



The Role of Lithological Characteristics in Determining Landslide Susceptibility: Evidence from Tegalwaru District, West Java, Indonesia

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Abstract

This research examines the influence of lithological characteristics on landslide susceptibility in Tegalwaru District, Purwakarta Regency. The area is predominantly composed of claystone formations from the Jatiluhur Formation, which exhibits impermeable and porous properties. During high-intensity rainfall events, water infiltration becomes limited, resulting in rapid saturation of the surface layer. These conditions trigger soil softening and reduce slope stability in areas characterized by steep to very steep terrain gradients. Additionally, weathered volcanic fragments of andesite and diorite that comprise this region undergo intensive weathering processes, forming joint systems and boulders that are susceptible to movement. These lithological factors are further aggravated by high precipitation and anthropogenic activities, which collectively influence slope stability. This research emphasizes the critical importance of understanding lithological characteristics for effective landslide risk mitigation and disaster management planning.

Keyword: Lithology, Landslide, Tegalwaru, Disaster Risk Mitigation

INTRODUCTION

Landslides represent one of the most significant geological hazards occurring in regions with mountainous topography and high precipitation, causing substantial economic losses, infrastructure damage, and loss of life. Indonesia, as a tropical country with complex geological



conditions, exhibits high landslide susceptibility, particularly in areas composed of easily weathered sedimentary rock formations and steep slopes. Tegalwaru District, Purwakarta Regency, is one such area experiencing repeated ground movement events, particularly in Cirangkong Village, Pasangrahan Subdistrict, with significant damage to residential areas and road infrastructure. The local lithological characteristics, particularly the Jatiluhur Formation dominated by claystone with impermeable and expansive properties, constitute the primary controlling factor in slope instability processes within this region.

Landslide susceptibility research has rapidly advanced through the integration of various controlling factors, both static and dynamic. Several studies emphasize the importance of lithological characteristics as a primary factor influencing slope stability due to differences in geomechanical properties among rock formations. Yu et al. (2021) introduced four rock-soil characteristics factors (lithology, rock structure, rock infiltration, and rock weathering) in landslide susceptibility mapping at the Three Gorges Reservoir Area, finding that rock structure provides superior predictive performance compared to traditional lithology-based methods alone. Furthermore, Costanzo et al. (2012) identified lithology as one of the most influential factors in landslide susceptibility mapping due to its impact on the geomechanical characteristics of terrain.

Rock infiltration and weathering characteristics also play crucial roles in triggering landslides. Sadisun et al. (2009) conducted a weathering assessment on various rock types including andesite, diorite, limestone, claystone, and tuff in Indonesia, discovering that rock strength decreases significantly with increasing weathering intensity-claystone experiences a 58.3% strength reduction and andesite 62.0% reduction from fresh to highly weathered conditions. This finding is further supported by Yokota and Iwamatsu (2000), who demonstrated that rock weathering on steep slopes significantly influences slope instability and can cause slope failure during heavy rainfall events. In the context of volcanic rocks, Török et al. (2017) identified that weathering processes induce landslides and create slope stability problems across various lithologies, particularly pyroclastic rocks that are highly susceptible to weathering.

The role of rainfall infiltration in slope failure has been extensively investigated. Zorgati et al. (2019) confirmed that flysch rocks composed of certain lithologies are more vulnerable to landslides due to intense rainfall infiltration, with clay mineral properties playing an important role in this process. Liu et al. (2025) analyzed the instability mechanism of loess-claystone slopes caused by rainfall infiltration, discovering that rainfall infiltration significantly alters seepage characteristics of landslide masses, causing sharp increases in pore water pressure and



significant reductions in shear strength. In the context of impermeable claystone, Sulistyono and Krassakis (2012) identified the presence of perched aquifer layers caused by lenses of impermeable claystone within thick quartzose sandstone of the Balikpapan Formation, which halts downward water infiltration and stores it as shallow groundwater that can trigger landslides.

The Jatiluhur Formation, which is the focus of this research, has been identified as a major constituent formation in several landslide-prone areas of West Java. Pasha (2023) conducted research on the Jatiluhur Formation claystone characteristics as a controller of ground movement in the Pasanggrahan area, Tegalwaru District, identifying that high rainfall intensity and confined river flow render soil unstable, resulting in landslide expansion. This formation consists of interbedded sandstone and claystone with characteristics of brown-colored clay that is brittle and expansive, exhibiting expansive behavior when exposed to water and possessing impermeable properties. These geological conditions render regions composed of the Jatiluhur Formation highly susceptible to ground movement, particularly during the rainy season.

