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Spatial Analysis of Landslide Hazard Mapping Using GIS And Weighted Overlay in Semarang Regency

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ABSTRAK. This study aims to assess landslide hazards using a Geographic Information System (GIS)-based weighted overlay analysis in Semarang Regency, a region in Central Java Province, Indonesia. Integrating multiple parameters, including rainfall, slope gradient, geology, soil type, and land use. Weightings and scores for each parameter were derived from expert judgments in published literature, adjusted to reflect local conditions. The analysis reveals that 0.29% of the area is classified as a very high hazard zone, 17.74% as high, 61.66% as moderate, 18.91% as low, and 1.40% as very low. Model validation using the Area Under the Curve-Receiver Operating Characteristic (AUC-ROC) method and the result is 0.822, indicating good predictive accuracy. The findings provide critical insights for disaster risk reduction and sustainable land-use planning, ensuring a balance between regional development and environmental resilience. Furthermore, results of this study contribute to the knowledge of GIS-based landslide hazard assessment by offering a replicable framework for similar areas in tropical and tectonically active environments.

Kata kunci: Landslide hazard mapping; GIS; weighted overlay analysis; disaster risk reduction; Semarang Regency; AUC-ROC validation.

INTRODUCTION

A disaster is an event that occurs suddenly and can cause damage to the order of life and infrastructure that requires effective management and response to reduce the impact of a disaster (Graveline and Germain 2022). In a region with high disaster vulnerability, such as Southeast Asia, governments and policymakers have implemented policies and developed frameworks to improve disaster preparedness and response. As an illustration in Indonesia, have regulation aims to operationalize the disaster management system throughout Indonesia through structured disaster risk management (Nawang, Bangun, and Budiarto 2024). The increasing development of technology in recent years has also underpinned the shift of disaster management methods from traditional to more modern methods of providing real-time data essential for emergency response efficiency (Song and Yang 2023).

Landslides are categorized as geological disasters caused by the movement of a mass of rock, soil, or debris that moves downward due to the force of gravity. (Song and Yang 2023; Zamroni, Kurniati, and Prasetya 2020). Semarang Regency is an area that has various natural disaster hazards; landslides are one of the most significant hazards in this area (Jamhur et al. 2021). Based on records from the Badan Penanggulangan Bencana Daerah Kabupaten Semarang (BPBD Semarang Regency/Regional Disaster Management Agency of Semarang Regency) from 2020 to 2024 third quarter, there have been 465 recorded landslides. In a hazardous area, appropriate disaster mitigation measures must be formulated to control the impact of a disaster. Preparedness plans developed through collaboration with local communities tend to be more effective when compared to mitigation models imposed from outside the community (Boetto et al., 2021; Yunita et al., 2025) Apart from that, the ability of individuals and families to access information about disasters and support in community social nodes both before and after a disaster is also important to consider in taking appropriate mitigation measures to increase community resilience (Ujianti 2023).

Geographic information systems (GIS) are technologies used for spatial analysis and mapping in various fields, including disaster management, regional planning, and environmental studies (Lü et al. 2019). Artificial intelligence and machine learning are also transforming the paradigm of landslide disaster management into predictive analysis. Informatics techniques coupled with GIS enable landslide event prediction to be more dynamic and real-time based (Wang 2024). The integration of technological developments, including remote sensing, geographic information systems, machine learning, and community engagement strategies, will provide a comprehensive landslide management framework. These technologies not only improve the accuracy of hazard mapping but also facilitate appropriate intervention strategies, adaptive land use planning, and community preparedness efforts that are critical to mitigating the impacts resulting from landslides (Nawang et al. 2024; Wang 2024). In the context of landslide disaster studies, GIS has a vital role in producing hazard maps, assessing an area's vulnerability, and helping to identify areas vulnerable to landslides spatially.

This is very helpful in improving community preparedness and disaster mitigation efforts (Lu, Zhai, and Zhou 2024). One of the functions of geographic information system technology in landslide hazard determination is its ability to integrate diverse geospatial data such as topography, soil type, rainfall, and land use. The incorporation of these factors makes it possible for researchers to analyze what factors contribute to landslide hazard (Agboola et al. 2024). Some analytical techniques or approaches used in GIS to map landslide hazards include the Analytical Hierarchy Process (AHP), weighted overlay method, and Multicriteria Decision Analysis (MCDA) (Al-Rawabdeh et al. 2024). This reinforces the idea that GIS can comprehensively support disaster hazard assessment by considering regional variables under environmental conditions (Song and Yang 2023).

Landslide susceptibility hazard zonation assessment has undergone many developments. The current trend of hazard zonation assessment is to combine various contexts and methodologies. This shows how technological advances in geospatial and analytical techniques can improve the understanding and management of landslide risk, recent studies accommodate many using weighted overlay methods, logistic regression, frequency ratio, and various remote sensing techniques illustrating the broad applicability of these methods across different geographical locations (Thennavan and Ganapathy 2020).

