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The Correlation Between Slope Gradient and Volcanic Rocks in Landslide Prone Area of Sumedang Regency

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ABSTRACT

The study was conducted in Sumedang Regency, which is geologically dominated by Quaternary volcanic rocks. This research aims to identify the correlation between slope gradient, which is associated with landslide, and the distribution of volcanic rocks percentage. The study utilized Digital Elevation Model (DEM) imagery for data processing. ArcGIS 10.0 software was used to support data processing, while Microsoft Excel was employed for data calculation and analysis. Based on the results, parts of South Sumedang, Situraja, Buahdua, and Conggeang have slopes more than 40°, other areas such as South Sumedang, Buahdua, Conggeang, Ganeas, Cisitu, Situraja, Darmaraja, Rancakalong, Jatigede, and Jatinunggal have slopes ranging from 30° to 40°, regions such as Tanjungmedar, Cimanggung, Surian, and Cibugel have slopes between 20° and 30°, and the remaining areas have slopes less than 30°. The potential for landslide, as reflected by the slope gradient, shows a very strong correlation with the proportion of volcanic rocks (correlation coefficient or R = 0.875). This finding highlights a significant correlation between the slope gradient, which serves as a key trigger for landslides, and the spatial distribution of volcanic rocks within the study area.

Keywords: landslide, land use, slope, statistic, Sumedang, volcanic rock,

1. INTRODUCTION

Landslide is phenomenon involving the movement of a large mass of soil and rock in a specific area. This phenomenon can occur either suddenly or gradually over time, and may be preceded by intense erosion (Rendra et al., 2024). In general, landslide is caused by land or slope instability within a certain area. Such instability, which leads to landslide hazards, can be accelerated by several natural factors, including slope gradient, rainfall, land use, as well as the type of rock and geological structure of the area (Eka Kadarsetia, 2011; Raharjo & Nur, 2013). Landslide hazards in Indonesia, especially on the Java, are fundamentally influenced by the island's complex geology, intense rainfall, and the ongoing expansion of land use (Fathani et al., 2016; Utomo, 2013). West Java, in particular, has been recognized as a zone of high risk due to its topography and widespread occurrence of Quaternary volcanic deposits with deep weathering. Sumedang Regency in this geologically active area is very prone to slope failure.

According to Indonesian National Board for Disaster Management, the frequency of landslides in West Java rose sharply over the decade, climbing from 50 cases in 2005 to 400 cases in 2010 (KemenkoPMK, 2014). This steady escalation placed West Java among the most vulnerable regions to landslides in Indonesia (Anonymous, 2012). In Sumedang Regency, landslides have been reported frequently from 2000 to 2005 (Pemerintah Kabupaten Sumedang, 2008). In the 2000, there were 23 recorded incidents, which increased to 81 in 2005. Areas that frequently experience landslides include the subdistricts of South Sumedang, Situraja, Jatinunggal, and Tanjungmedar. Other high-risk zones for landslides include Cadaspangeran, Cigendel, Pamulihan, Sukasirnarasa, Pasir Biru, Pamekaran, Sumedang–Wado–Malangbong, Sukaluyu, Palasari, Kaduwangi, Nagarawangi, and the surrounding areas of Cimalaka Sub-district.

In Sumedang Regency, landslide occurrences are strongly influenced by the steepness of the terrain. Steep slopes tend to be more prone to failure, especially under conditions of intense rainfall or soil saturation. Evaluating slope gradient is therefore critical in determining landslide risk. Tools such as remote sensing and elevation models play an important role in detecting and mapping areas with high landslide susceptibility (Haryani, 2012; Rendra et al., 2015, 2019)

Prior research in Indonesia has frequently evaluated landslide hazards using qualitative or weighted overlay techniques (Firdaus & Sukojo, 2015). These methods may be subjective and lack statistical rigor, despite being useful in defining broad hazard zones. By providing a statistical framework to investigate correlation between physical-geographic characteristics and landslide susceptibility, this study seeks to close that gap. This study focuses on identifying the correlation between slope gradient and volcanic rocks. With the use of remote sensing, GIS-based spatial analysis, and statistical correlation techniques, this study offers a scalable, objective, and reproducible method for assessing the risk of landslides in other areas with comparable conditions.