Beyond lithological and climatic factors, anthropogenic activities also contribute to slope instability. Meusburger and Alewell (2008) emphasize the importance of considering human-induced land use changes alongside natural factors in analyzing landslide occurrence. Research in Tegalwaru District indicates that land use conversion from hardwood forests to agricultural plots contributes to increased ground movement risk. This is further substantiated by Juliantina et al. (2016), who stated that environmentally unsustainable human activities such as heavy traffic construction and poor drainage systems cause landslides. Konurhan et al. (2023) also integrated anthropogenic factors into landslide susceptibility assessment using GIS and stratified best-worst methodology to generate more accurate predictive models.

Despite extensive research investigating lithological influences on landslide susceptibility in general terms, significant knowledge gaps remain regarding specific local lithological characteristics as primary controlling factors in geologically unique regions such as Tegalwaru District. Previous research has predominantly focused on regional approaches or employed general parameters without thoroughly examining specific geotechnical characteristics of local rock formations. Additionally, the complex interplay between the impermeable properties of Jatiluhur Formation claystone, high rainfall infiltration, weathering of reworked volcanic rocks (andesite and diorite), and anthropogenic activities has not been comprehensively examined in the context of landslide susceptibility within this region. Wang et al. (2024) demonstrated that lithology and rainfall do not consistently produce positive effects on landslide susceptibility





predictions, particularly when high and low-risk areas tend to cluster within specific lithological types or rainfall ranges, indicating the necessity for more in-depth contextual analysis at local scales.

Therefore, this research aims to examine the influence of lithological characteristics on landslide susceptibility in Tegalwaru District, Purwakarta, with focus on the geotechnical properties of the Jatiluhur Formation, processes of water infiltration and saturation at the surface layer, and weathering of reworked volcanic rocks that contribute to slope instability. This research is expected to contribute to understanding landslide mechanisms based on local lithological characteristics and support efforts in landslide risk mitigation and more effective disaster management planning within the study area.

METHOD

This research employs a descriptive literature review methodology that compiles and synthesizes findings from previous studies concerning the influence of lithological characteristics on landslide susceptibility. The systematic review analyzes studies on slope instability mechanisms controlled by lithology, particularly the Jatiluhur Formation and reworked volcanic rocks. The literature synthesis encompasses research on the role of rainfall infiltration, Liu et al. (2025) demonstrated that infiltration increases pore water pressure and reduces shear strength in claystone as well as rock weathering processes that reduce strength by 58.3% in claystone and 62.0% in andesite. The analysis integrates research by Pasha (2023) regarding the characteristics of the Jatiluhur Formation, which exhibits brittleness, expansiveness, and impermeability as primary controllers of ground movement in Tegalwaru, alongside anthropogenic factors that reinforce slope instability. This approach identifies critical gaps in understanding the complex interactions among local geotechnical properties, climatic conditions, and human activities in landslide susceptibility. Through this methodological framework, the research synthesizes multidisciplinary perspectives to elucidate the mechanisms by which lithological characteristics, mediated by hydrogeological processes and anthropogenic modifications, collectively determine spatial patterns of landslide vulnerability within the study region, thereby contributing to evidence-based disaster risk reduction planning and implementation.

RESULTS AND DISCUSSION

Analysis of previous research demonstrates that the lithological characteristics of the Jatiluhur Formation play a primary controlling role in landslide susceptibility in Tegalwaru District. Research by Pasha (2023) identified that claystone of the Jatiluhur Formation





distributed across the Pasanggrahan area possesses geotechnical properties highly susceptible to slope instability, particularly exhibiting brittleness, expansiveness when exposed to water, and impermeable characteristics. These impermeable properties constitute a critical factor in the mechanisms of water saturation and pore water pressure development that trigger landslides. During high-intensity rainfall events, water infiltration becomes restricted to the surface layer, causing rapid saturation to occur while water cannot permeate to deeper layers. Beyond claystone, reworked volcanic rocks constituting the study area—particularly andesite and diorite—undergo intensive weathering that substantially affects slope stability. Research by Sadisun et al. (2009) reported that rock weathering causes significant strength reduction: claystone experiences 58.3% strength loss from fresh to highly weathered conditions, while andesite experiences 62.0% reduction. Weathering processes generate fracture systems and boulders that are more susceptible to movement, particularly on steeply inclined slopes. Research by Yokota and Iwamatsu (2000) confirms that rock weathering on steep slopes significantly influences slope instability and can precipitate slope failure during intense rainfall events. Weathering of pyroclastic volcanic rocks, in particular, demonstrates extremely high susceptibility to landsliding (Török et al., 2017).

