Good
AN 3.1	Breccia Laharic	35	35	Bad

The direction and inclination of bedding layers were determined through studio observations and analysis. The area exhibited various rocks, including folds, anticlines, and synclines. More minor markings indicated more fractured rocks, increasing the potential for ground movement, as shown in Table 3. Furthermore, rock quality classification was performed to assess the quality of the rock units, as shown in Tables 4 and 5 (Hoek, 1994). The acquired analysis results were classified into five (5) classes, as illustrated in Figure 6.

Table 4. Classification of rock mass quality based on GSI value (Hoek, 1994)

GSI Value	**95 - 76**	**75 - 56**	**55 - 36**	**35 - 21**	**<20**
Number Class	**I**	**II**	**III**	**IV**	**V**
Rock Mass Quality	**Very good**	**Good**	**Currently**	**Bad**	**Very Bad**
Diorite Intrusion Very Good Quality	v				
Laharic Breccia Good Quality		v			
Claystone-Sandstone Medium Quality			v		
Laharic Breccia Bad Quality				v	
Claystone-Sandstone Bad Quality				v	

Table 5 indicates the rock mass classification in the research area.

Table 5. Classification of mass rock (Hoek, 1994)

Parameter	Information	Class	Weight Parameter	Weight Value
Rock Mass	Diorite Intrusion Very Good Quality	1	0.04	0.17
	Laharic Breccia Good Quality	2	0.08	
	Claystone-Sandstone Medium Quality	3	0.15	
	Laharic Breccia Bad Quality	4	0.31	
	Claystone-Sandstone Bad Quality	5	0.42	

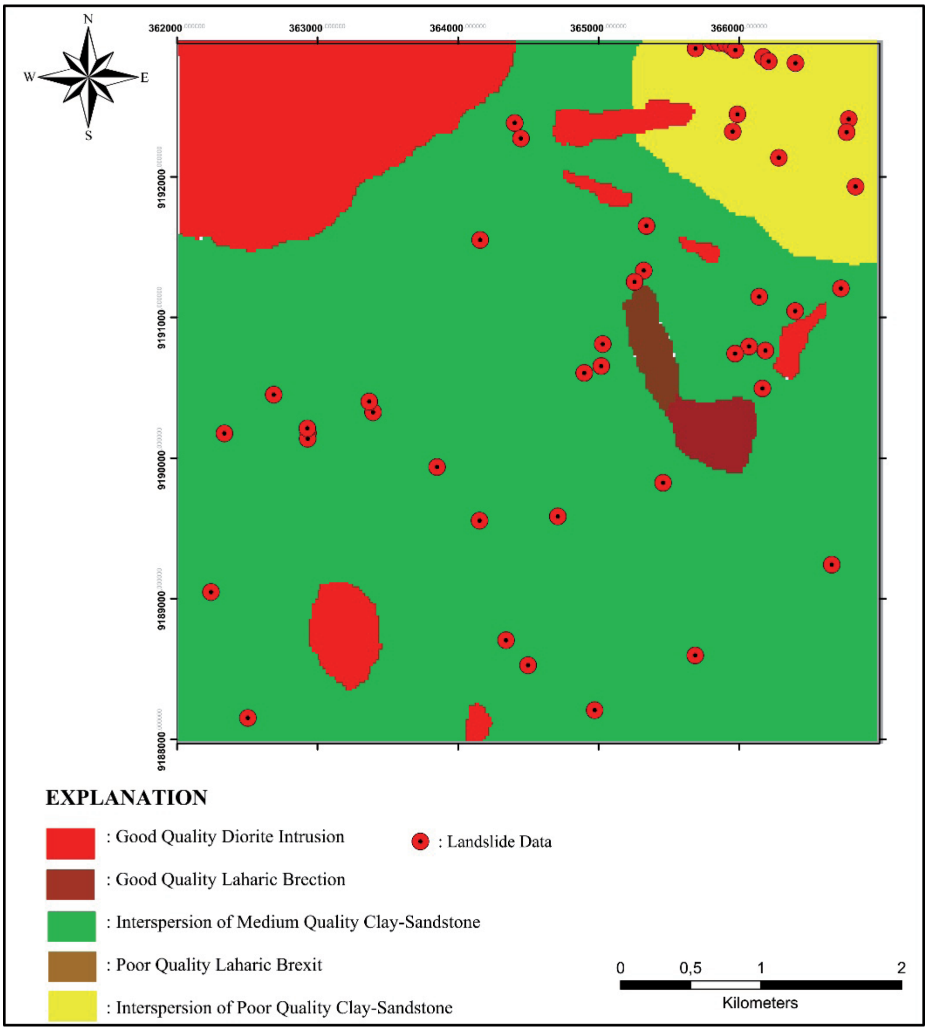

Figure 6. Rock Mass Map of Research Area

The information provided in Figure 7 contains evidence from several outcrops in the field that were utilized as indicators to identify rock quality in the area.