The weighted overlay method is one of the essential techniques in determining landslide hazards using a geographic information system (Muhammad Usman Arshid et al. 2024). This method emphasizes the integration of various factors that contribute to the occurrence of landslides in an area. These factors include rainfall, slope steepness, soil type in the area, and land use in the area (Al-Rawabdeh et al. 2024). Each influential factor is given a weight that reflects the significance of the factor component in influencing the hazard, which, in this context, is the landslide hazard (Muhammad Usman Arshid et al. 2024). The results obtained from this weight overlay analysis reflect a comprehensive hazard map by spatially analyzing an area based on the distribution of landslide hazard (Pratiwi et al. 2021). Weighted overlay analysis can be combined with other analysis methods, such as AHP and multicriteria decision analysis, to get more comprehensive mapping results (Yassar et al. 2020). WOM provides a robust framework for generating landslide hazard maps by consolidating factors into a thorough analysis. The comprehensive, systematic, and combinative application of GIS makes it possible for researchers and practitioners to effectively identify precise hazard areas, which will be helpful in formulating appropriate interventions (Goswami, Sen, and Majumder 2024; Yassar et al. 2020).

Sedangkan untuk konten pada bagian pendahuluan, harus memuat: *Pertama*, pemaparan topik utama penenelitian. *kedua*, memuat literatur terbaru terkait dengan mensitasi literatur penelitian terbaru terkait dengan artikel yang dikaji. *Ketiga*, harus menunjukkan kesenjangan yang belum terisi oleh penelitian/literatur, ketidakkonsistenan dan kotrovrsi yang muncul diantara literatur yang ada. *Keempat*, memuat permasalahan, tujuan kajian, kontek kajian, dan unit analisis yang digunakan, dan *Kelima*, menampilkan apa yang dibahas dalam struktur artikel.

METHOD

This research uses the geographic information system method with data analysis using a weighted overlay to produce a landslide hazard map in the study area. The stages carried out in this research are shown in the following flowchart.

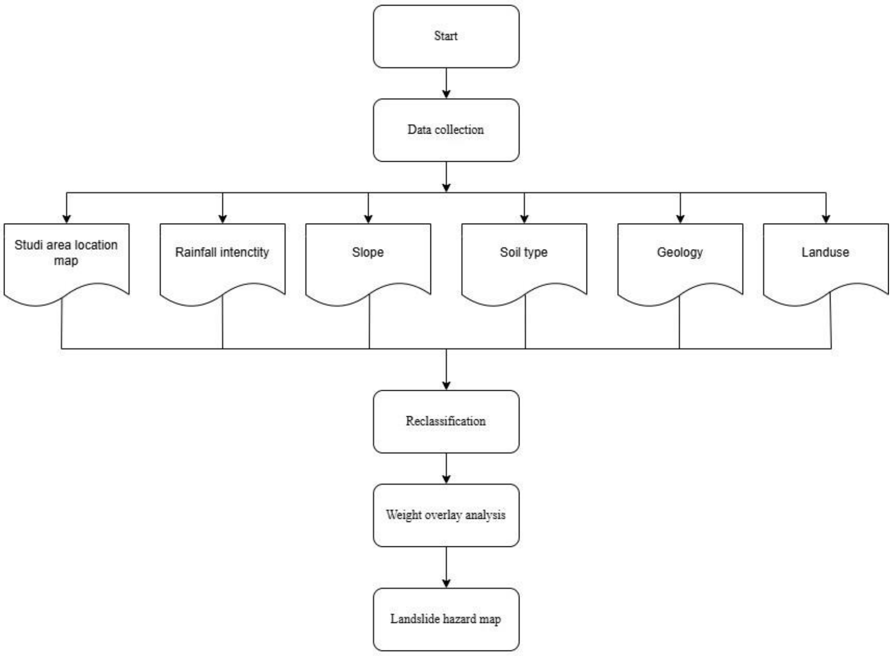

Figure 1. Research Flowchart
Source: Author's analysis, 2025

Research Location

The area of this research is Semarang Regency, more precisely located at coordinates 703'57"- 7030'0" south latitude to 110°14'54.74"-110°39'3" east longitude. The region is bordered by various regencies and cities around it, namely in the north, Semarang City borders it; in the west it is bordered by Temanggung Regency, in the south, Boyolali Regency and Grobogan Regency border it.

Data Collection

The research uses secondary data, including administrative data, for the research area. In this context, there is Semarang Regency, rainfall intensity data, slope data, soil type data, geological data, and land use data. The data was obtained from Dinas Pekerjaan Umum Kabupaten Semarang (DPU Semarang Regency) in 2024.

Data Processing

Data parameterized in landslide hazard mapping was processed using ArcGIS 10.8 software. The raw data is then processed into polygon data to produce shapefile format data. In conducting weighted overlay analysis, the data used is raster data; thus, data reclassification is required using Arc Toolbox.

Weighted Overlay Analysis Techniques

Mapping landslide hazards and threats requires an integrated accounting of the various factors that contribute to the disaster in an area. In this regard, the weighted overlay method (WOM) is a widely used technique in landslide hazard zoning and vulnerability mapping (Beigh and Bukhari 2024). WOM allows one to assess the relative weight of each parameter that contributes to a landslide event.

The creation of a landslide hazard map using weighted overlay analysis requires guidance on the scoring and weighting of parameters used in the study. The amount of score and weight used in this research refers to research from (Basharat, Shah, and Hameed 2016; Pratiwi et al. 2021), which is contextualized to the research area. In detail, the score value of each variable of landslide hazard estimation in Semarang Regency is presented in the following table 1.