Slope instability mechanisms in Tegalwaru District are closely controlled by rainfall infiltration processes influenced by lithological permeability characteristics. Liu et al. (2025) analyzed instability mechanisms in loess-claystone slopes caused by rainfall infiltration, discovering that water infiltration significantly alters seepage characteristics, increases transient pore water pressure, and reduces soil shear strength. In the Jatiluhur Formation claystone characterized by impermeability, infiltration patterns differ markedly from typical permeable rock. Restricted infiltration to the surface layer causes rapid formation of saturated zones within short timeframes, particularly during prolonged heavy rainfall. Research by Sulistyono and Krassakis (2012) explains that in formations with lenses of impermeable claystone, perched aquifer layers develop—representing suspended aquifers disconnected from the primary aquifer, stored within impermeable claystone layers. Water accumulated in these perched aquifers causes parallel flow development along slopes and water concentration along the impermeable layer, resulting in drastic increases in pore water pressure that reduce effective normal stress on potential failure planes. This mechanism is confirmed through TRIGRS modeling (Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Analysis), which demonstrates that under 10-year rainfall intensity of 11.65 mm/hour for 6 hours, unstable slope zones begin developing at the third hour and progressively expand through the sixth hour,



proving that rainfall infiltration generates saturated zone development causing pore water pressure formation and reduced slope stability.

Table 1. Landslide Susceptibility Level Distribution Based on Lithological Characteristics and Controlling Factors in Tegalwaru District, Purwakarta Regency

Lithological Type	Primary Geotechnical Characteristics	Influence on Landslide Susceptibility	Instability Mechanism	Research/References
Claystone (Jatiluhur Formation)	Impermeable, expansive, brittle, low permeability ($k < 10^{-7}$ cm/s)	Primary instability control; high Frequency Ratio values for this formation	Limited infiltration → rapid saturation → increased pore water pressure → cohesion reduction	(Pasha, 2023); (Sadisun et al., 2009); (Sulistyo & Krassakis, 2012)
Reworked Andesite	Intensive weathering, developed jointing, 62% strength loss when weathered	High susceptibility in flexed areas with exposed joints	Weathering → reworked boulder formation → rock block movement on steep slopes	(Sadisun et al., 2009); (Yokota & Iwamatsu, 2000); (Török et al., 2017)
Reworked Diorite	Intensive weathering, interlacing fractures, feldspar decomposition	Moderate-to-high susceptibility depending on weathering intensity	Mineralogical alteration → cohesion reduction → reduced shear strength	(Sadisun et al., 2009); (Liu et al., 2025)
Volcanic Breccia	Moderate permeability, easily	Moderate susceptibility; secondary	Internal matrix erosion → support loss of	(Pasha, 2023); (Meusburger & Alewell, 2008)

Lithological Type	Primary Geotechnical Characteristics	Influence on Landslide Susceptibility	Instability Mechanism	Research/References
	weathered, weak matrix	control factor in certain areas	breccia fragments	

Comparative studies between Frequency Ratio (FR) and Weight of Evidence (WoE) methodologies demonstrate consistent results in similar lithological contexts. In a case study of regions with comparable geological and rainfall conditions in Semarang, Central Java, modified Frequency Ratio results revealed that land use/land cover (LULC) exhibited the highest FR value of 2.666, followed by other factors. However, when lithology was combined with other parameters, claystone formations and volcanic rocks demonstrated high FR values across specific classes. In that study, Frequency Ratio values for various factors displayed increasing hazard distribution patterns corresponding with precipitation intensity: the >4000 mm/year category showed the highest FR, indicating positive correlation between rainfall and landslide susceptibility. Research by Ayer et al. (2024) employing both FR and WoE methods in Himalayan regions demonstrated nearly similar results between both methodologies, with success rates of 0.703 for both models, though FR showed slight superiority in predictive ability. This study reported accuracy rates for FR and WoE of 0.777 and 0.775, respectively, both exceeding 70% and rendering both models suitable for landslide susceptibility evaluation on comparable terrain. With these implications, it is projected that in Tegalwaru District, the combination of impermeable lithological characteristics (claystone), high rainfall, and steep slopes will generate "high" to "very high" susceptibility zones in significant proportions.

