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Application of Geospatial Technology for Landslide Risk Mapping Using Weighted Overlay Method in Bogor

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Abstract
Bogor Regency has a high risk of landslides due to geological factors, steep slopes, high rainfall, and changes in land use. This study analyzes the distribution of landslide risk using a Geographic Information System (GIS) with four main parameters (geology, rainfall, slope, and land use) that are weighted and overlaid using ArcGIS. The results show that the southern part of Bogor, especially Cigudeg, Nanggung, Leuwiliang, and Pamijahan, is at high risk due to a combination of geological and climatic conditions. The resulting landslide risk map provides important input for local governments in spatial planning, land management, and community preparedness. This study highlights the important role of geospatial technology in supporting evidence-based mitigation strategies and sustainable development in disaster-prone areas.
Keywords: Landslide, Geospatial Technology, Weighted Overlay Analysis

INTRODUCTION

Landslides are one of the most destructive geological disasters that occur in almost all tropical regions with mountainous topography. Their impact not only threatens human lives but also causes significant socio-economic and environmental losses Budhu (2011). In Indonesia, West Java is one of the regions most frequently affected by landslides due to its young volcanic geology, high annual rainfall, and steep slopes (Hidayat et al., 2019). Bogor Regency is one of the areas with the highest vulnerability, marked by frequent landslides, especially in the southern region, which has rugged topography and intensive land use. At least 286 landslides occurred in Bogor Regency in 2024. This figure shows the magnitude of the threat faced by the people of Bogor Regency from landslides. As population growth and urbanization increase, changes in land use in Bogor Regency further increase the potential for landslides. The conversion of forests into agricultural land and settlements contributes to a decrease in slope stability (Sittadewi et al., 2024). In a global context, various studies show that a combination of lithology, rainfall, topography, and human activity are the main determinant of landslides (Lombardo et al., 2016). Therefore, landslide risk analysis requires the spatial integration of these parameters to produce accurate and applicable vulnerability maps.

Landslide risk mapping methods have evolved from heuristic approaches to data-based quantitative approaches. Statistical models such as frequency ratio and logistic regression are widely used to understand the relationship between causal factors and actual landslide events (Hidayat et al., 2019; Lombardo et al., 2016). On the other hand, the analytical hierarchy process (AHP) and multi-criteria decision analysis (MCDA) approaches have also proven effective in integrating vulnerability parameters with specific weightings (Mengstie et al., 2024). However, these methods often require detailed landslide inventories, which are still limited at the district level. In this context, the use of Geographic Information Systems (GIS) with weighted overlay techniques is important because it is simpler, faster, and can utilize spatial data officially available from government agencies. This approach allows researchers to classify risks based on a combination of geological scores, rainfall, slope, and land use (Rana et al., 2025; Setiawan & Wibowo, 2023). Azizi et al. (2020) emphasize that the integration of geospatial data with overlay methods can be an important basis for disaster mitigation strategies because it can identify priority zones more efficiently.

Although there has been considerable research on landslides in West Java, most of it has focused on vulnerability analysis using statistical approaches or post-disaster studies. Relatively few studies specifically integrate official data from the Geospatial Information Agency (BIG) and the Meteorology, Climatology, and Geophysics Agency (BMKG) into risk analysis using simple overlay methods that are easily understood by local stakeholders. This indicates a research gap in the provision of risk maps based on national data that can be directly utilized in regional development planning. Based on this background, this study aims to analyze landslide risks in Bogor Regency through the integration of geological data, rainfall, slope inclination, and land use using the weighted overlay method. This study is expected to produce a landslide risk map with three zone categories (low, medium, high) that can be used as a reference for local governments in spatial planning, land management, and increasing community preparedness. The novelty of this study lies in the integrated use of official national geospatial data with the overlay method to produce evidence-based risk maps, which also strengthen disaster mitigation strategies in landslide-prone areas.

