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# Landslide Susceptibility Assessment of a Railroad Based on GIS Application

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**ABSTRACT**

This study uses GIS-based maps to identify the potential for landslide movement on the railroad section between Prupuk Station and Purwokerto Station. The preparation was conducted by overlaying various maps obtained by online resource data, including rainfall, slope, geology, soil type, and land use, by using the DVMBG 2004 landslide prediction model. The distribution of landslide susceptibility levels shows that of the overall railway lines, 1.10% was very low, 17.29% was low, 63.16% was medium, 18.25% was high, and 0.21% was very high. The results of this study can be used as a reference for operators to provide information systems, landslide monitoring, and mitigation systems, especially for railroads in areas with high and very high vulnerability for landslides. Detailed conditions of landslide parameters and assessment of landslide occurrence on the location are needed to improve the accuracy of the models.

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## 1. INTRODUCTION

Landslides can pose a significant threat to railways, cause disruption and delays, and endanger rail operations' safety. Identifying accurate and up-to-date landslide-prone areas is necessary to help identify potential locations and information for developing risk management strategies. Geographic Information System (GIS) is one method that allows for the preparation and analysis of detailed maps that can be used to identify and monitor landslide-prone areas along railway corridors.

The Government of Indonesia has prepared various recommendations for potential disasters, including landslides, as compiled by the Ministry of Public Works through a ministerial regulation for Landslide

Disasters through the Spatial Planning Guidelines for Landslide Disaster Areas [1]. This regulation contains a formula for estimating landslide areas by considering natural physical and human activity aspects with different weighting and parameters. In addition, the Indonesian National Standard has also formulated a map of the landslide susceptibility of a location using several approaches, including heuristics, statistics, and determinism [2]. Other references that are commonly used in various studies as compiled by Puslittanak 2014 and by the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG) in 2004 and DVMBG 2005 [3][4].

Various studies have developed identification of landslide-prone areas using GIS. Research on landslide-prone zones is usually carried out for large areas [5][6][7][8][9][10][11] [12], which produces a percentage of areas that have low, medium, and high landslide susceptibility. Research on landslide-prone zones has also been developed for roads [13][14] using estimation models and parameters of geological maps, rainfall maps, slope maps, and land cover maps. Research on landslides for railroads has been carried out to predict landslide susceptibility rates [15]. However, this study is only limited to the scope of Semarang-Pekalongan so that the identification of landslide-prone areas can be continued for other locations with similar potential.

A search of the Landslide Hazard Map in the Central Java study location found that for the area of national roads and railroads, there is a GIS map of landslide susceptibility areas compiled by the Center for Volcanology and Geological Hazard Mitigation - the Geological Agency in the Indonesian Disaster Mitigation Portal throughout Indonesia which updated every month. The map can be accessed on the ESDM One Map geoportal [16]. The data on the map shows that the road and railway line areas between the Purwokerto and Bumiayu areas have a high potential for landslides, marked in red. The railroad section with high potential for ground movement in April 2022 is in Central Java, from Purwokerto Station to Prupuk Station, Purwokerto-Tegal railway line. However, the detailed location for landslide susceptibility along the railroad was unclear on the map. A study that detailed the location of landslide vulnerability along the railway route is needed to ensure railway operation safety.

Based on this, this study tries to identify the potential for landslide movement on the railroad section between Prupuk Station to Purwokerto Station with a GIS-based map by overlaying various landslide contributing factors, including rainfall, slope, geology, soil type, and land use. The results can be used as a reference by train operators for information systems, landslides monitoring, and mitigation in the operating area.

## 2. RESEARCH METHOD

### 2.1 Method

The first step in creating a GIS landslide map is gathering the necessary data. These data include topographic maps, soil types, rainfall, and land use. Once this data is collected, it can be processed and analyzed using a GIS application by various tools and techniques. Elevation data is used to create slope maps, which show areas with steeper slopes that are more prone to landslides. Similarly, soil data can be used to create maps showing locations with soil types more vulnerable to erosion.

After the data has been collected from various online sources, the data for each parameter is processed using the QuantumGIS software for processing, displaying the data, and producing a map for each parameter in predicting landslide vulnerability. The landslide vulnerability parameter uses the prediction model from DVMBG 2004 by using the formula:

Landslide Hazard Score = (30% × rainfall factor) + (20% × geological conditions factor) + (15% × soil type factor) + (15% × slope factor) + (15% × land use factor).

Landslide vulnerability is divided into five classes: very low, low, medium, high, and very high. The conclusion of the score interval is determined by a relative approach by selecting the maximum and minimum scores and then dividing by the number of classes. The weighting parameters for Potential Landslide [4] as in Table 1.

**Table 1** Weighting Parameters for Landslide Susceptibility

| Parameter | Classification | Value | Scoring | Weight | References |
|---|---|---|---|---|---|
| Rainfall (mm/year) | Very wet | >4000 | 5 | 30% | [12] |
| | Wet | 3000-4000 | 4 | | |
| | Moderate | 2000-3000 | 3 | | |
| | Dry | 1000-2000 | 2 | | |
| | Very dry | <1000 | 1 | | |
| | Very steep | >45 | 5 | 15% | [4] |

| Parameter | Classification | Value | Scoring | Weight | References |
|---|---|---|---|---|---|
| Slope inclination (%) | Steep | 25-45 | 4 | | |
| | A Bit Steep | 15-25 | 3 | | |
| | Sloping | 8-15 | 2 | | |
| | Flat | 0-8 | 1 | | |
| Lithology | Very Vulnerable | Sediment | 3 | 20% | [3] |
| | Vulnerable | Volcanic | 2 | | |
| | Not Vulnerable | Limestone and igneous rock | 1 | | |
| Soil Type | Very high | Regosol, Litosol | 5 | 20% | [3] |
| | High | Andosol, Grumosol, Podsolik | 4 | | |
| | Moderate | Mediteran | 3 | | |
| | Low | Latosol | 2 | | |
| | Very Low | Alluvial | 1 | | |
| Landuse | Very high | Empty land | 5 | 15% | [3] |
| | High | Industrial and residential area | 4 | | |
| | Moderate | Plantation and irrigated rice fields | 3 | | |
| | Low | Garden and scrub mix | 2 | | |
| | Very Low | Forest and Water Body | 1 | | |
| Total | | | | 100% | |