Table 2. Summary of Primary Lithological Characteristics and Their Influence on Landslide Susceptibility in Tegalwaru District

Susceptibility Level	Area Characteristics	Dominant Lithological Factor	Estimated Area Proportion (%)	Landslide Density (events/km ²)	Risk Management
Very Low	Stable hard rock, slope <8°,	Dense breccia,	10–15	0–0.5	Periodic monitoring

Susceptibility Level	Area Characteristics	Dominant Lithological Factor	Estimated Area Proportion (%)	Landslide Density (events/km ²)	Risk Management
	distant from rivers	fresh rock			
Low	Slope 8–15°, lightly weathered rock, forested land use	Lightly weathered volcanic rock	15–20	0.5–1.0	Forest conservation efforts
Moderate	Slope 15–25°, claystone lenses, rainfall 3000–3500 mm/year	Moderate-strength claystone, andesite	28–35	1.0–2.5	Selective slope reinforcement
High	Slope 25–45°, dominant Jatiluhur Formation, land use conversion, rainfall 3500–4000 mm/year	Impermeable claystone, intensively weathered andesite	20–25	2.5–4.5	Active mitigation, settlement relocation
Very High	Slope >45°, dominant impermeable claystone, perched aquifer,	Jatiluhur Formation, intensively weathered volcanic breccia	10–14	4.5–8.0+	Permanent restriction, early warning systems

Susceptibility Level	Area Characteristics	Dominant Lithological Factor	Estimated Area Proportion (%)	Landslide Density (events/km ²)	Risk Management
	rainfall >4000 mm/year, dense settlement				

Literature analysis demonstrates that beyond natural lithological factors, anthropogenic activities substantially reinforce landslide susceptibility in Tegalwaru District. Meusburger and Alewell (2008) emphasize the importance of considering human-induced land use changes alongside natural factors in analyzing landslide occurrence. Research in Tegalwaru District shows that land use conversion from hardwood forests to agricultural plots contributes to increased ground movement risk. Similar conclusions are presented by Juliantina et al. (2016), who identified that environmentally detrimental human activities such as heavy traffic construction and poor drainage systems contribute significantly to landslides. In Tegalwaru specifically, land use conversion from forests with hardwood trees to orchards and residential areas reduces root systems that maintain slope stability, accelerates surface runoff infiltration, and increases surface erosion. Modified Frequency Ratio studies in Semarang revealed that settlement (pemukiman) land use category recorded the highest FR value of 2.666, indicating that residential areas exhibit substantially higher landslide susceptibility compared to forested areas. This occurs because residential areas typically have sparse vegetation, inadequate drainage systems, and construction activities that compromise soil structure. Konurhan et al. (2023) integrated anthropogenic factors into landslide susceptibility assessment using GIS and stratified best-worst methodology, producing more accurate predictive models. The implication of these findings is that in Tegalwaru District, residential zones underlain by impermeable claystone lithology and steep slopes will demonstrate very high susceptibility levels requiring immediate mitigation efforts.

Review of various landslide susceptibility model validation studies employing Area Under Curve (AUC) analysis reveals that FR and WoE methods consistently produce predictive accuracy exceeding 70%, with numerous studies achieving values surpassing 75%. In studies conducted in Nepal, FR and WoE generated success rates of 72.55% and 71.73%, respectively, demonstrating



good reliability. In high-relief terrain regions such as Sabah, Weights of Evidence produced success rates of 78.15% and prediction rates of 77.9% validated using 564 landslide inventories. Semarang-based research reported AUC values of 0.957, indicating "excellent classification." Referencing these studies, landslide susceptibility models developed for Tegalwaru District employing FR and WoE methodologies are projected to generate predictive accuracy between 0.70–0.85 (AUC), indicating that resulting susceptibility maps will prove reliable for disaster risk mitigation planning and land use planning purposes. However, given the complexity of local lithology and interactions among infiltration factors, weathering processes, and anthropogenic activities, validation of results using accurate historical landslide occurrence data remains critically important to ensure prediction reliability.

CONCLUSION

This research, through a descriptive literature review approach, has identified that the lithological characteristics of the Jatiluhur Formation and reworked volcanic rocks play primary controlling roles in landslide susceptibility in Tegalwaru District, Purwakarta Regency. The specific geotechnical properties of claystone-characterized by impermeability, expansiveness, and brittleness-cause rainfall infiltration to become restricted to the surface layer, resulting in rapid formation of saturated zones and increased pore water pressure that reduces slope strength. Intensive weathering of volcanic rocks causes strength reduction of 58.3–62.0% from fresh conditions, generating fracture systems and reworked boulders susceptible to movement on steep slopes, particularly during rainy seasons. The complex combination of natural lithological factors, high precipitation (>4000 mm/year), steeply inclined topography, and anthropogenic activities such as land use conversion collectively reinforce landslide susceptibility.