RESEARCH METHODS

This study uses the weighted overlay and scoring methods in Geographic Information Systems (GIS). This method is carried out by classifying each parameter, namely geology, rainfall, slope, and land cover into three vulnerability classes (low, medium, high). Each class is scored on a scale of 1–5, where the highest score indicates a greater level of vulnerability to landslides. Furthermore, each parameter is weighted based on its level of influence on landslide potential with reference to the literature, namely geology 25%, rainfall 25%, slope 30%, and land use 20% (Rana et al., 2025; Azizi et al., 2020). The data used consists of geological maps obtained from BIG, annual rainfall maps from BMKG, slope maps generated from a 30 m resolution Digital Elevation Model (DEM), and land use maps from BIG covering forests, settlements, rice fields, plantations, and moorlands. In addition, landslide event inventories from the National Disaster Management Agency (BNPB) and the Bogor Regency Disaster Management Agency (BPBD) were used as validation data to test the accuracy of the risk mapping results.

Cumulative Score = (25% x Rainfall Factor) + (30% x Slope Factor) + (20% x Land Use Factor) + (25% x Geological Factor). The landslide risk map is classified into three categories: green (low landslide risk), yellow (medium risk), and red (high risk). This weighting is in line with the Multi-Criteria Decision Making (MCDM) approach, such as AHP, which also relies on the weighting of causal factors (Tesfa & Sewnet, 2024). This classification is obtained based on the determination of each hazard class interval using the following formula (Suharyadi, 2008).

$$NI = \frac{(N_{Max}) - (N_{Min})}{Jk}$$

Where NI is Interval Value, N_{Max} is Maximum Value, N_{Min} is Minimum Value, and J_k is Number of Classes.

Study Area

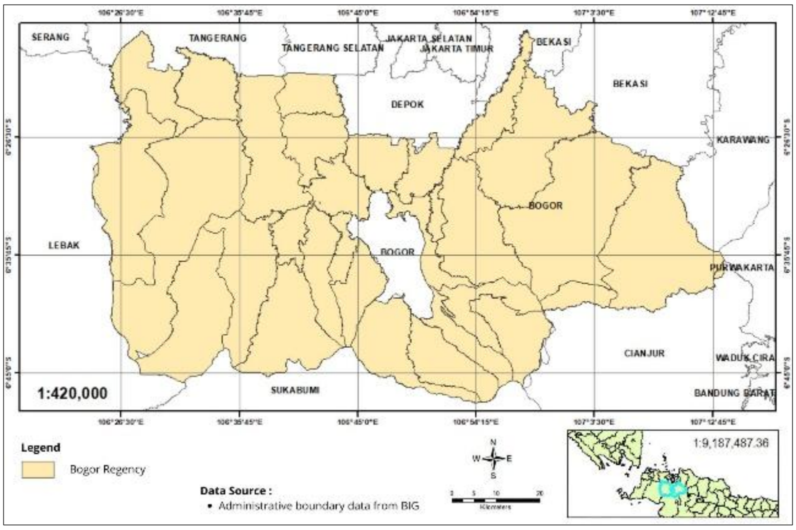


Figure 1. Research Area Map

The research location was Bogor Regency, West Java, located between 6°18'–6°47' south latitude and 106°23'–107°13' east longitude, with an area of ±2,664 km². Bogor Regency was chosen because it has hilly to mountainous topography with an altitude of 100–3,000 meters above sea level, annual rainfall >3,500 mm, and young volcanic lithology, which makes it prone to landslides (Hidayat et al., 2019). The southern part of Bogor Regency, particularly the subdistricts of Cigudeg, Nanggung, Leuwiliang, and Pamijahan, is known as the area most frequently affected by landslides

RESEARCH RESULTS AND DISCUSSION

Analysis using multiple criteria or multiple data to obtain risk classifications and safe zones and find suitable areas. The classification refers to (Muhammadi et al., 2019). The following are the scores for each parameter:

Table 1. Geological Scoring of Bogor Regency

Geological	SPL	Score	Area(ha)	Percentage (%)
Volcanic rocks, Breccia, agglomerate, tuff, and lava are basaltic andesite, containing sandstone, shale, and limestone intercalations.	2, 4, 6, 8, 9, 10, 12, 13, 14, 15, 16	4	4.208,46	68,81
Volcanic rocks: tuff, lapilli tuff, breccia, lava, and lava are andesitic in nature and contain many pumice fragments.	1, 3, 5, 7, 11	3	1.907,18	31,19
Young volcanic rocks; lava, bombs, lapilli, and ash	-	2	-	-
Sediment deposits and old rivers; sand, silt, and clay	-	1	-	-
Total Area			6.115,64	100

Table 2. Rainfall scoring for Bogor Regency

Rainfall (mm/year)	SPL	Score	Area(ha)	Percentage (%)
>4000 (Very Wet)	-	5	-	-
>3000-4000 (Somewhat Wet)	1 to 16	4	5.458,28	89,35
>2000-3000 (Moderate)	3, 5, 6, 7, 8	3	657,36	10,75
>1000-2000 (Somewhat Dry)	-	2	-	-

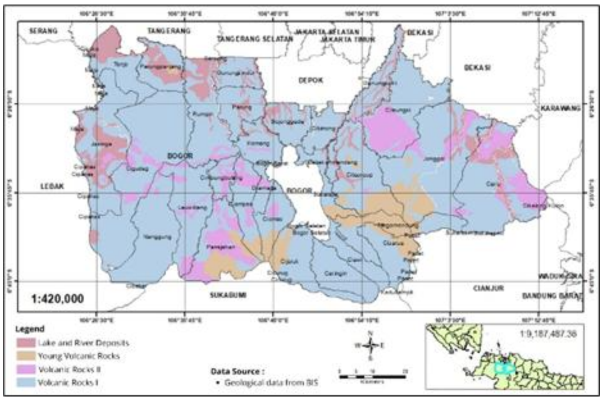
<1000 (Dry)	-	1	-	-
Total Area			6.115,64	100

Table 3. Land Use Scoring for Bogor Regency

Land Use	SPL	Score	Area(ha)	Percentage (%)
Rice fields and lakes	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	5	861,22	14,08
Scrubland	6, 7, 8, 10, 12, 13, 14, 15, 16	4	451,26	7,38
Forests and plantations	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	3	3.680,76	60,19
Settlements	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15	2	1.122,40	18,35
Fish ponds, reservoirs, and waterways	-	1	-	-
Total Area			6.115,64	100

Table 4. Slope gradient scoring in Bogor Regency

Gradient Slope (%)	SPL	Score	Area(ha)	Percentage (%)
0-8 (Flat)	1, 2	5	108,46	1,77
>8-15 (Gentle Slope)	3, 4, 9	4	684,29	11,19
>15-25 (Moderately Steep)	5, 6, 10, 11, 14	3	1.820,81	29,77
>25-45 (Steep)	7, 8, 12, 15	2	3.126,06	51,12
>45 (Very Steep)	13, 16	1	376,02	6,15
Total Area			6.115,64	100