### 2.2 Data Collection

Data collection was carried out using secondary data downloaded from available online resources. The scale of each data map varies according to the available sources. Topographical Earth Map, 1:25.000 from the Geospatial Information Agency, will be used to prepare slope maps. A map of Administrative Boundaries with a scale of 1:50.000 was obtained from the Geospatial Information Agency. A rainfall Map with a scale of 1:250.000 was processed from the Climate Hazards Center USA. A lithology map with a scale of 1:250.000 was obtained from the Ministry of Energy and Mineral Resources. Soil type Map with a scale of 1:250.000 was obtained from the Ministry of Agriculture. A Map of Land Use with a scale of 1:10.000 was obtained from the Ministry of Agrarian Affairs and Spatial Planning (ATR)/BPN.

## 3. RESULTS

### 3.1. Case Study Location

The Cirebon-Kroya railway line has three corridors: Cirebon-Prupuk, Prupuk-Purwokerto and the Purwokerto-Kroya. The Prupuk-Purwokerto railway line in the highlands (west mountainside of Mount Slamet) is dominated by a hilly topographic condition that makes the area prone to landslides [17]. Therefore, information about the potential for landslides on the railway line in the area was needed for disaster mitigation planning. As in Figure 1, the railway line is located in the middle of central Java through three districts and nine sub-districts. The train is operated by PT KAI DAOP 5 Purwokerto.

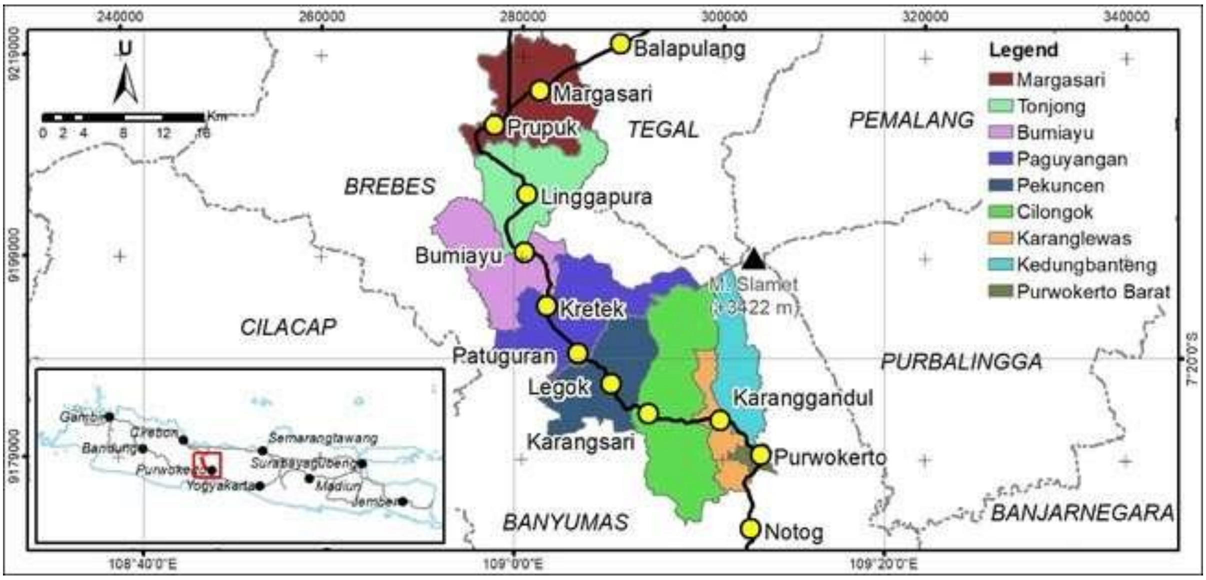


**Figure 1** Location of the Study

The details about the study area can be seen in Table 2. The railway line consists of nine operational stations. The station's elevation along the line varied between 36m to 329m above mean sea level, with 56 km of total length.

**Table 2** Purwokerto Prupuk Railway Profil

| Station Name | Code | Class | Elevation (msl) | Kilometre (km) | Distance (m) | Districts | Sub-districts |
|---|---|---|---|---|---|---|---|
| Prupuk | PPK | 2 | 36 | 293+937 | | Tegal | Margasari |
| | | *District Boundary* | | 298+183 | 10.772 | | |
| Linggapura | LG | 3 | 156 | 304+709 | | | |
| | | | | | 7.851 | | |
| Bumiayu | BMA | 2 | 236 | 312+560 | | | |
| | | | | | 6.998 | Brebes | Tonjong, Bumiayu, Paguyangan |
| Kretek | KRT | 3 | 285 | 319+558 | | | |
| | | | | | 5.916 | | |
| Patuguran | PAT | 3 | 329 | 325+474 | | | |
| | | *District Boundary* | | 326+929 | 5.043 | | |
| Legok | LGK | 3 | 299 | 330+517 | | | |
| | | | | | 5.651 | | |
| Karangsari | KRR | 3 | 233 | 336+163 | | Banyumas | Pekuncen, Cilongok, Karang Lewas, Kedung Banteng, Purwokerto Barat |
| | | | | | 7.760 | | |
| Karanggandul | KGD | 3 | 142 | 343+928 | | | |
| | | | | | 6.017 | | |
| Purwokerto | PWT | 1 | 75 | 349+955 | | | |
| | | | | Total | 56.008 | | |

### 3.2. Soil Types Map

The soil type map is used to determine the physical properties that contribute to susceptibility to landslides. Sand and silt-textured soil is vulnerable to landslides compared to clay texture, which is better to hold water. The soil with textures of sandy clay is generally soft and easy for water to pass through, which is vulnerable to landslides [18]. Fine-grained soils like silt and clay retain water more effectively than coarser soils, which can lead to increased pore water pressure. When this pressure builds up, it reduces the soil's stability, making it more susceptible to landslides [19]. Soil type map data used in this study was a 1:250.000 scale issued by the Center for Research and Development of Agricultural Land Resources (BBSDLP), Ministry of Agriculture Republic of Indonesia. The results of identifying the area's soil type are shown in the following figure.