Table 1. Classification and score of landslide parameters

No.	Parameters	Classification	Score	Weight
1.	Rainfall Intensity	Very wet (>3000)	5	20%
		Wet (2501-3000)	4	
		Medium (2001-2500)	3	
		Dry (1501-2000)	2	
		Very dry (<1500)	1	
2.	Rock Parameters	Volcanic rocks	3	20%
		Sedimentary rocks	2	
		Alluvial rocks	1	
3.	Slope	>45	5	20%
		31-45	4	
		16-30	3	
		9-15	2	
		0-8	1	
4.	Soil type	Regosol	5	20%
		Andosol	4	
		Latosol	3	
		Mediterranean	2	
		Alluvial	1	
5.	Land use	Rice field, moor	5	20%
		Shrubs	4	
		Forest and plantation	3	
		Settlements, buildings	2	
		Water	1	

Source: (Pratiwi et al. 2021) with contextualization in research area

The final result of the landslide hazard zone processing is classified into five classes: very high hazard class, high hazard class, medium hazard class, low hazard class and very low hazard class. Classification is determined using the following calculation method:

$$\frac{maximum\ score\ -\ minimum\ score}{total\ classification}$$

RESULT AND DISCUSSION

The results of the analysis of the landslide hazard map using weighted overlay analysis in this study contain five factors. The determination of the hazard zone is measured by determining the number of classes referred from the number of pixels analyzed in ArcGIS software. The hazard map contains five hazard classes, where each of the hazard classes represents the extent to which severity can occur. The values of 1, 2, 3, 4, and 5 represent the sequential class values of very low, low, medium, high, and very high. The relationship between factors causing landslide hazard will be explained below.

Rainfall Intensity

The intensity of rainfall in an area is one of the factors that affect the potential hazard of landslides. The causal relationship between rainfall and landslides includes infiltration, which involves the reduction of water matric suction in the soil, increased pressure on water pores, and decreased strength of soil sliding properties on steep slopes (Amarasinghe et al. 2024). In an area that has unstable rock conditions, landslides will easily occur. Semarang Regency has rainfall ranging from 1500-3000 mm/year. With such high intensity combined with hilly topography, the chance of landslides increases during the rainy season (Kim et al. 2024). This correlation is in line with the records of landslides from Badan Penanggulangan Bencana Daerah Kabupaten Semarang (BPBD Semarang Regency/Regional Disaster Management Agency of Semarang Regency), which occurred between November and March.

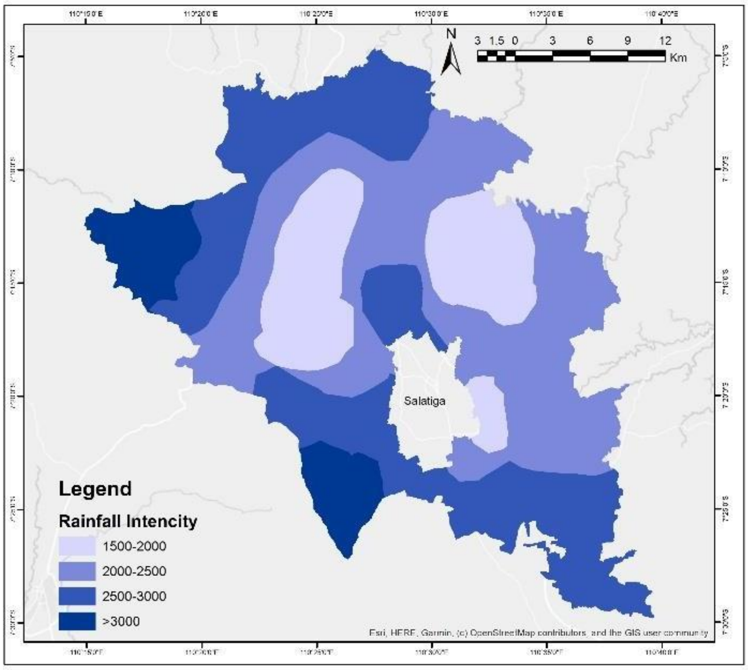

Figure 2. Rainfall Intencity Maps
Source: Author's analysis, 2025

Geology

The rock structure or geology in an area has a role in determining how significant a hazard will occur against landslides (Aparna et al. 2024). Geological material structure, which includes rock and soil composition, has an essential contribution to landslide hazard (Vásquez-Antipán et al. 2025; Xie et al. 2021). Pyroclastic soil-forming rock structures for example are weak and unconsolidated, making them highly susceptible to landslides (Vásquez-Antipán et al. 2025). Based on data obtained from the Dinas Pekerjaan Umum Kabupaten Semarang (DPU Semarang Regency), the existing geological structures in this research area include six groups, namely volcanic alluvium, cocaine sediment, old quate-mary vo, pleoscale volcan, young quatemary, and one cluster that is less detectable or grouped into undifferentiated.