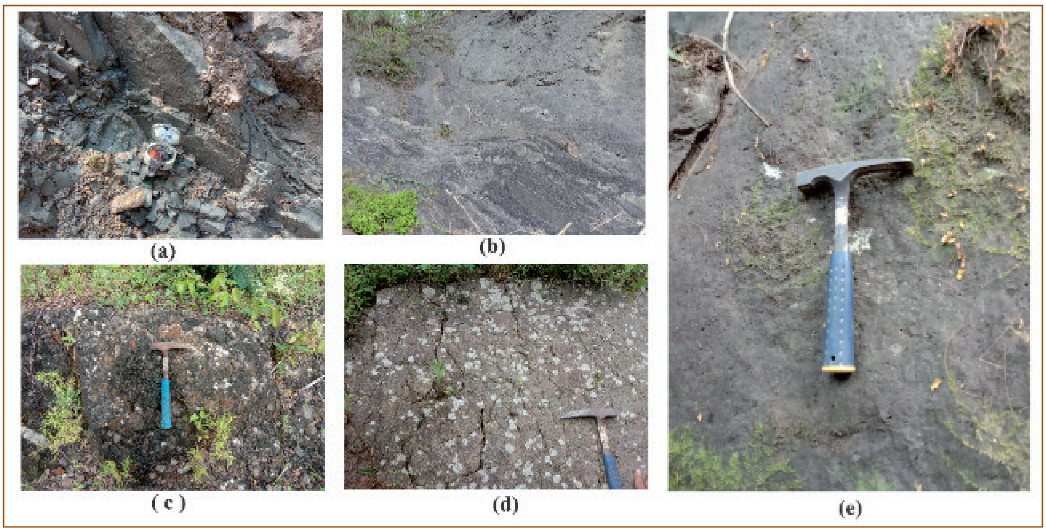

Figure 7. (a) Alternating Claystone-Sandstone in poor condition, (b) Claystone-Sandstone in medium condition, (c) Laharic Breccia in poor condition, (d) Laharic Breccia in good condition, (e) Diorite Intrusion

4) Land Cover

Land cover refers to the complete range of environmental elements, encompassing soil, climate, water systems, vegetation, and human activities. Using the SAS Planet software, land cover data were obtained by digitizing satellite images. The land cover types within the research area have been categorized into four main categories and simplified for analysis purposes, as shown in Table 6 and Figure 8 (Meena *et al*., 2019).

Table 6. Classification Land Cover (Meena *et al*., 2019).

Parameter	Information	Class	Weight Parameter	Weight Value
Land Cover	Forest	1	0.057	0.11
	Field	2	0.12	
	Rice field	3	0.26	
	Settlement	4	0.56	