Fihure 2. Geology of Bogor Regency

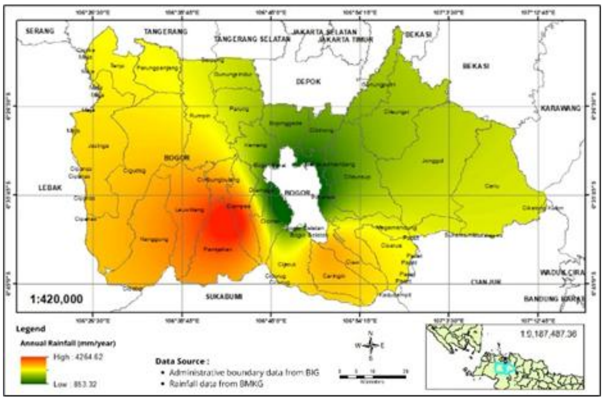


Figure 3. Rainfall in Bogor Regency

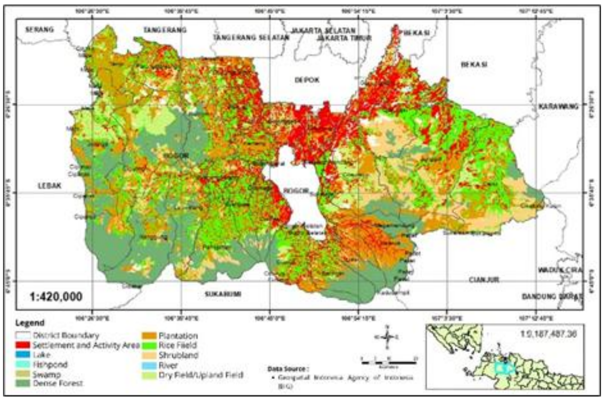


Figure 4. Land use in Bogor Regency

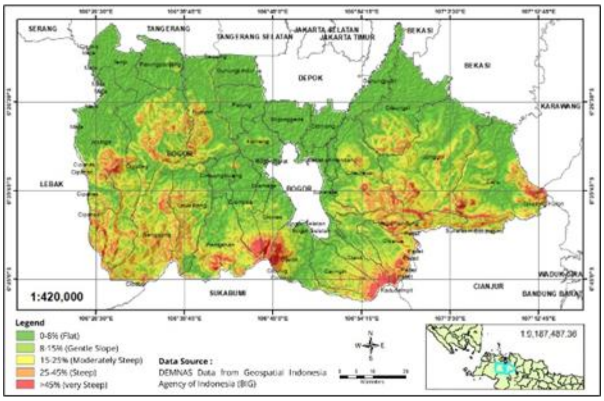


Figure 5. Slope Gradient in Bogor Regency

Discussion

Geology

Most of the Bogor Regency area consists of volcanic rocks in the form of breccia, agglomerate, tuff, and lava with an andesite-basalt composition interspersed with sandstone, shale, shale, and limestone. This lithology dominates 4,208.46 ha or 68.81% of the area. These rocks are generally highly weatherable and have moderate to low cohesion, making them highly susceptible to weathering and mass movement on steep slopes with high rainfall. The geological score for this category is 4, which means that the risk of landslides is quite high. Meanwhile, the second type of lithology that is quite widespread is volcanic rock in the form of tuff, lapilli tuff, breccia, lava, and lava with andesite composition with pumice fragments, covering 1,907.18 ha or 31.19% of the area. This type of rock scored 3, indicating a moderate level of vulnerability. Geotectonically, tuff and lava rocks tend to be easily eroded and experience strength degradation when saturated with water. This explains why areas with volcanic lithology, such as this, especially in the western and central parts of Bogor Regency, still have significant landslide potential, although not as significant as areas dominated by breccia and agglomerate. When viewed in relation to the geological map in Figure 2(a), it can be seen that volcanic lithology dominates almost the entire Bogor Regency, while old alluvial deposits and young volcanic rocks do not occupy a significant area. This pattern is consistent with the location of Bogor Regency in the volcanic mountain zone of West Java. The combination of volcanic rock dominance, high rainfall, and undulating to steep topography makes this region highly prone to landslides, especially in the southern parts such as Cigudeg, Nanggung, Leuwiliang, and Pamijahan. Therefore, geological aspects are a fundamental factor that reinforces the results of landslide risk analysis, where rapidly weathered volcanic rocks play a major role in determining the vulnerability of the region.