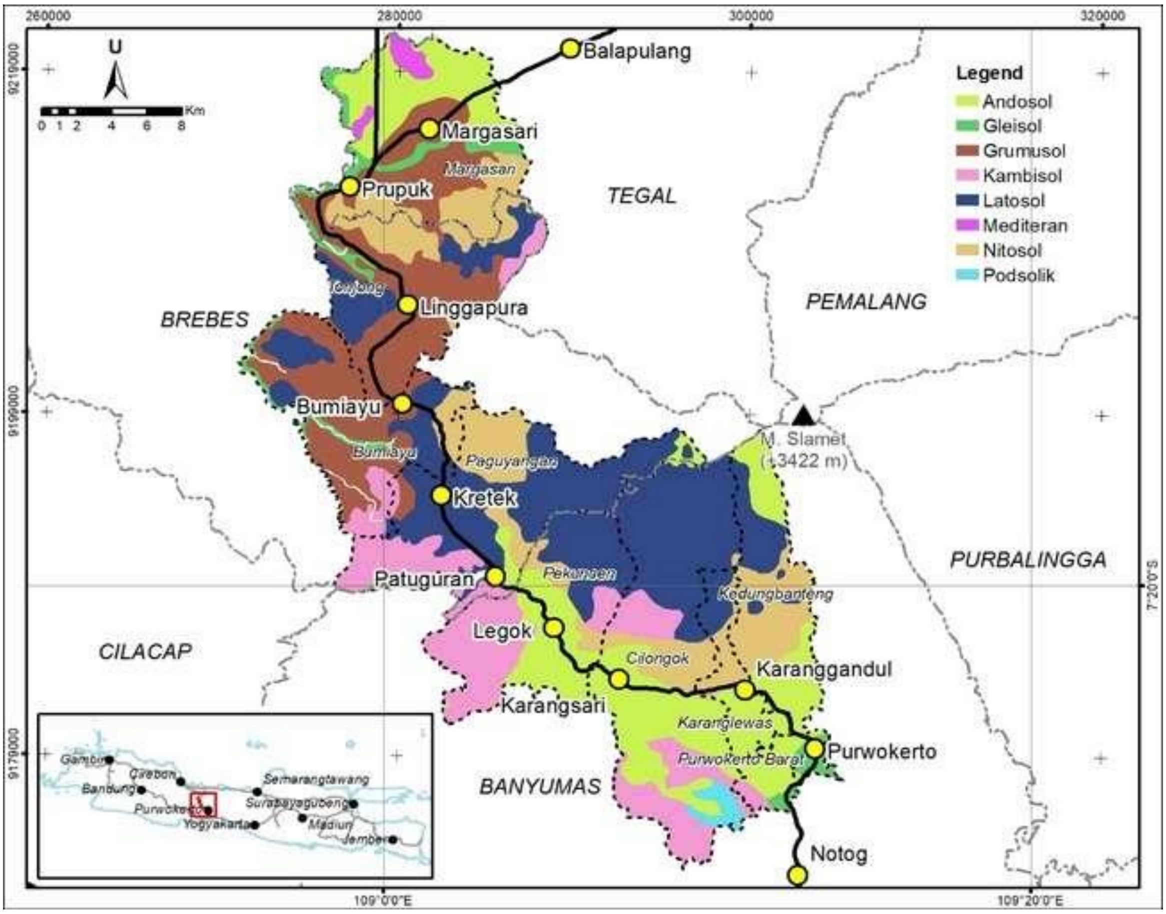


**Figure 2** Soil Types Map

Figure 2 shows the map of soil types in locations between the Prupuk and Purwokerto stations. The soil types vary for every km of railroad. The soil types at the railroad track location are dominated by grumusol, latosol, and andosol. These types of soil are vulnerable to landslides. From Table 1, grumusol and latosol were categorized as very high and andosol as high. The soil type parameter contributes 20 percent to the model for landslide susceptibility based on the model from DVMBG 2004.

### 3.3. Slope Map

Slopes with steep angles are more susceptible to landslides because the gravitational force pulling the soil downslope is more significant, especially when combined with other factors like heavy rainfall or earthquakes. The slope map is generated by analyzing the DEM data by creating the slope percentage. The Digital Elevation Model (DEM) represents the shape of the earth's surface, which was obtained by downloading raster format files via the DEMNAS website from the Geospatial Information Agency. DEMNAS data is an integration of altitude data from IFSAR (5-meter resolution), TERRASAR-X (5-meter resolution), and ALOS PALSAR (11.25 meters) and has a resolution of up to 8 meters. In Indonesia, DEMNAS can be used to obtain more detailed altitude information from the topographic results, which can be compared to the results of the UAV

Drone Survey. However, it could not be used as the basis for detailed engineering design [17]. The results of the slope inclination along the railway route as shown in the following figure.