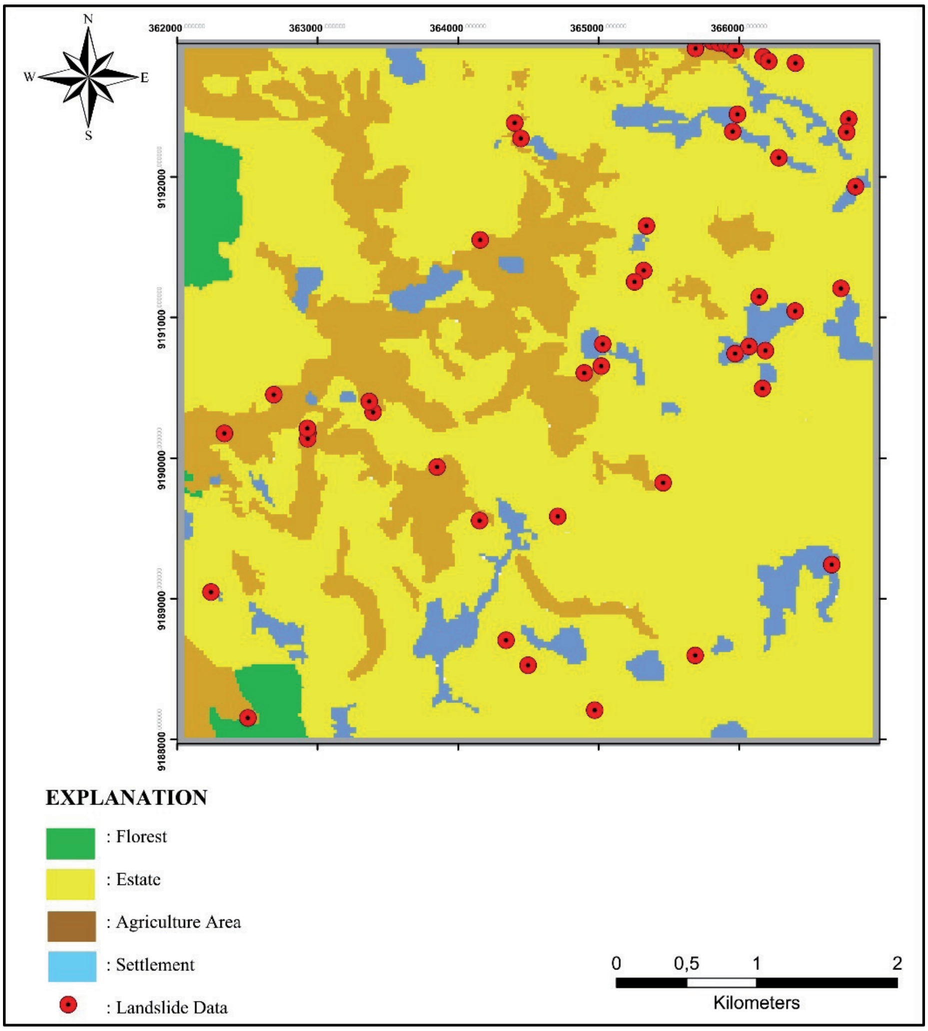

Figure 8. Land Cover Map of Research Area

5) Elevation

Elevation, or height, is derived from processing Digital Elevation Model (DEM) data. It plays a significant role in the movement of rock and soil, as materials tend to move from higher to lower areas. Elevation directly influences landslides, as the slope of a surface is determined by the angle and tilt of the land. Classification of the elevation in the shared three classes of the area is presented in Table 7 and Figure 9 (Chalkias *et al.,* 2014).

Table 7. Classification of Elevation (Chalkias *et al.,* 2014)

Parameter	Information	Class	Weight Parameter	Weight Value
Elevation	234-524	1	0.1	0.09
	525-851	2	0.23	
	852-1244	3	0.67	