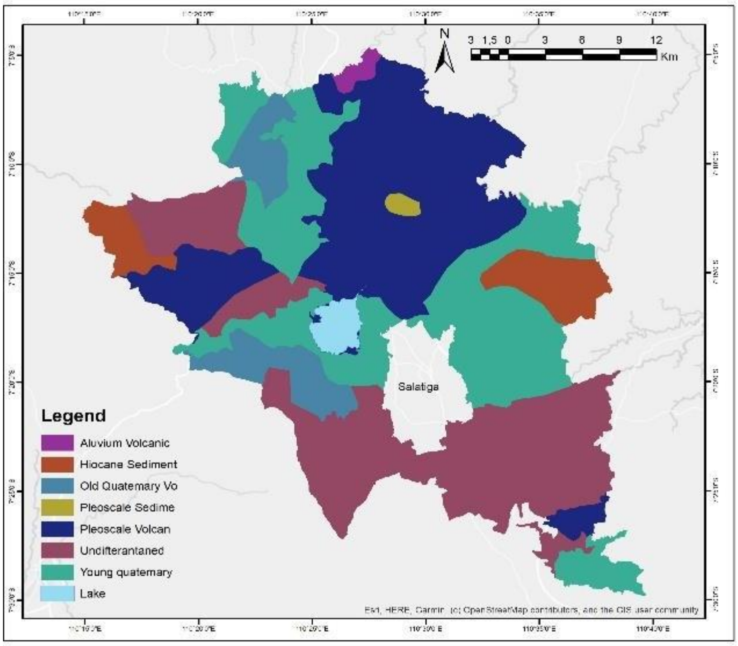

Figure 3. Geology Maps
Source: Author's analysis, 2025

Soil Type

In landslide hazard studies, the type of soil present in an area is an essential factor influencing the probability of landslide occurrence (Picarelli et al. 2021). Different soil types will have various levels of consistency in resistance to vibration and movement. Some of the influences of the properties of a soil type on landslides can include the clay content as well as the grain texture of the soil. Higher clay content in soil can increase the susceptibility of soil to landslides; this is due to the low shear strength and high plasticity of the clay type that will form a weak soil layer and has low permeability properties; this will trigger landslides to occur easily in the area (Temme 2021). Then, soil texture will also affect the vulnerability of landslide hazards. Granular soils that have very loose material and almost resemble sand have a very fragile response to rain (Trisnawati and Hidayatillah 2022). In the study area of Semarang Regency, there are ten soil type classifications which include brown alluvial, brown andosol, gray grumosol, gray andosol group, red latosol group, regosol, and ash grumosol group, dark brown latosol, red yellow latosol and black brown lithosol, red brown lithosol, and dark brown mediteran. The soil classification is contextualized based on the character and color of the soil published data by the government. The soil types indicate that the majority of soils in the study area have a high sensitivity to landslides, supported by steep slope conditions and high rainfall, which will increase the danger of landslides if not appropriately treated.

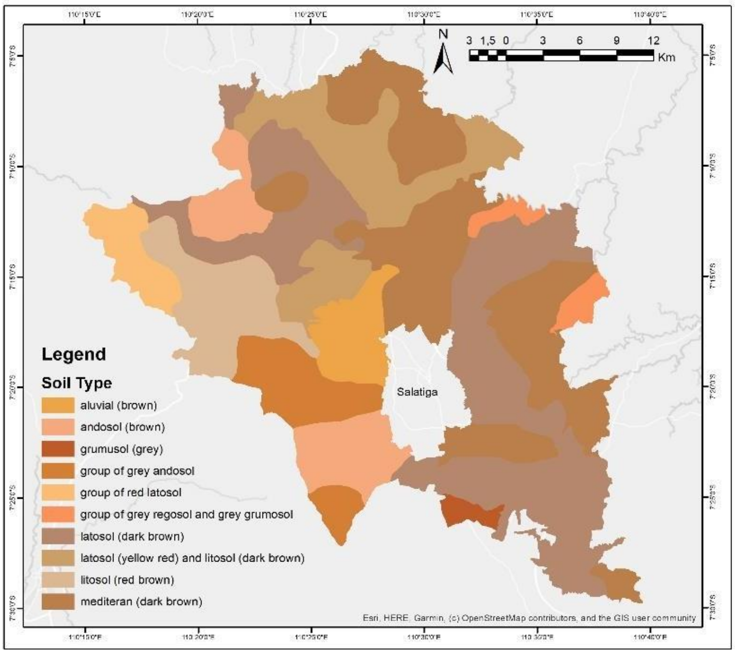

Figure 4. Soil Type Maps

Source: Author's analysis, 2025

Slope

The slope is an important factor considered in landslide hazard assessment. Steep slopes have a higher hazard of landslides due to gravity acting on soil and rocks. The steeper the slope in an area, the greater the risk. In this research, the hill is classified into five slope classes; the analysis shows that Semarang Regency has a high slope in the western part. The slope map is shown in red. In other words, the western part of the regency has higher landslide drivers than the eastern and southern parts. The steep slope condition will worsen the condition of the area when heavy rains occur, and the water flow can trigger the collapse of rocks and soil structures in the regions that have steep slopes.