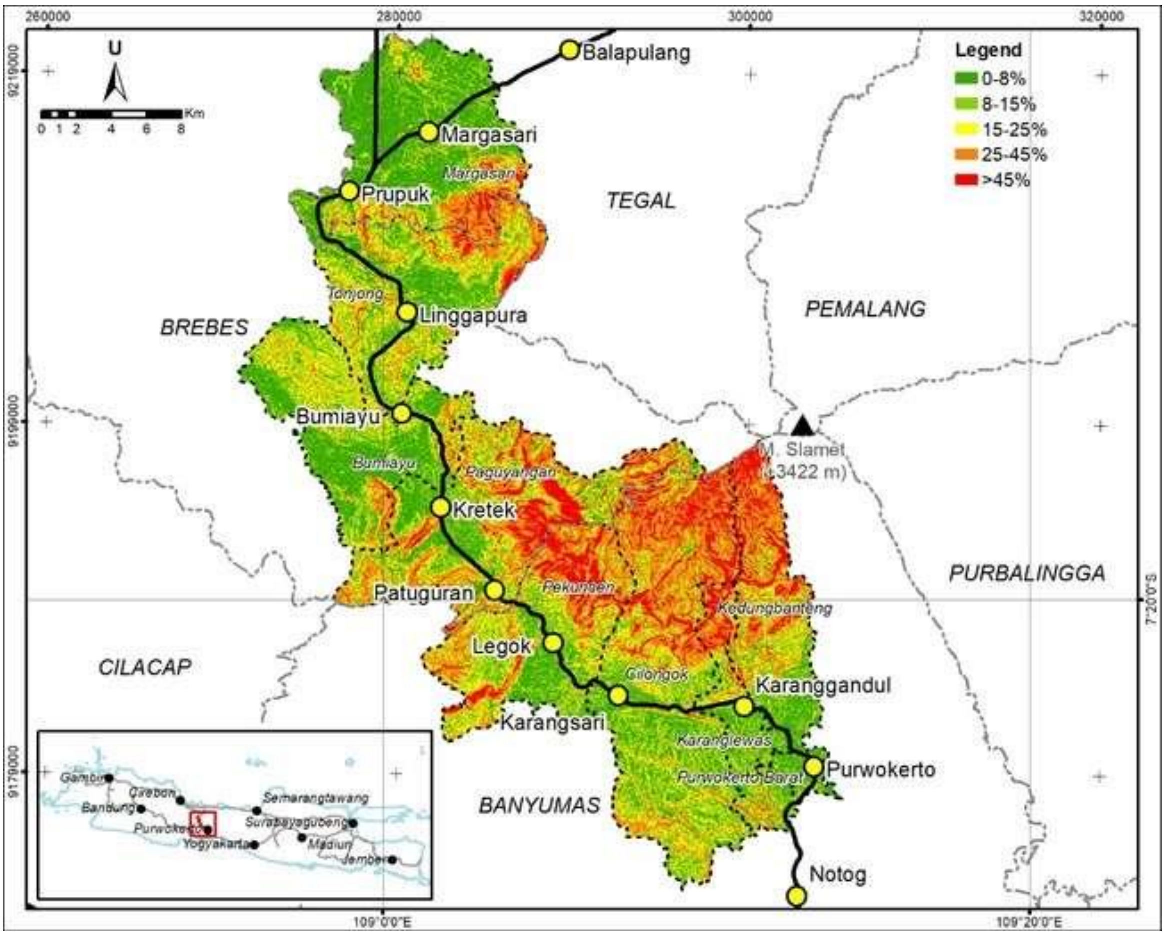


**Figure 3** Slope Maps

The results of the slope inclination map in Figure 3 show that 21% of the study area has a slope of 15 to 25 percent and 8.98% has a slope of greater than 45 degrees, which classifies it as very steep near the mountainside area. The area around the railway line dominated with a slope of 0 to 15 percent, indicated with green color on the map.

### 3.4. Rainfall Map

Rainfall data is one of the essential parameters that will be able to determine how big the chance and location of landslides will be. However, Indonesia's uneven distribution of rainfall observation stations is still an obstacle. CHIRPS (Climate Hazards Group InfraRed Precipitation with Stations) is present as an alternative because the results of analysis from satellites with a resolution of 5 km have advantages over other data [20]. The data used is monthly data for 2012 – 2022 downloaded from the CHRIPS website, and then the average annual rainfall is calculated. The map result is shown in Figure 4. below.

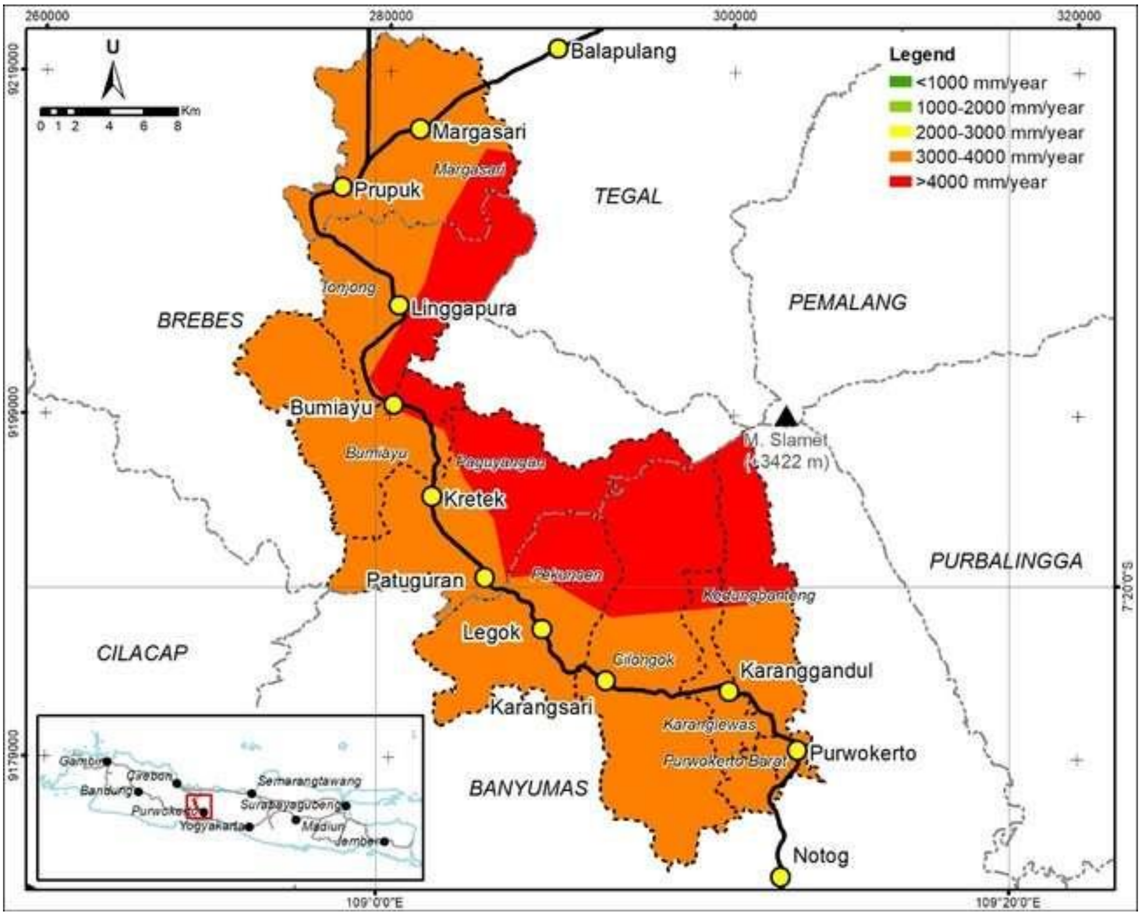


**Figure 4** Rainfall Map

The results of the rainfall map in Figure 4 show that all areas of the railway line have rainfall above 3000 mm per year. This indicates that the precipitation rate at the study site is high and very high or very wet. High intensity and duration of rainfall is one of the key triggering factors combined with the type of soil types, lithologies, the slope of the terrains, and land use of the area.