2. METHODOLOGY

2.1 Data Sources and Preprocessing

This study utilized a multi-source geospatial dataset to conduct analysis of landslide susceptibility in Sumedang Regency. The integration of remote sensing, geological, and historical landslide records data allowed for spatial and statistical interpretation of the factors contributing to landslide. The primary datasets used include:

- ASTER Digital Elevation Model (DEM) with a 30-meter spatial resolution, which was employed to derive slope gradients across the study area.
- Regional Geological Map of Sumedang (Djuri, 1995; Silitonga, 2003), which provided lithological and structural geological information including volcanic rock distributions.
- Historical landslide records from 2007 to 2014 (BPS Kab. Sumedang, 2007, 2009, 2010, 2011, 2013, 2014)

All spatial data were georeferenced to the projection system (Zone 48S), and preprocessing was conducted using ArcGIS to ensure consistency across datasets.

2.2 Slope Analysis

Slope gradient plays a critical role in landslide susceptibility. Using ArcGIS 10.0, slope maps were generated from ASTER-DEM using the spatial analyst toolset. The resulting slope values were then reclassified into five categories, modified from the slope classification (Van Zuidam, 1986), ranging from flat (0°) to very steep (>45°). This classification was used to assess how terrain steepness correlates with landslide-prone area.

2.3 Statistical Correlation

The collected research data were further analyzed using a probabilistic approach supported by statistical testing. Statistical analysis was conducted to produce robust and reliable results with a specific confidence level, ensuring broader scientific acceptance. The verification of findings through the probabilistic method involved statistical testing of the observed phenomena, aiming to determine the significance level (α) or an acceptable degree of confidence in the results (Hirnawan, 2015). The statistical testing in this study was carried out using a probabilistic approach through correlation test. The degree of correlation between two or more variables can be determined by examining the value of the correlation coefficient (Sugiyono, 2007).

Table 1 – Slope Classification (Van Zuidam, 1986) in (Yazida et al., 2021).

Slope class	Percentage	Slope angle	Information
Flat to almost flat	0–2 %	0–2°	No meaningful denudation process
Gentle	2–7 %	2–4°	Ground motion speed is low. Sheet and soil erosions are identified.
More gentle	7–15 %	4 –8°	The same as above, but with a higher magnitude.
Slightly steep	15–30 %	8–16°	Flat landslides with a lot of ground movement and erosion
Steep	30–70 %	16–35°	Intensive denudation processes and ground movements are common
Very steep	70–140 %	35–55°	Rocks generally begin to unfold, a very intensive denudational process, have begun to produce rework material.
Very steep	> 140 %	> 55°	Exposed rocks, a very strong denudational process and prone to falling rocks, rarely grown plants (limited)

Table 2 - Interpretation of the correlation coefficient (Sugiyono, 2007).

Correlation coefficient interval	**Criteria (level)**
0.00 – 0.199	Very low
0.20 – 0.399	Low
0.40 – 0.599	Medium
0.60 – 0.799	Strong
0.80 – 1.000	Very strong

3. RESULTS AND DISCUSSIONS

3.1 Slope Gradient of the Research Area

Slope gradient serves as an important indicator of an area's susceptibility to natural hazards. For instance, steep slopes typically present a higher degree of risk compared to gently sloping terrain. This distinction forms the basis for identifying and assessing regional characteristics in relation to potential landslide activity. Based on the Slope map of the Sumedang Regency, the study area displays a wide range of slope variations (Figure 1). These differences reflect the complex geological conditions of the region, which in turn lead to varying levels of landslide susceptibility across different zones. parts of South Sumedang, Situraja, Buahdua, and Conggeang have slopes more than 40°, other areas such as South Sumedang, Buahdua, Conggeang, Ganeas, Cisitu, Situraja, Darmaraja, Rancakalong, Jatigede, and Jatinunggal have slopes ranging from 30° to 40°, regions such as Tanjungmedar, Cimanggung, Surian, and Cibugel have slopes between 20° and 30°, while Cisitu, Tomo, and Paseh generally have slopes between 10° and 20°. The gentlest slopes, from 0° to 10°, are mainly located in Ujungjaya, Jatinangor, and Tanjungsari. Based on the slope gradient, an initial analysis of landslide-prone areas can be conducted.