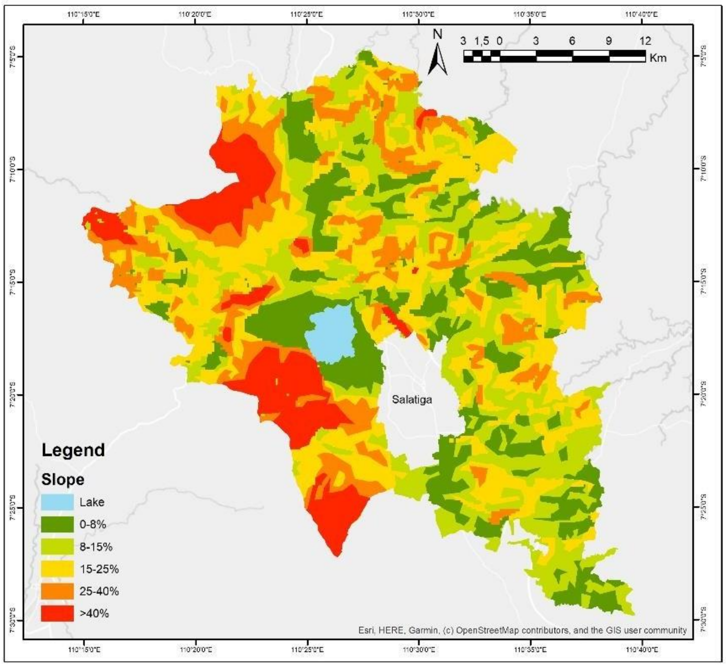

Figure 5. Slope Maps

Source : Author's analysis, 2025

Land use has been a widely considered factor when considering landslide hazards in an area. Previous studies have analyzed that land use change can significantly impact the danger and severity of impacts from landslides (Upadhyay and Dixit 2024). Regional development in Semarang Regency has triggered changes in existing land use. With the trend of development towards the west, while the physical condition of the area is a steep slope, the danger of landslides is always a time bomb in regions that experience development. Land use data from Dinas Pekerjaan Umum Kabupaten Semarang (DPU Semarang Regency) shows that community settlements continue to grow along with the increase in population, which in turn requires residential facilities and infrastructure. Land use is classified into ten types, which include lake, field, moor, shrub, dry rice field, wet rice field, plantation, forest area, settlement area, and building area. Deforestation by the community, as well as agricultural practices such as perennial crops, can increase landslide hazard by reducing vegetation cover that can stabilize the soil.