### 3.5. Lithology Map

Lithology maps are used to determine rock characteristics based on the formation process that influences the vulnerability of landslides in the area. Certain types of lithology, or rock and soil types, are more prone to landslides than others due to their inherent characteristics. In areas where the rock hardness is weak, the slope deformation and failure effect are intensified, and the area is prone to landslides [21]. Volcanic sedimentary rocks and sedimentary rocks composed of fine volcanic particles and mixtures of gravel will quickly become soil due to weathering processes and are very vulnerable to landslides on a steep slope [17]. The lithology map used in this study is 1:250.000 scale data issued by the Ministry of Energy and Mineral Resources. Figure 5 show the lithology map produced by obtained data. From the figure and GIS processing data, it was known that 33.86% of the study area was loose sediment (indicated by yellow color), which was very vulnerable to landslide, and 48.86% (indicated by orange color) was solid sediment, which was considerably vulnerable to a landslide.

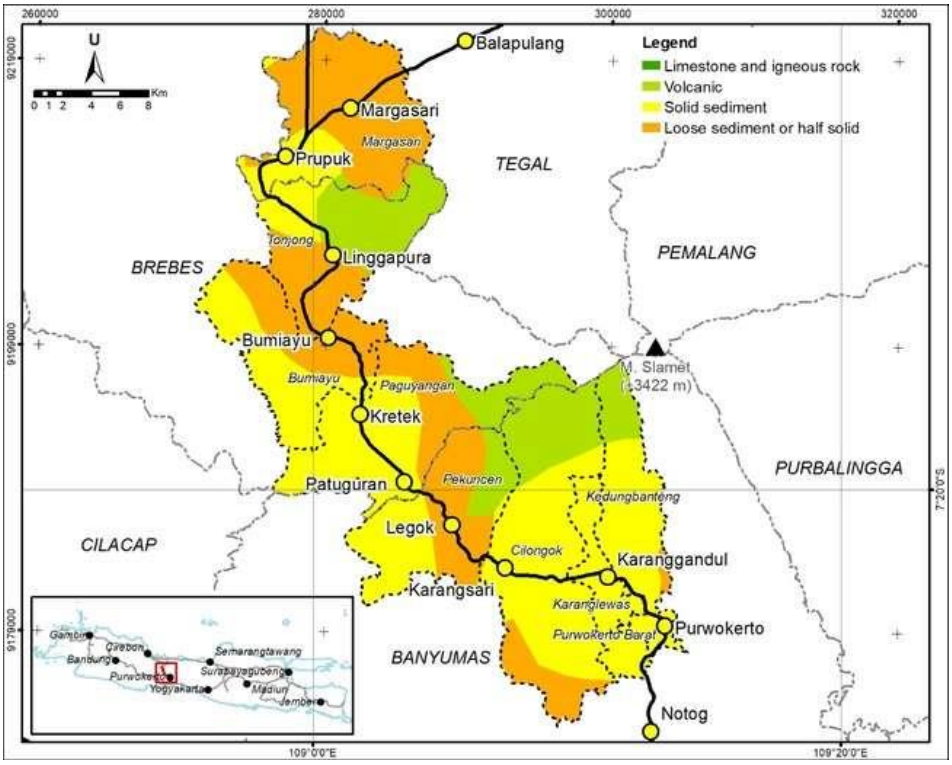


**Figure 5** Lithology Map

### 3.5. Landuse Map

Land use results from human efforts towards land use to meet various needs and have opportunities for potential landslide disasters (8). The land use map used comes from the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency at a scale of 1:10000. The results of the land use map can be seen in Figure 7 below.