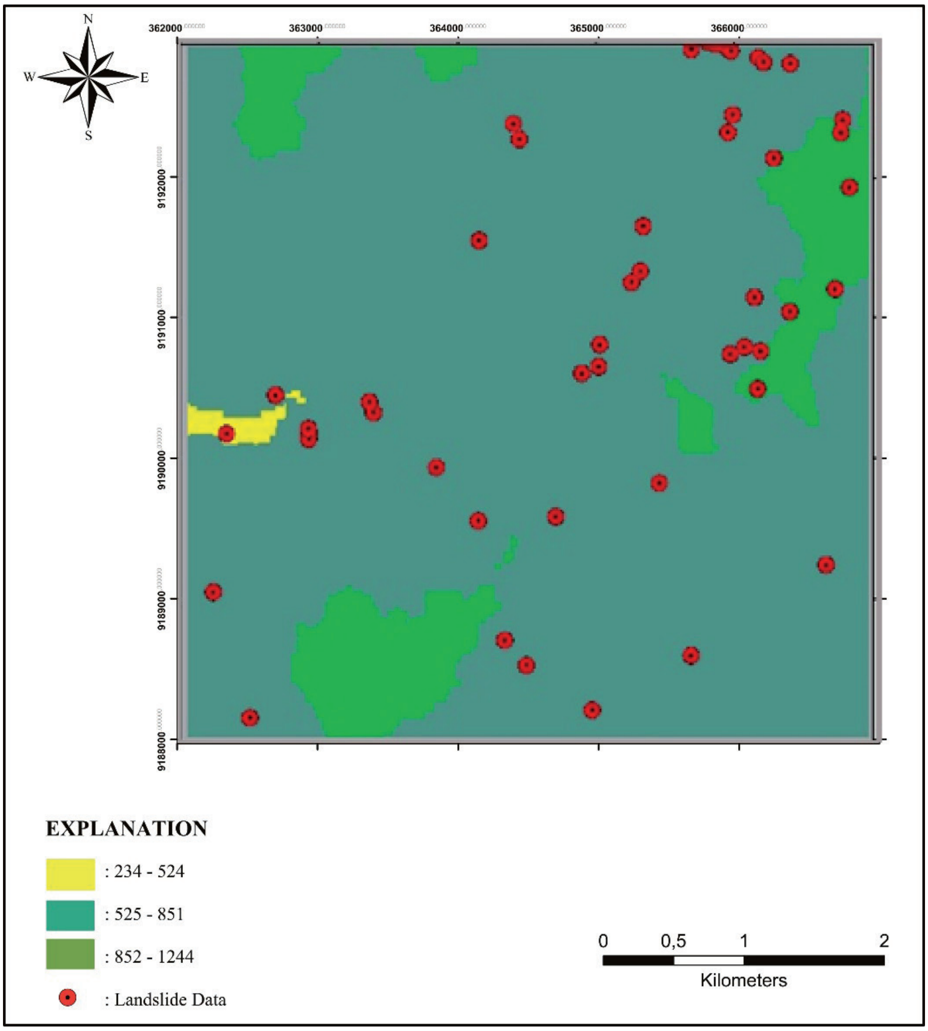

Figure 9. Elevation Map of Research Area

6) Road Buffers

Road construction activities often involve the excavation of slopes (cut slopes) and the placement of fill material (embankment slopes), which can lead to the development of inclined slopes and increase the risk of landslides (Karlina & Mardianto, 2015). Additionally, the vibrations generated by transportation activities can contribute to the cracking of land and roads (Soeprobowati, 2018). The method was performed on the distance parameter from the road through the buffer, then converted to raster format and graded with interval distance, as shown in Table 8 and Figure 10 (Meena, 2019).

Table 8. Classification Road *Buffers* (Meena, 2019).

Parameter	Information	Class	Weight Parameter	Weight Value
Road *Buffers*	>150	1	0.06	0.04
	100-150	2	0.12	
	50-100	3	0.26	
	0-50	4	0.56	