Rainfall

Based on the scoring results in Table 2, Bogor Regency is dominated by areas with high rainfall in the moderately wet category (>3000–4000 mm/year), covering 5,458.28 ha or 89.35% of the total area. This condition places almost the entire Bogor Regency in a high level of vulnerability to landslides because intensive rainfall can increase soil saturation, weaken slope strength, and accelerate the weathering process of volcanic rocks, which dominate the local lithology. Meanwhile, areas with moderate rainfall (2000–3000 mm/year) only occupy 657.36 ha or 10.75% of the total, with a score of 3. There are no areas classified as very wet (>4000 mm/year) or moderately dry to dry (<2000 mm/year), so rainfall in Bogor is generally of medium to high intensity. The rainfall map in Figure 2(b) shows a spatial distribution that is consistent with the tabulation results, where the western and southern parts of Bogor Regency show higher rainfall intensity than the northern and eastern parts. Southern areas such as Cigudeg, Nanggung, Leuwiliang, and Pamijahan appear in red-orange, representing high rainfall, consistent with the areas mentioned in the abstract as the most landslide-prone areas. In contrast, the eastern region has relatively lower rainfall (green-yellow), although it remains in the moderately wet category. This confirms that climatic factors, particularly high rainfall intensity, are one of the dominant triggers that increase the risk of landslides in Bogor Regency, especially when combined with volcanic geological conditions and steep slope topography.

Land Use

Based on the land use scoring results in Table 3, it can be seen that forests and plantations dominate Bogor Regency with an area of 3,680.76 ha or 60.19% of the total research area. This condition essentially provides benefits in maintaining soil stability because vegetation can reduce the rate of erosion. However, the score, which is in the moderate category, indicates that the area still has potential vulnerabilities, especially if it is located on steep slopes and is not managed sustainably. On the other hand, settlements rank second with an area of 1,122.40 ha (18.35%) and a low score. The high level of human activity in this area has the potential to exacerbate land degradation due to land use change, which reduces soil absorption and increases the risk of landslides. In fact, research shows that urban areas can be up to ten times more prone to landslides than non-urban areas when triggered by rainfall, mainly due to topographical modifications and loss of vegetation cover (Johnston et al., 2021). The land use map in Figure 2 (c) reinforces the findings from the table by showing a fairly clear spatial distribution. The southern part of Bogor Regency is dominated by forests and plantations, but geomorphologically, this area also has steep slopes and high rainfall, so the potential for landslides remains high even though vegetation dominates. Meanwhile, the central and northern areas show an increasingly dense concentration of settlements closer to urban areas, such as Depok and Jakarta. The growth of these built-up areas puts pressure on the environmental balance due to the reduction of absorption areas and increased load on slopes.

Gardient Slope

Slope gradient is one of the main determining factors in landslide susceptibility. The data in Table 4 shows that 51.12% of the Bogor Regency area is classified as steep (>25–45%), while 29.77% is classified as moderately steep (>15–25%). Although only 6.15% of the area is classified as very steep (>45%), this area remains critical because it has the potential for large-scale landslides. These findings reinforce empirical evidence from various previous studies. Mahmud et al. (2013), through a case study in Kuala Lumpur, showed that the very steep slope class (>35° or >70%) had the highest weightage score, confirming slope as the most significant conditioning factor. Consistently, Dam et al. (2022) in a study in Uttarakhand, India, also confirmed that slope is the main trigger for landslides, with quantitative results showing the highest frequency ratio in the 30%–45% slope class, which means that the probability of landslides increases sharply at that slope. Slope mapping (Figure 2d) shows a contrasting spatial pattern between the southwestern and northern parts of Bogor Regency. The southern and western areas are dominated by steep to very steep slopes, while the northern part is relatively gentle to flat. This distribution explains why more than half of Bogor Regency is located in a high-risk morphological area. When this factor is combined with geological conditions, rainfall, and land use, the risk picture becomes even clearer: the southern part of Bogor Regency is highly vulnerable to landslides. An integrative analysis of the four parameters of lithology, rainfall, land use, and slope shows that the areas of Cigudeg, Nanggung, Leuwiliang, and Pamijahan are the most vulnerable. Fragile volcanic lithology, high annual rainfall, and human pressure on land cover exacerbate the dominance of steep slopes in these areas. Conversely, although the northern part of Bogor Regency is experiencing urbanization pressure, its gentler morphology makes the risk relatively lower. These findings are in line with the research abstract, which confirms that geospatial technology can produce evidence-based spatial descriptions that are essential for local governments in supporting spatial planning, controlling land use, and formulating mitigation and community preparedness strategies.