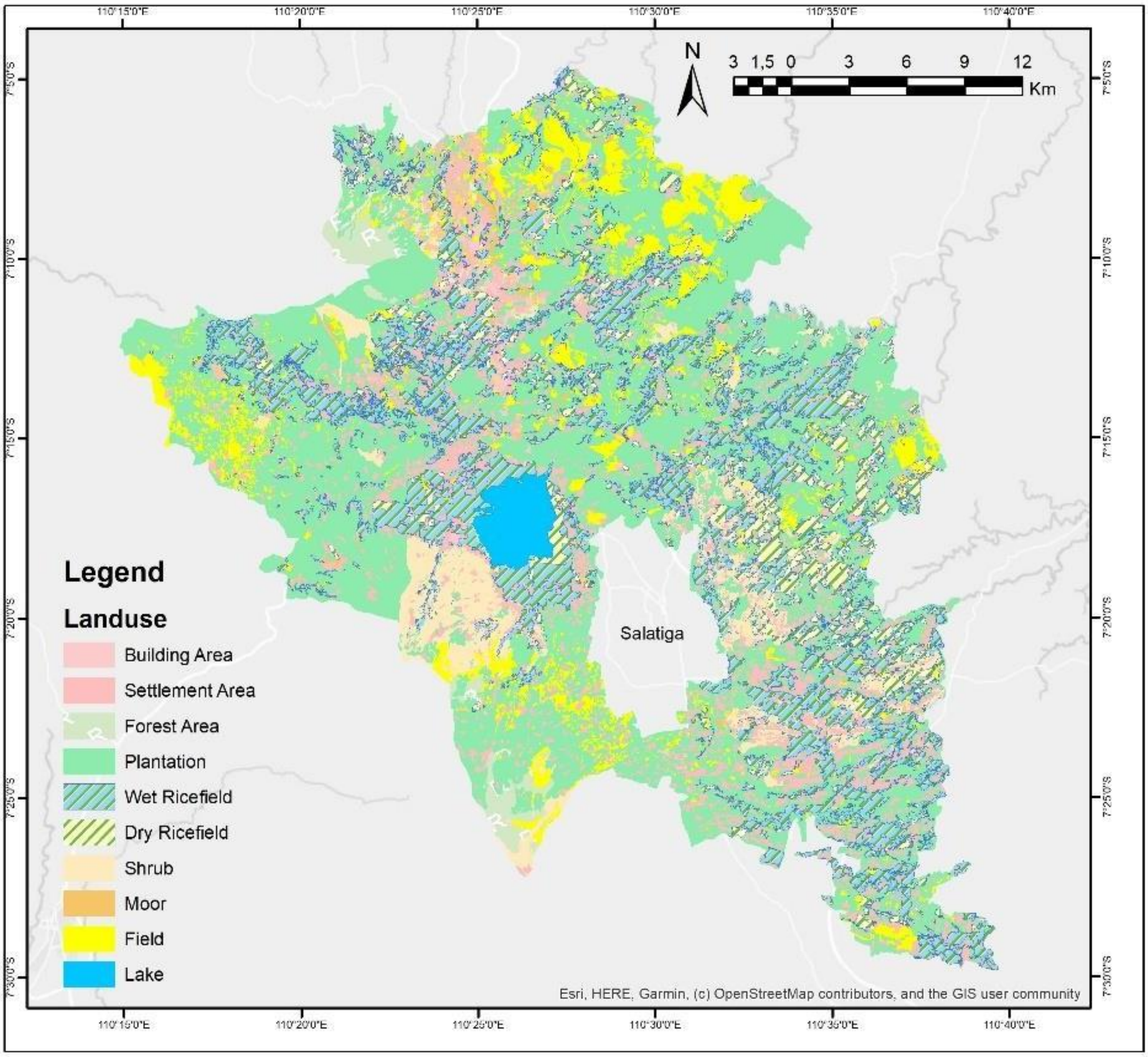

Figure 6. Land Use Maps
Source: Author's analysis, 2025

Landslide Hazard Zone

The landslide hazard index map of the study area represents the distribution of land area in zones with different stability levels; in this study, the processing parameters used in determining landslide hazard are processed using knowledge-based weights for each parameter. The weight determination is obtained from expert opinion through previous studies that have been published in scientific journal articles. Parameters used in determining landslide zones include rainfall, soil type, geology, slope, and land use. The use of these parameters is adapted from research that has been conducted by (Basharat et al. 2016; Pratiwi et al. 2021). In the same area (Nugraha et al. 2019) have conducted similar research. Still, due to the growing condition of the area, the author feels the need for an update to the research study on landslide hazard mapping to refine the previous research further. The research conducted by (Nugraha et al. 2019) did not consider soil type as one of the factors considered; it is different from what the author did in this research by considering soil type as one of the factors considered in determining landslide hazard in the study area. The results of the landslide hazard mapping of Semarang Regency are presented in the figure 6, and the color gradation indicates the hazard condition from the highest to the lowest level.

Banyubiru, Sumowono, and Getasan are sub-districts with high-hazard zones. These three sub-districts have a very high landslide hazard zone presentation because they are located in low-lying areas.