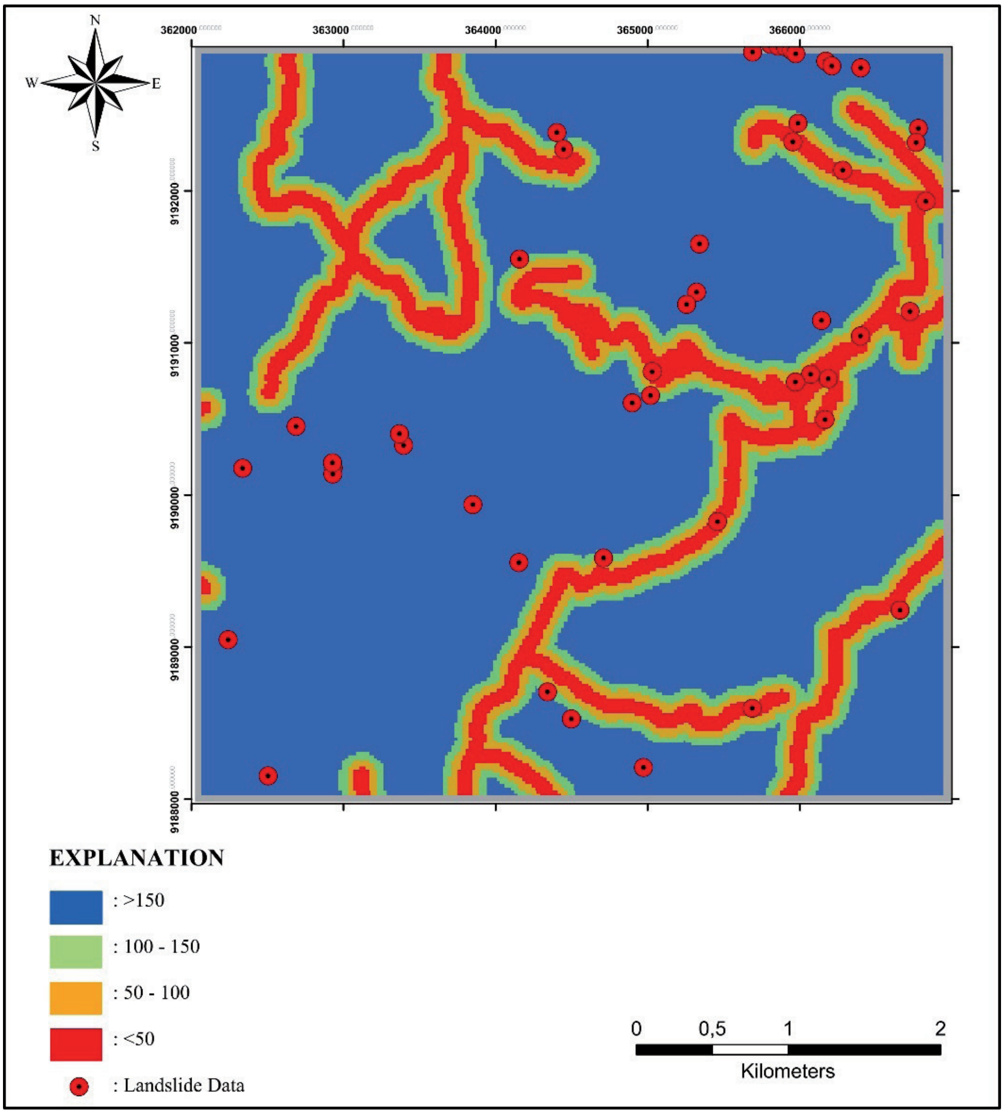

Figure 10. Road Buffer Map of Research Area

7) River Buffers

Erosion along river cliffs is another factor contributing to the occurrence of landslides. The continuous action of the river erodes and wears away the banks of the river, known as stream bank erosion. Several factors, such as vegetation, river velocity, soil texture, agricultural activities, and river dimensions, can contribute to erosion. The research area is located near rivers and often experiences poor drainage. The distance of the slope from the river affects the water saturation level on the slope, which in turn influences slope stability. The classification distance from the river in the area studied was divided into 4 classes, as shown in Table 9 and Figure 11 (Meena, 2019).

Table 9. Classification River *Buffers* (Meena, 2019)

Parameter	Information	Class	Weight Parameter	Weight Value
River *Buffers*	>300	1	0.08	0.06
	300	2	0.13	
	200	3	0.3	
	100	4	0.5	

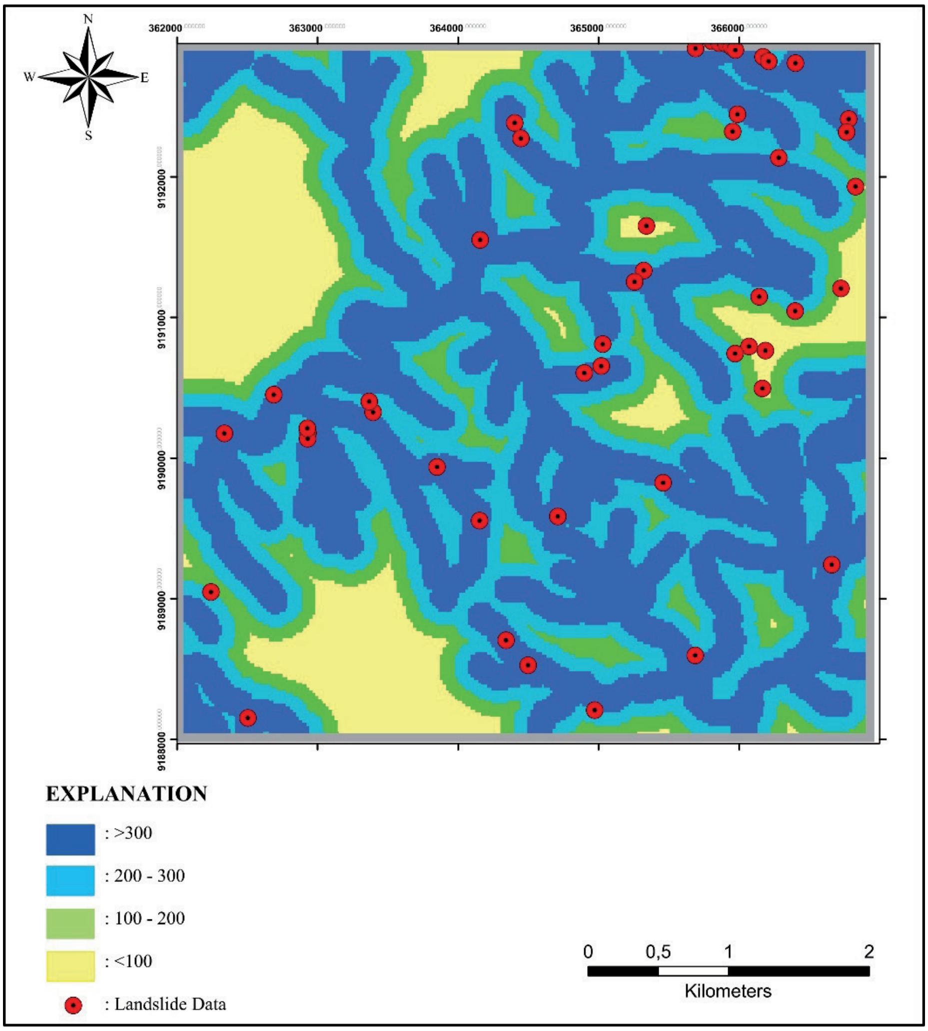

Figure 11. SMCE River Buffer Map of Research Area

8) *Aspect*

Aspect refers to the direction a slope faces based on the slope (β) gradient. It is determined using eight compass directions, including North (U), East (T), South (S), West (B), Southeast (TG), Southwest (BD), Northwest (BL), and Northeast (TL). Based on the surface analysis, the aspect follows the compass direction. The aspect does not directly influence erosion patterns; however, it affects the amount of solar radiation received, impacting the formation and weathering processes on the ground. The distribution class is shared among eight compass directions, as shown in Table 10 and Figure 12 (Meena, 2019).