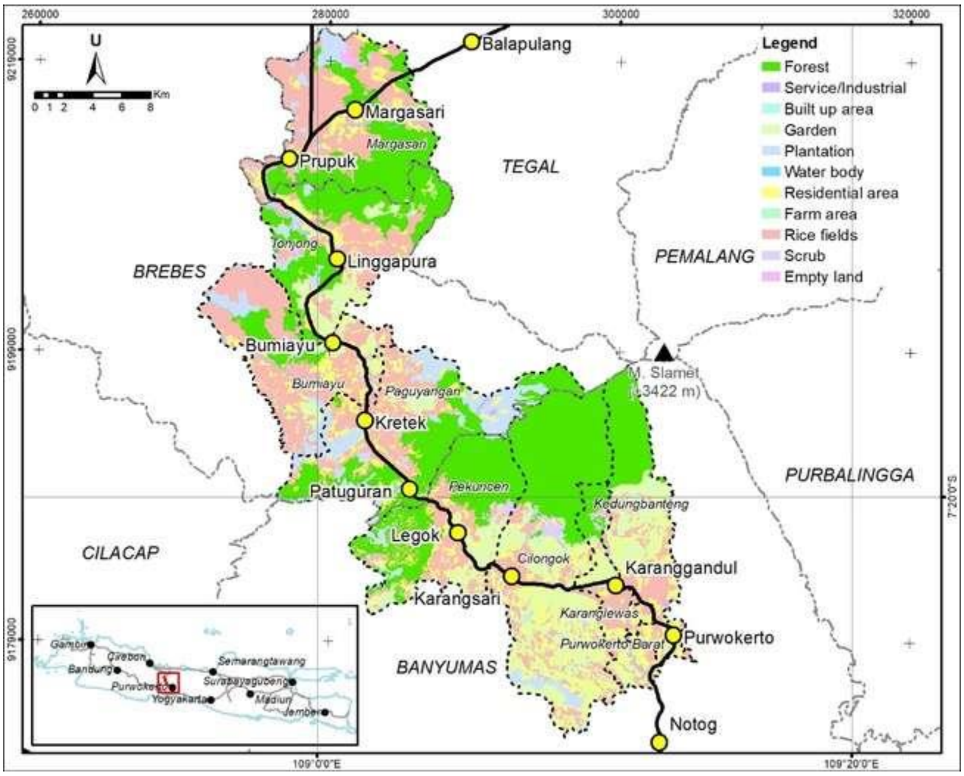


**Figure 6** Landuse Map

The land use map in Figure 6 shows that 0.24% of the land includes open land, 0.36% includes services/industries, and 0.12% includes built-up areas. From the results, it can be concluded that most of the railway lines are in paddy fields and mixed gardens.

### 3.6. Landslide Susceptibility Map

Determination of the potential level of landslide hazard in the study area is based on a model for estimating landslide-prone areas by the Center for Volcanology and Geological Hazard Mitigation (PVMBG), which was compiled in 2004, namely: Landslide Prone = (30% x factor of rainfall class) + (20% x factor lithology class) + (20% x soil type class factor) + (15% x land use class factor) + (15% x slope class factor)

Determination of landslide vulnerability classification class is divided into five categories: very low, low, medium, high, and very high. Determination of the score interval is determined by a relative approach by determining the maximum and minimum scores, then dividing by the number of classes. The results of the map preparation can be seen in the following figure.

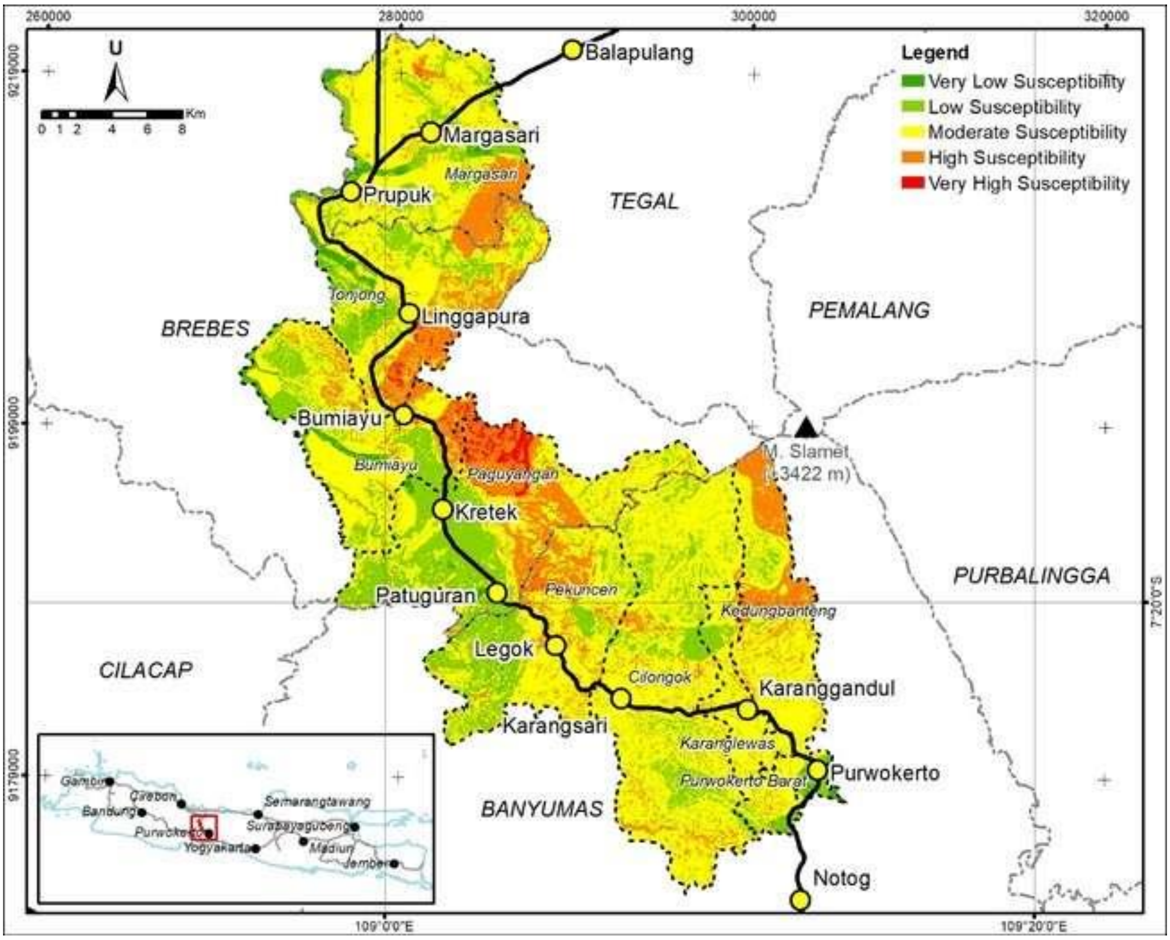


**Figure 7** Land Susceptibility Map

The results of the distribution of landslide susceptibility levels in Figure 7 shows that of the entire area, 0.94% includes areas with very high landslide potential, 17.51% has high potential, 56.49% medium potential, 23% low potential, and 2.06% has very low potential. A detailed description of the railway line vulnerability can be seen in Figure 8.