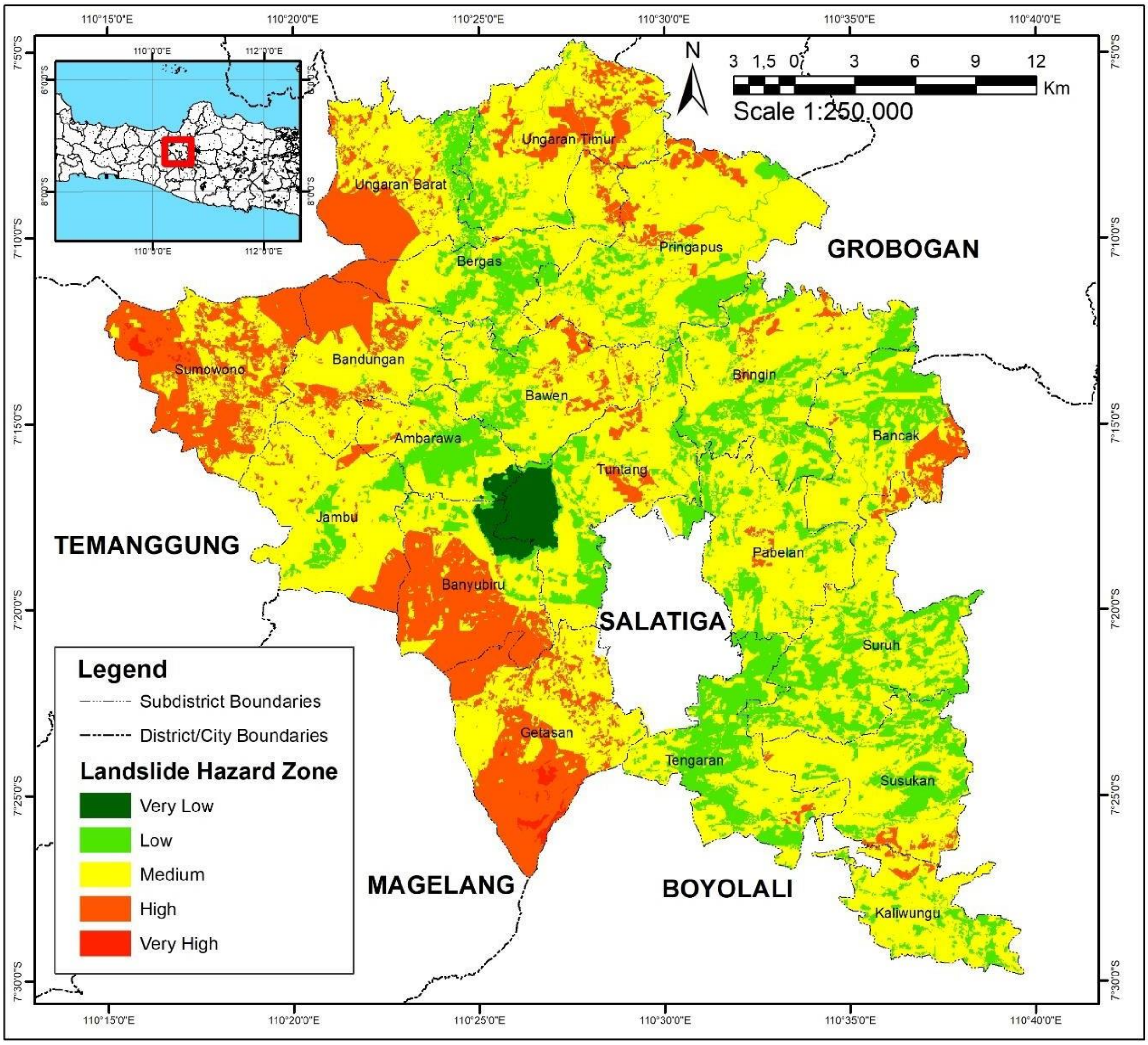

Figure 7. Landlide Hazard Maps

Source: Author's analysis, 2025

Although each parameter has a balanced value in the weight classification, the mapping results show that the landslide hazard is directly proportional to the slope. Areas with extreme slopes, in this case above 40%, have higher landslide hazards compared to areas with gentle slopes. This is in line with (Preti et al. 2025), which states that slope stability is fundamental to reducing landslide hazards. In addition, rainfall conditions also have a significant influence on the occurrence of landslides; this is evidenced by the record of disasters published by Badan Penanggulangan Bencana Daerah Kabupaten Semarang (BPBD Semarang Regency/Regional Disaster Management Agency of Semarang Regency), which shows that the percentage of landslides occurs more in the rainy season compared to the dry season. Areas with landslide hazards should receive more attention, especially from the local community, when conducting life activities that include clothing and shelter needs. Agricultural practices in the landslide hazard zone must be taken into account; the existence of settlements where people live but are located in the landslide hazard zone must also be a serious concern. This is done to reduce the impact caused if, at any time, a landslide occurs. The government must also pay more attention to overcoming and minimizing the effects. Development direction in hazardous zones must be controlled so as not to worsen the condition of the dangerous area.

The results of the landslide hazard mapping analysis using weighted overlay show that most of Semarang regency is in the medium hazard zone; this zone reaches 61%. The detailed percentage of hazard zones is shown in the table 2.

Table 2. Distribution of Landslide Hazard Zone

No.	Hazard Class Classification	Area (KM^2)	Percentage (%)
1.	Very low	14,2641	1,40%
2.	Low	192,4713	18,91%
3.	Medium	627,498	61,66%
4.	High	180,4887	17,74%
5.	Very High	2,9745	0,29%

Source: Author's analysis, 2025

The analysis of landslide hazard zones can be used as a basis for the direction of regional development in Semarang Regency. The direction of development, which was once concentrated in the northern region, has now shifted towards the west and partly towards the south. Although there is no scientific research that explicitly discusses the direction of regional development in Semarang Regency, the existence of a national strategic project for the construction of the Bawen-Jogja toll road and the direction for the development of tourism areas targeting Bandungan Sub-district and its surroundings are enough to strengthen the basis for the direction of development in this region. Meanwhile, if seen in the visualization of landslide hazards, it is precisely this developing area that has a red zone of disaster hazards. This means that the development of the area is heading towards the disaster hazard zone. In line with this research (Pangi et al. 2017) mentioned that the spatial development in Semarang Regency is relatively high. Built-up land changes up to 300 ha/year. Research from (Kurniawan 2015; Setiawan and Vanel 2023) indicates that the tourism sector in Bandungan Sub-district continues to develop and increase and receives excellent support from both the community and the government. On the other hand, this has triggered land use changes in the area.

Accuracy of Landslide Hazard Mapping

To improve the mapping results, the accuracy of the hazard maps was tested through field validation, which aimed to confirm whether the maps were consistent with the actual conditions in the field. Based on the analysis, 36 field validation sample points were selected, spread across six subdistricts with high landslide hazards. The detailed field validation locations are presented in figure. 8.