Table 10. Classification *aspects* (Meena, 2019)

Parameter	Information	**Class**	**Parameter Weight**	**Weight Value**
Aspect	North	1	0.04	0.02
	Northeast	2	0.07	
	East	3	0.06	
	Southeast	4	0.23	
	South	5	0.08	
	Southwest	6	0.1	
	West	7	0.13	
	Northwest	8	0.29	

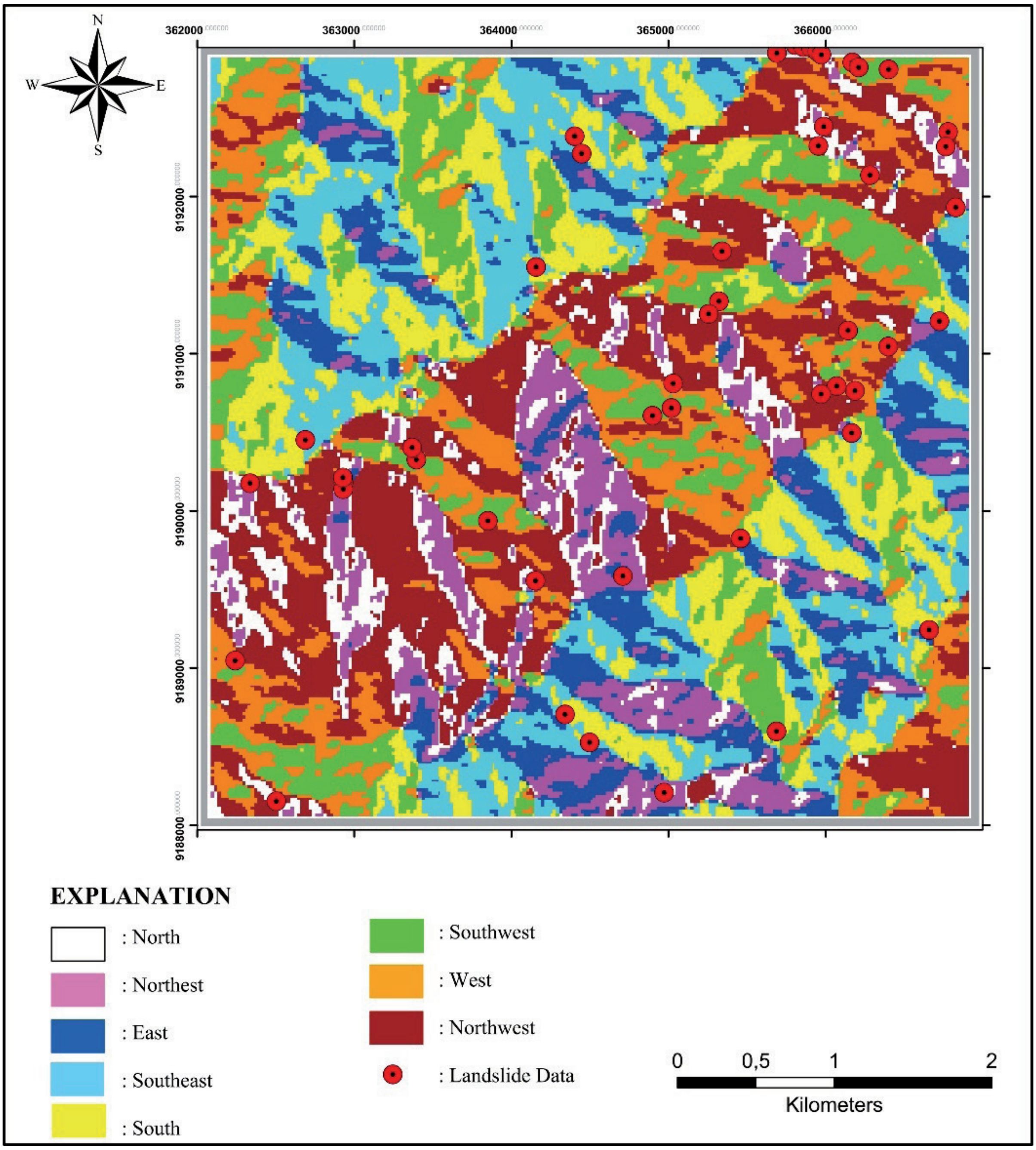

Figure 12. Aspect Map of Research Area

Analysis Results from Susceptibility to Ground Movement Method SMCE

The scoring process involved assigning numerical values to each parameter based on their level of importance or influence on landslide occurrence. The scores were sorted in descending order, with the highest indicating the most influential factor for landslide occurrence. This scoring process generated attribute data in a spatial data format, representing each factor's relative importance or influence in contributing to landslides, as shown in Figure 13.