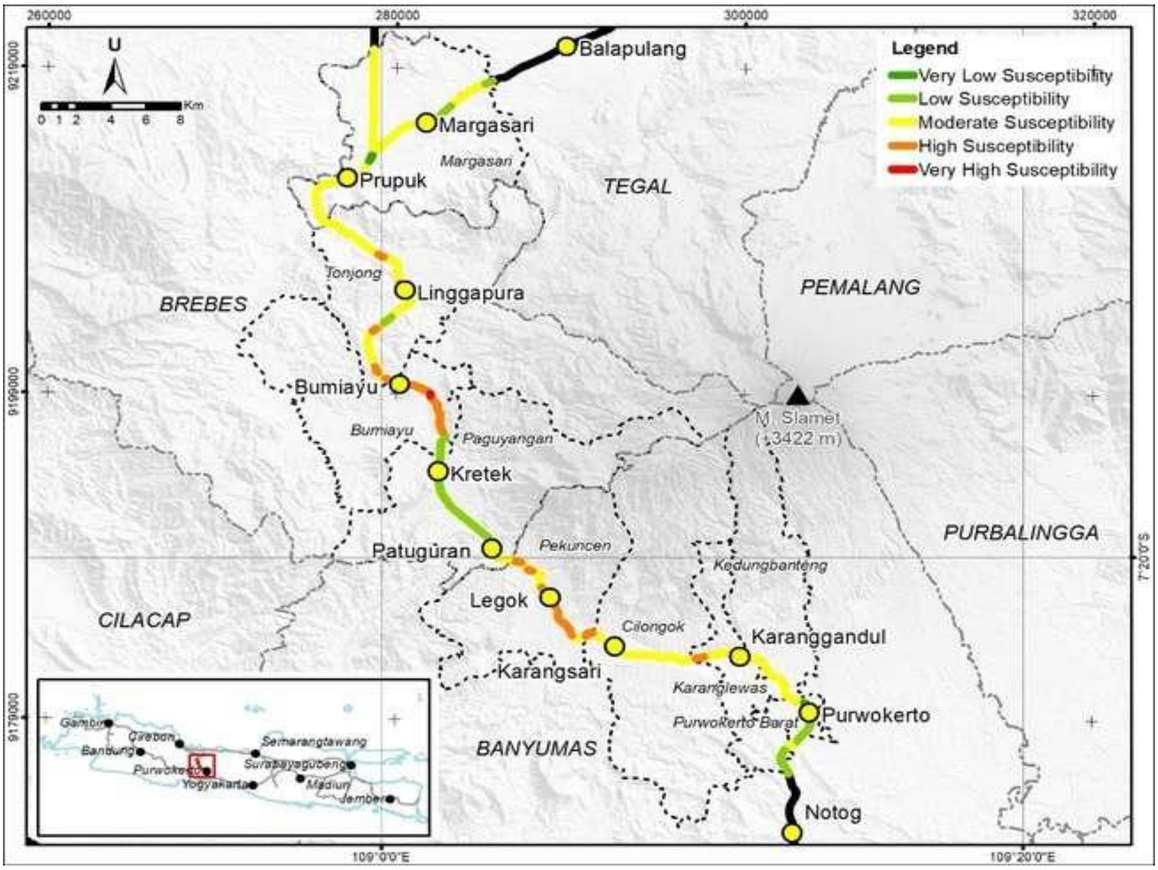


**Figure 8** Landslide Susceptibility of Railway Line

Figure 8 shows the landslide susceptibility map for railway lines summarised as 1.10% very low, 17.29% low, 63.16% medium, 18.25% high, and 0.21% very high. The location of the landslide susceptibility varies along the railway. For instance, the exceptionally high landslide susceptibility results located at railway line kilometers 314+393 to 314+510 as 117 m between Bumiayu Station and Kretek Station. Based on the results, train operators in the study location can provide information systems, landslide monitoring, and mitigation in railway lines.

This research primarily used secondary data from online resources to develop the models. Assessment of landslide history along the location is needed to validate the accuracy of the model [4]. Furthermore, a detailed investigation of the soil type, rainfall, land use, and especially slope inclination is needed to improve the accuracy of the models. The weighting of each parameter can also be improved by using the Analytical Hierarchy Method (AHP) to increase the precision of the prediction model [22] [23]. More parameters that can contribute to landslide vulnerability can also be added to the next model, such as slope aspect, altitude, curvature, solar radiation, topographic wetness index, and distance from rivers and roads [12]. The model can also expanded to accommodate seismic and vulcanic activity [24], considering the location of the railway line was in the highlands (west mountainside of Mount Slamet).

This research identified that 18 percent of the railroad in the research area was located in a vulnerable landslide. An assessment of possible measures to reduce potential consequences is needed. This measure could include proper land-use planning, slope stabilization measures, and early warning systems should be carried out to reduce the risk associated with landslide vulnerability [25].

## 4. CONCLUSION

The results of the distribution of landslide susceptibility levels for each landslide vulnerability parameter: rainfall, slope inclination, lithology, soil types, and land use were described on each map. The results of landslide susceptibility from the prediction models described the landslide vulnerability, which consists of km, distance, and susceptibility criteria. The results are 0.6 km as very low with a percentage of 1.10%, 9.6 km as low with a percentage of 17.29%, 35 km as medium with a percentage of 63.16%, 10 km as high with a percentage of 18.25%, and 0.1 km as very high with a percentage of 0.21%. A very high landslide susceptibility was located at kilometers 314+393 to 314+510 between Bumiayu Station and Kretek Station. This research can be used as a reference for operators to carry out necessary soil improvements, especially for areas with a high potential for landslides.

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**REFERENCES**

[1] D. P. Umum, “Pedoman Penataan Ruang Kawasan Rawan Benncana Longsor PM No.27/PRT/M/2007,” no. 21. 2007.

[2] Badan Standardisasi Nasional, “Penyusunan dan Penentuan Zona Kerentanan Gerakan Tanah,” *Sni*, vol. 8291, no. 2016. pp. 1–7, 2016.

[3] S. Selaby, E. Kusratmoko, and A. Rustanto, "Landslide Susceptibility in Majalengka Regency, West Java Province," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 884, no. 1, 2021, doi: 10.1088/1755-1315/884/1/012053.

[4] S. I. Gumilang, Sutoyo, and H. Putra, "Landslide analysis in the Cisarua District using geographic information system," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 871, no. 1, 2021, doi: 10.1088/1755-1315/871/1/012049.