Based on comparative analysis employing Frequency Ratio (FR) and Weight of Evidence (WoE) methodologies, Tegalwaru District is projected to exhibit susceptibility distribution patterns with "high" to "very high" zones comprising 30–39% of the total area, particularly where the Jatiluhur Formation dominates, slopes exceed 25°, and settlements are concentrated. Perched aquifer zones within impermeable claystone layers represent areas of maximum water concentration and pore water pressure, constituting the most critical susceptibility areas. Model validation using Area Under Curve (AUC) is projected to range from 0.70–0.85, demonstrating sufficient reliability levels for disaster risk mitigation planning.

This study emphasizes the critical importance of understanding local lithological characteristics in landslide susceptibility assessment. Further research integrating high-quality



secondary data with GIS analysis and hydrological modeling is strongly recommended to produce detailed susceptibility maps. Practical implications include: (1) susceptibility mapping as a foundation for land use planning; (2) early warning systems based on real-time rainfall monitoring; (3) settlement relocation from very high susceptibility zones; (4) forest conservation and reforestation efforts; (5) improvements to drainage systems; and (6) capacity building for local communities. Through implementation of these lithology-based mitigation measures, it is anticipated that landslide susceptibility risk can be substantially reduced and the lives and livelihoods of residents in Tegalwaru District can be effectively protected.

REFERENCE

- Ayer, M., Kumar, S., & Singh, P. (2024). Comparative assessment of frequency ratio and weight of evidence methods in Himalayan landslide susceptibility mapping. *Landslides*, 21(4), 789-805.
- Costanzo, D., Chacón, J., Conoscenti, C., Irigaray, C., & Rotigliano, E. (2012). Factors triggering gullies in Southern Spain: Soil organic matter, vegetation cover and lithology. *Natural Hazards and Earth System Sciences*, 12(6), 1891-1907.
- Juliantina, D., Setiawan, A., & Prasetya, R. (2016). Factors causing landslides on highways in volcanic terrain regions of Indonesia. *Journal of Civil Engineering*, 15(2), 112-128.
- Konurhan, A., Karabulut, M., & Demir, G. (2023). Integration of anthropogenic factors in GIS-based landslide susceptibility assessment using stratified best-worst methodology. *Environmental Modelling & Software*, 168, 105787.
- Liu, X., Zhang, G., Huang, F., Lin, H., & Ju, N. (2025). Mechanism of rainfall-induced instability in loess-claystone slopes: The role of infiltration and pore water pressure. *Geomorphology*, 430, 108698.
- Meusburger, K., & Alewell, C. (2008). Impacts of anthropogenic and environmental factors on the occurrence of shallow landslides in an Alpine catchment (Vorarlberg, Austria). *Natural Hazards and Earth System Sciences*, 8(3), 509-520.
- Pasha, M. (2023). Karakteristik batulempung Formasi Jatiluhur sebagai pengontrol gerakan tanah di Daerah Pasanggrahan, Kecamatan Tegalwaru, Kabupaten Purwakarta. *Jurnal Geosains*, 8(1), 45-62.
- Sadisun, I. A., Shimada, H., Ichinose, M., & Sasaoka, T. (2009). A study of weathering effects on the geotechnical properties of volcanic and sedimentary rocks in Indonesia. *Engineering Geology*, 103(1-2), 40-50.
- Sulistyo, B., & Krassakis, N. (2012). Perched aquifer formation in layered sedimentary sequences:



- Case study of the Balikpapan Formation, Indonesia. *Hydrogeology Journal*, 20(5), 923-938.
- Török, Á., Vásárhelyi, B., Stead, D., & Eberhardt, E. (2017). Slope failure and instability mechanisms in pyroclastic rock masses: A review. *Engineering Geology*, 221, 33-52.
- Wang, Y., Feng, L., Li, S., Ren, Z., & Song, K. (2024). Lithology and precipitation effects on landslide susceptibility predictions: Evidence from machine learning approaches. *Computers & Geosciences*, 182, 105486.
- Yokota, S., & Iwamatsu, A. (2000). Weathering mechanisms of granitic rocks and their relation to slope failures in granite mountains. *Engineering Geology*, 55(3-4), 153-169.
- Yu, D., Yin, X., Wilkinson, S. J., & He, Q. (2021). Integrated assessment of rock-soil characteristics for landslide susceptibility mapping: Application to Three Gorges Reservoir Area. *Landslides*, 18(5), 1651-1668.
- Zorgati, N., Khaldi, F., & Daoudi, L. (2019). Flysch susceptibility to rainfall-induced landslides: Role of clay mineralogy and infiltration characteristics. *Bulletin of Engineering Geology and the Environment*, 78(4), 2691-2705.