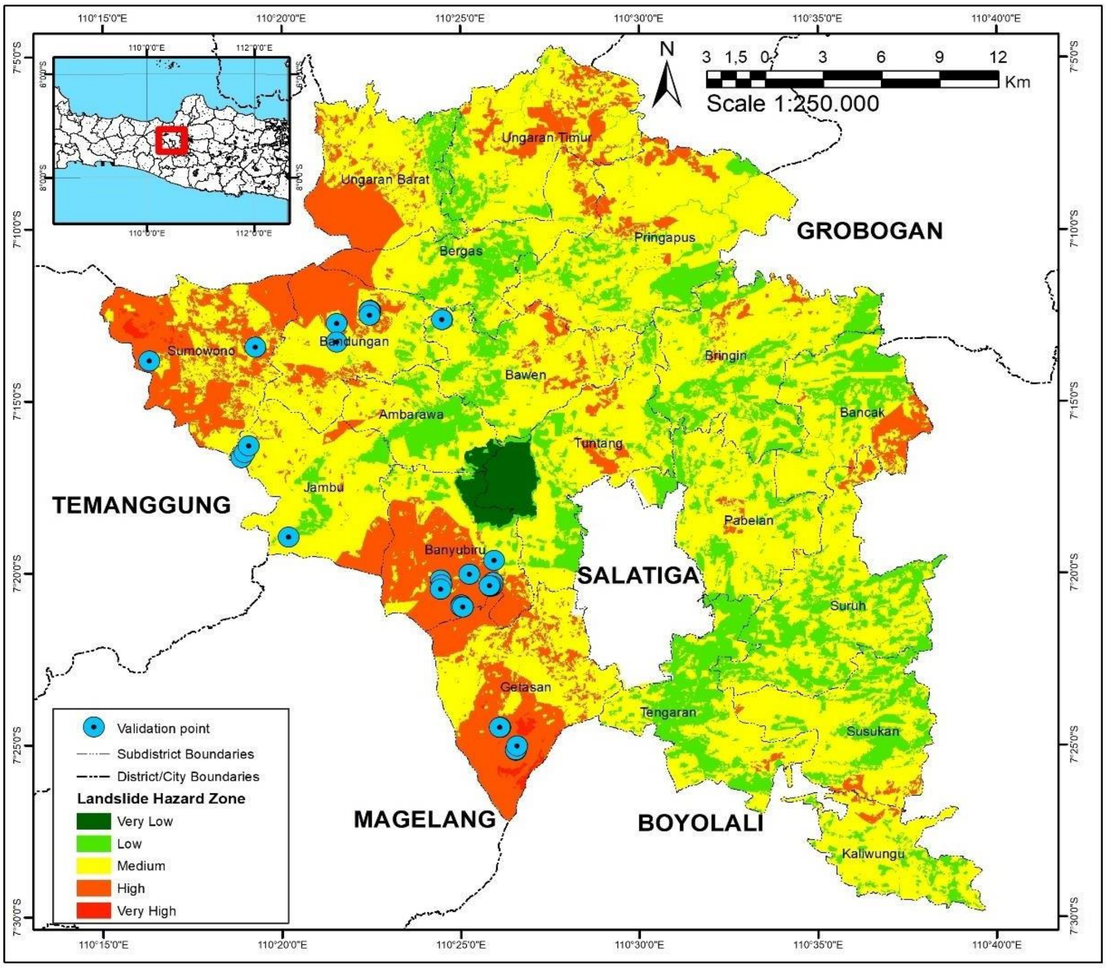

Figure 8. Validation point distribution
Source: Author's analysis, 2025

Figure 9. Field Condition of Landslide Hazard Area
Source: Author's documentation, 2025

Validation testing was conducted using the AUC (area under the curve) ROC (receiver operating characteristic) curve. Validation testing of landslide hazard maps using AUC-ROC has been widely conducted, as reported by (Aparna et al. 2024; M.U. Arshid et al. 2024; Basharat et al. 2016). The results of the AUC-ROC testing for landslide hazard zone mapping in Semarang Regency were 0.812, which falls into the good category.

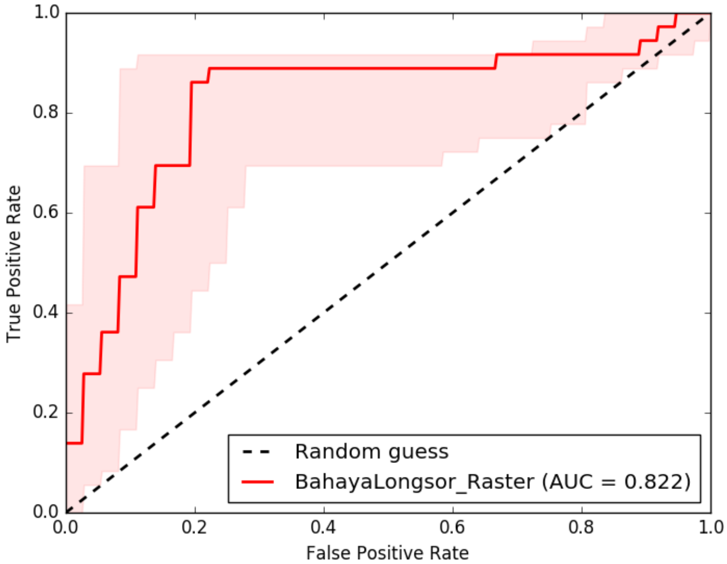

Figure 10. AUC-ROC Curve of Landslide Hazard Analysis
Source: Author's analysis, 2025

CONCLUSION

The development of technology in the field of geographic information systems has brought significant changes in the analysis of regional development and territorial studies. One aspect that is taken into consideration when developing a region is the existing disaster hazards. Using geographic information system analysis with the weighted overlay method shows that the Semarang Regency area has landslide hazards. The presentation of the landslide hazard zone, which is included in the high hazard category, reaches 17.74%. This should be a concern for both the community and the government because the direction of regional development begins to intersect with areas that have landslide hazards. Capacity building of communities located in areas with moderate to high landslide hazard zones, settlement management rules, and development control are essential. The result of this research can be used as one of the bases for special development direction from the aspect of landslide hazard to minimize the impact of development in Semarang Regency. In the development of landslide hazard maps, the use of detailed landslide inventory documents will help in testing the accuracy of the prediction of mapped landslides, and it would be better if this is taken into consideration in future research.

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