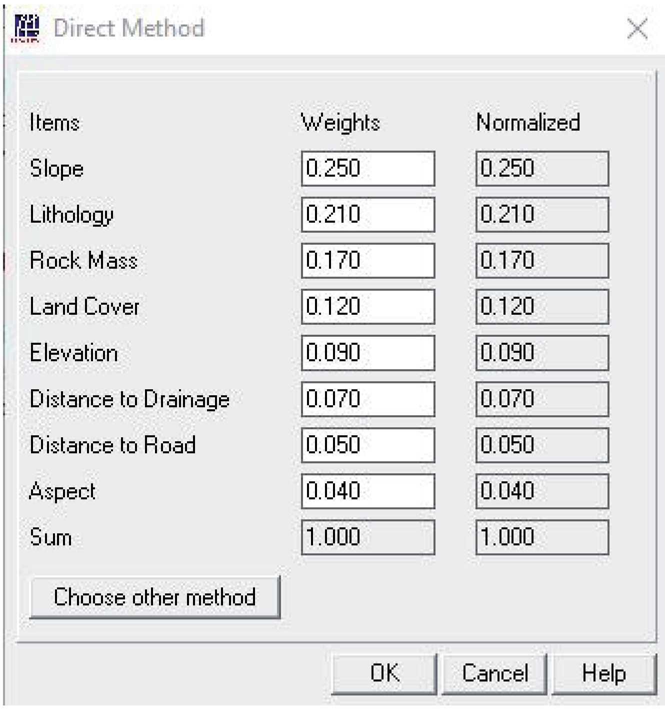

Figure 13. Weighted Value of Susceptibility Parameters

In the next stage, overlay and obtained results map the soil movement (landslide), as shown in Figure 14.

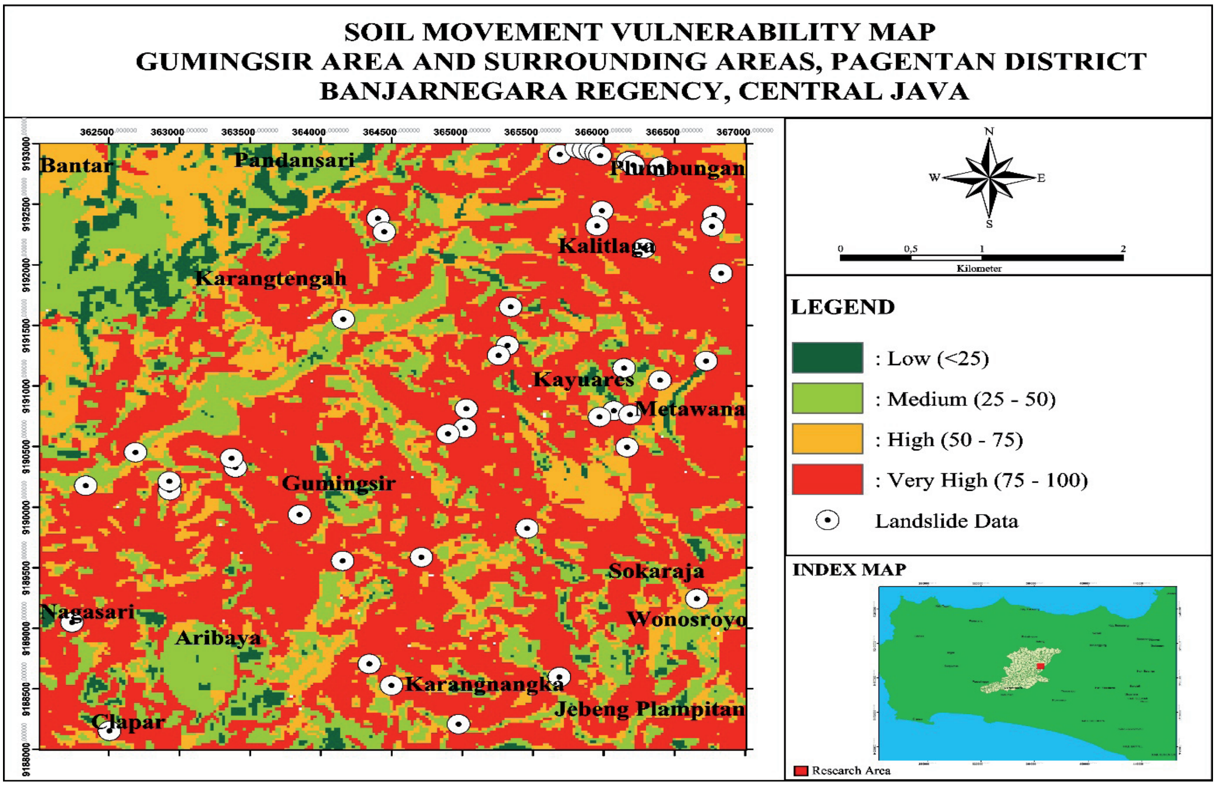

Figure 14. Susceptibility Map of Landslide

The mapping overlay results revealed the spatial distribution of susceptibility levels in the studied areas. They were categorized into four distinct parts based on the severity of susceptibility, namely low, medium, high, and very high.