[5] M. Latif and A. Hakam, "Analisis Tingkat dan Sebaran Bencana Tanah Longsor di Kabupaten Bengkulu Tengah Analysis of the Level and Distribution of Landslide Disasters in Bengkulu Tengah Regency," vol. 11, no. 2, pp. 217–226, 2023.

[6] R. Rahmad, S. Suib, and A. Nurman, “Aplikasi SIG Untuk Pemetaan Tingkat Ancaman Longsor Di Kecamatan Sibolangit, Kabupaten Deli Serdang, Sumatera Utara,” *Maj. Geogr. Indones.*, vol. 32, no. 1, p. 1, 2018, doi: 10.22146/mgi.31882.

[7] D. R. DIAH KIRANA KRESNAWATI, dan DESSY APRIYANTI, “Analisis dan Pembuatan Peta Daerah Potensi Longsor di Kabupaten Bogor Tahun 2019 Menggunakan Metode Pembobotan pada Sistem Informasi Geografis (Analysis And Map Of The Potential Longsor Area At Bogor in 2019 Using Weighting Methods On Geographic Informati,” *J. Tek. | Maj. Ilm. Fak. Tek. UNPAK*, vol. 21, no. 2, 2021, doi: 10.33751/teknik.v21i2.3277.

[8] R. Wiranandar and E. D. Mayasari, “Analisis Tingkat Kerawanan Longsor Menggunakan Sistem Informasi Geografis (Sig) Pada Daerah Tugumulya Dan Sekitarnya Kecamatan Darma Kabupaten Kuningan Provinsi Jawa Barat,” *Appl. Innov. Eng. Sci. Res. 13*, pp. 451–457, 2021.

[9] A. Y. Effendi and T. Hariyanto, “Pembuatan Peta Daerah Rawan Bencana Tanah Longsor dengan Menggunakan Metode Fuzzy logic,” *J. Tek. ITS*, vol. 5, no. 2, pp. A714–A722, 2016.

[10] A. Kurniawan, “Identifikasi Daerah Rawan Tanah Longsor Megunakan SIG,” *J. ITS*, vol. 3, no. 2, 2010.

[11] B. Sulistyo, “Peranan Sistem Informasi Geografis Dalam Mitigasi Bencana Tanah Longsor,” *Google Sch.*, no. March, pp. 1–1, 2016, doi: 10.13140/RG.2.2.16705.97128.

[12] H. A. Azizi, H. Asupyani, F. Akbar, and N. Sulaksana, "Landslide Zoning with GIS Analysis Method: Case Study Cipelah and Its Surroundings Area, Rancabali Subdistrict, Bandung Regency, West Java," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 412, no. 1, 2020, doi: 10.1088/1755-1315/412/1/012023.

[13] V. P. WICAKSONO, “Pemodelan Potensi Longsor Lereng Pada Ruas-Ruas Jalan Di Wilayah Kota Semarang,” 2023.

[14] Z. B. Harwinda *et al.*, “Inovasi Pemanfaatan Data Geospasial Kementerian PUPR (Studi Kasus: Analisis Kerawanan Longsor Ruas Jalan Nasional di Provinsi Yogyakarta),” pp. 1–9, 2019.

[15] F. W. Istiaji and A. L. Nugraha, “Analisis Zona Kerawanan Longsor pada Jalur Kereta Api Semarang - Pekalongan (Studi Kasus: Stasiun Semarang Tawang–Stasiun Pekalongan),” *J. Geod. UNDIP*, vol. 6, no. 3, pp. 87–96, 2017.

[16] PVMBG, “Peta Perkiraan Terjadinya Gerakan Tanah pada Jalur Jalan Provinsi Jawa Tengah,” 2012. https://vsi.esdm.go.id/index.php/kegiatan-pvmbg/download-center/doc_download/6410-jawa-tengah-mudik-lebaran-2022.

[17] F. Muzakki, B. Tjahjono, and D. P. T. Baskoro, “Analisis Bahaya Longsor di Area Rencana Pembangunan Jalur Kereta Cepat Jakarta-Bandung CK 88-CK 114 (Studi Kasus Kabupaten Bandung Barat),” *Semin. Nas. Geomatika*, vol. 3, p. 1071, 2019, doi: 10.24895/sng.2018.3-0.999.

[18] Priyono, “Hubungan klasifikasi longsor, klasifikasi tanah rawan longsor dan klasifikasi tanah pertanian

rawan longsor," *Gema,* vol. 27, no. 49, pp. 1602–1617, 2015.

[19] P. Batumalai, N. S. Mohd Nazer, N. Simon, N. Sulaiman, M. R. Umor, and M. A. Ghazali, "Soil Detachment Rate of a Rainfall-Induced Landslide Soil," *water*, vol. 15, no. 12, p. 2149, 2023, doi: 10.3390/w15122149.

[20] H. Setiawan, A. Wibowo, and Supriatna, "Pembuatan Peta Curah Hujan Untuk Evaluasi Kesesuaian Rencana Tata Ruang Hutan Kabupaten Bogor," *Geomedia*, vol. 19, no. 2, pp. 113–121, 2021, [Online]. Available: https://journal.uny.ac.id/index.php/geomedia/article/view/43227/16848.

[21] X. Yu, K. Zhang, Y. Song, W. Jiang, and J. Zhou, "Study on landslide susceptibility mapping based on rock–soil characteristic factors," *Sci. Rep.*, vol. 11, no. 1, pp. 1–27, 2021, doi: 10.1038/s41598-021-94936-5.

[22] N. Amin, S. A. Lias, and A. Ahmad, "Potential landslide-prone areas in the Kelara sub-watershed using the analytical hierarchy process method," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 807, no. 2, 2021, doi: 10.1088/1755-1315/807/2/022080.

[23] Muzani, *Bencana Tanah Longsor: Penyebab dan Potensi Longsor*. 2021.

[24] L. M. Highland and P. Bobrowsky, "The landslide Handbook - A guide to understanding landslides," *US Geol. Surv. Circ.*, no. 1325, pp. 1–147, 2008.

[25] F. Nadim and S. Lacasse, "Strategies for mitigation of risk associated with landslides," no. July, pp. 1–28, 2015.