Landslide Risk Zone

The spatial distribution of landslide risk zones in Bogor Regency, as shown on the Landslide Risk Zone Map (Figure 3), shows clear variations in vulnerability levels across the region. The classification into three categories low (green), moderate (yellow), and high (red) shows that landslide risk is not evenly distributed, but rather concentrated in the central and southern parts of the regency. The northern region is dominated by low vulnerability levels, which correspond to relatively flat topography (0–8%), lower annual rainfall, and more controlled land use such as productive agricultural areas and urban settlements. These factors collectively reduce slope instability, thereby minimizing the frequency of landslides in this region. This condition is consistent with the findings of previous studies which show that flat areas with stable land use patterns tend to have lower levels of mass movement hazard (Wafid et al., 2025; Chen et al., 2017; Park et al., 2019). On the other hand, the central and southern regions show moderate to high vulnerability, as indicated by the dominance of yellow and red zones on map 3. These regions include subdistricts such as Cigudeg, Nanggung, Leuwiliang, Pamijahan, Cisarua, and Megamendung. The high vulnerability in these zones is mainly due to the interaction between steep to very steep slopes (>25%), fragile volcanic lithology (breccia, agglomerate, and tuff), and annual rainfall exceeding 3,000 mm. These conditions trigger soil saturation, increase gravitational stress, and accelerate weathering processes, which ultimately trigger both shallow and deep landslides. The dominance of volcanic lithology and steep slope morphology is consistent with the regional geotectonic setting of West Java, which has been widely recognized as a landslide-prone area (Hadmoko et al., 2010).