The low susceptibility area, marked green in Figure 14, is predominantly characterized by lithology-related sandstones. The land in this area exhibits tilt-sloping to very steep slopes. The rock mass falls under the “good” category, with moist conditions and minimal signs of weathering. The rock surface is rough and slightly fragile, allowing landforms suitable for various purposes such as plantations, housing, and agriculture. This zone is adjacent to the northwest and southwest areas, extending towards the northern area.

The moderate susceptibility zone, highlighted in green in Figure 14, is characterized by claystone-sandstone layers and laharic breccias with steep to very steep slopes. The rock mass in this area falls under the Good category, but it exhibits some signs of weathering, with wet conditions and a slightly fragile nature. Landforms within this zone can be utilized for plantations, housing, and agriculture. This zone is situated adjacent to the northwest-southwest area, extending towards the southeastern area of the map, marked with green.

The high susceptibility zone, indicated by the orange color in Figure 15, is characterized by steep slopes dominated by claystone-sandstone layers and laharic breccias. The rock mass in this area is classified as Good but displays some signs of weathering, including moist conditions and a slightly brittle nature. Landforms within this zone offer the potential for plantations, housing, and agriculture. It is adjacent to the northwest and east areas labeled as research on the map. In contrast, the exceptionally high susceptibility zone, marked in red in Figure 15, predominantly comprises lithology-related sandstones with steep tilt slopes. The rock mass in this area is categorized as Bad, featuring wet conditions, significant weathering, and increased fragility. The landforms within this zone are suitable for plantations and housing. This zone covers a large portion of the research area highlighted in red on the map, as shown in Figure 15.

Assessing susceptibility and land projections is facilitated using Geographic Information System (GIS) data. The overlay results significantly influence the determination of susceptibility levels. The visual representation indicated that instances of land movement and incidents occur predominantly in areas with a very high level of susceptibility. These areas include Plumbungan, Kalitlaga, a substantial portion of Gumingsir, Aribaya, part of the southwest area, and Kayuares, which fall within the high-strain zone. Within the susceptibility zones, Gumingsir Village on the eastern side and parts of Pandansari to the northwest-north exhibit a dominant level. The current susceptibility zones encompass Suwidak, Karangtengah, Karangnangka, Larangan, Talunamba, Clapar, Pakelen, Kayuares, Sokaraja, and Jebeng Plampitan. However, it is worth noting that landslides have also been observed in certain areas with a low susceptibility level. These areas include Pandansari, Karangtengah, their surrounding areas, and South Aribaya.

The utilization of the SMCE method for processing results offers several advantages. One key advantage is its ability to generate balanced decision-making outcomes, even when employing different parameters (Oktaviani & Fadhil, 2019). The SMCE method has a higher accuracy rate of 75.2% compared to the Landslide Susceptibility Index (LSI) (Chalkias et al., 2014). Another advantage is that determining the rational weight for the criteria does not necessitate expert adjudication.

Based on previous research by Raditya (2018), a spatial analysis was carried out to identify landslide-prone areas in Pagentan District. The analysis utilized parameters such as soil type, slope, land use, elevation, and rainfall, assigning each class a score (Nugroho et al., 2009). The analysis results classified the areas into five susceptibility classes: very low, low, medium, high, and very high. The research findings revealed that the Pagentan District is predominantly characterized by a very high susceptibility to landslides. Therefore, it is crucial to implement disaster mitigation measures and preventive actions to address the area’s susceptibility.

CONCLUSION

Landslide susceptibility mapping using the SMCE method has been applied. The parameters used are 8 with the highest weight being the slope and the lowest being the aspect. Based on the SMCE method, the area's susceptibility is divided into four zones: low, moderate, high, and very high. The low susceptibility zone dominates the northwestern part of the study area, including Pandansari and Karangtengah. Susceptibility zones are being spread throughout the research area, including Wonosroyo, Aribaya, Karangtengah, Pandansari, and Bantar. Most of the high-susceptibility zones are in Bantar and Karangtengah. Meanwhile, very high susceptibility zones dominate the research area, including Gumingsir, Plumbungan, Kalitlaga, Kayuares, Nagasari, Karangnangka, and Mentawana.

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