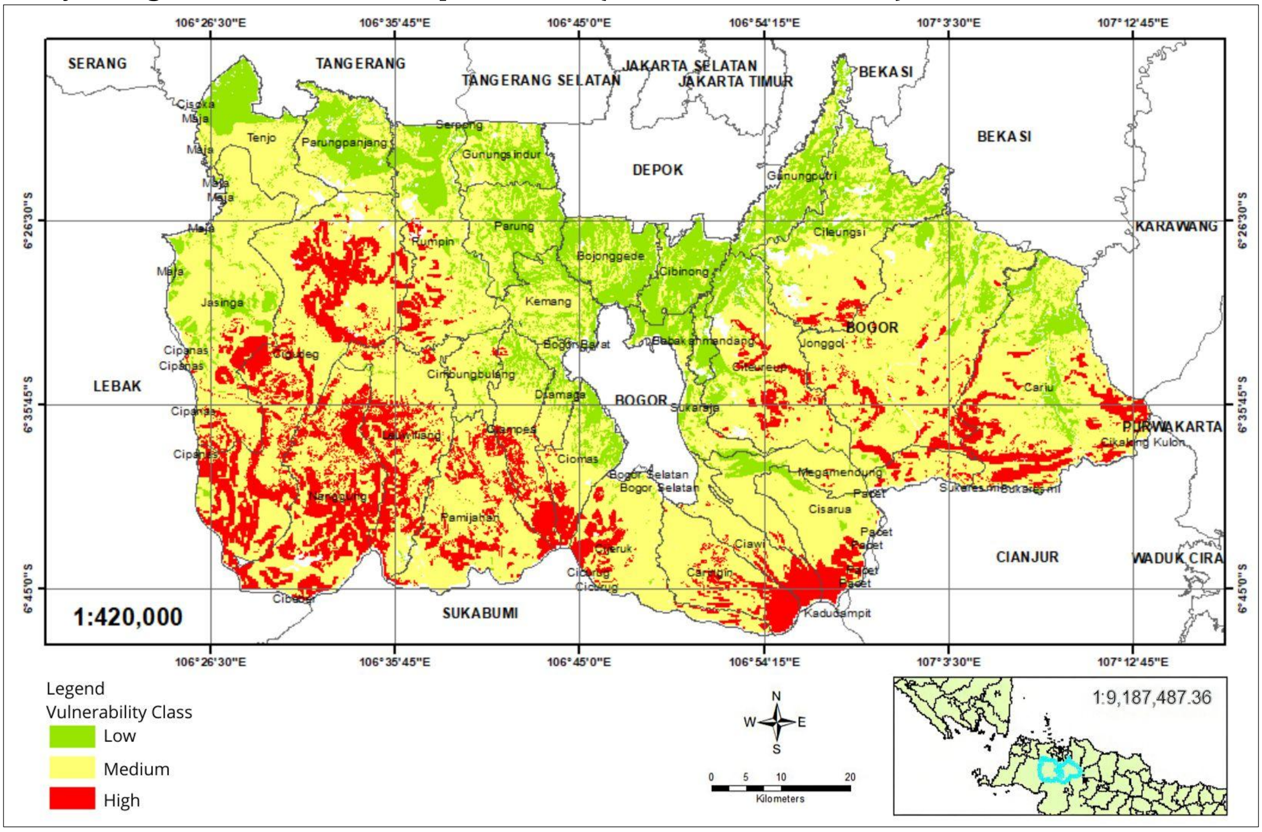


Figure 6. Landslide Risk Zone Map, Bogor Regency

Land use dynamics further exacerbate this vulnerability. Although forests and plantations still dominate the southern region, unsustainable practices such as deforestation, land conversion, and settlement expansion reduce the stability of natural slopes. Dense settlements in these areas put additional pressure on slopes and reduce infiltration capacity, thereby increasing the likelihood of slope failure during prolonged rainfall events. Similar findings have been reported in other tropical regions, where anthropogenic land use changes have been identified as a key factor in increased landslide risk (Glade & Crozier, 2012; Gariano & Guzzetti, 2016). Overall, the integration of geological, climatic, topographical, and anthropogenic factors explains the strong spatial contrast in landslide risk in Bogor Regency. The concentration of high-risk zones in the southern part highlights the urgent need for evidence-based land use planning, stricter enforcement of spatial policies, and increased community preparedness in the region. By combining geospatial analysis with risk zoning, this study provides a scientific basis for local governments to design targeted mitigation strategies to reduce the socio-economic impact of future landslide events.

CONCLUSION

This study shows that the risk of landslides in Bogor Regency is the result of a complex interaction between geological factors, rainfall, land use, and slope inclination. The integration of these four parameters through GIS analysis has successfully mapped landslide-prone zones with a level of accuracy that can be used as a reference in spatial planning and disaster mitigation strategies. The main findings confirm that the southern part of Bogor Regency, such as Cigudeg, Nanggung, Leuwiliang, and Pamijahan, is classified as high risk due to the influence of fragile young volcanic lithology, high rainfall, massive land use changes, and the dominance of steep slopes. This shows that natural and anthropogenic factors reinforce each other in increasing the vulnerability to landslides in these areas. Although this study has successfully presented a useful landslide risk map, there are still limitations in the availability of high-resolution and long-term data, which can affect the detail of the results. Therefore, further research needs to be conducted by incorporating more detailed spatial data, such as high-resolution satellite imagery, long-term rainfall data, and additional variables such as soil conditions and population density. This effort is expected to produce more accurate risk maps while strengthening the scientific basis for the formulation of disaster risk reduction policies in Bogor Regency.

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