3.2 Geology of the Research Area

The Sumedang Regency is composed of various rock types, each exhibiting distinct geological characteristics. The lithological classification in the study area is based on the geological map (Djuri, 1995; Silitonga, 2003). Different rock types show varying levels of susceptibility to landslides. Generally, unconsolidated Quaternary volcanic rocks and sedimentary formations influenced by geological structures are more prone to landslides compared to more compact rocks that are structurally stable. In addition, intensive weathering processes can significantly contribute to slope instability. Based on these considerations, the geological map of the study area is presented in Figure 2.

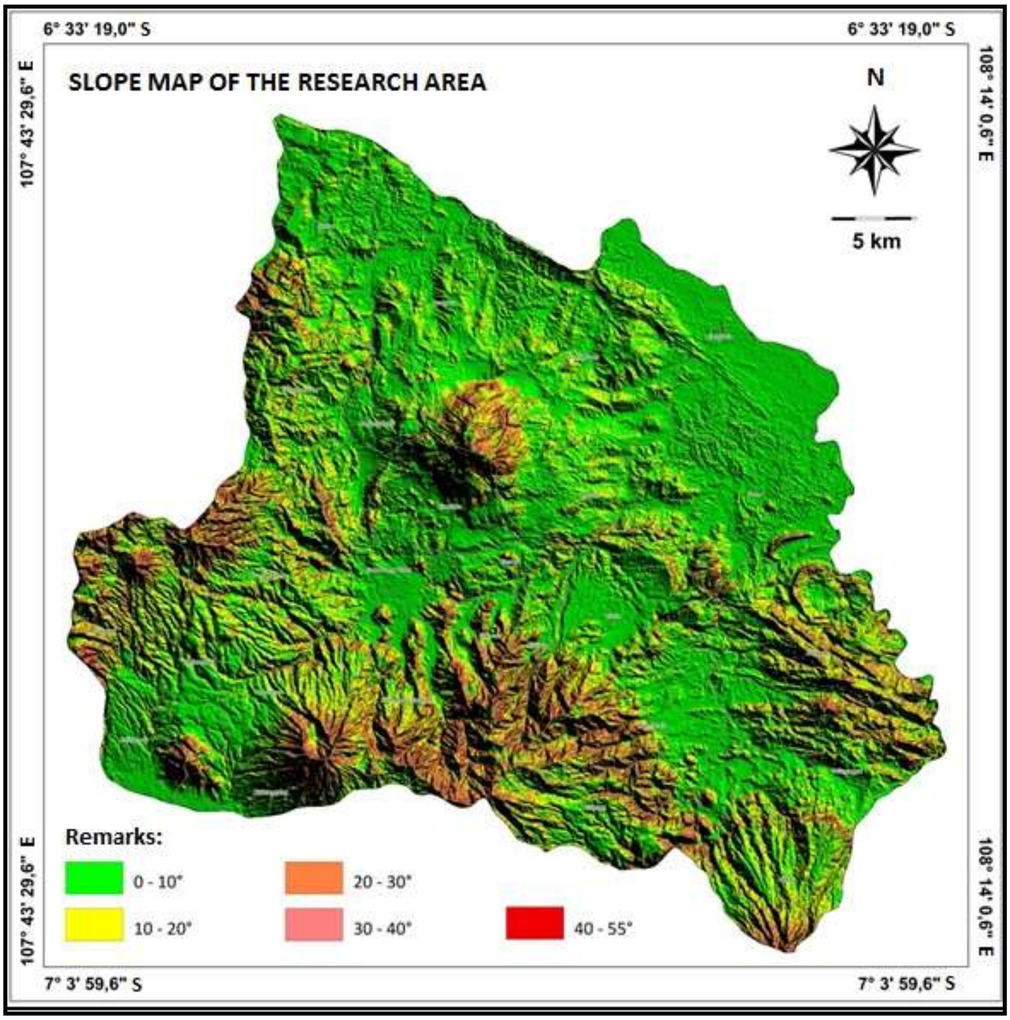

Fig. 1 - Slope map of the Sumedang Regency (Rendra et al., 2025)

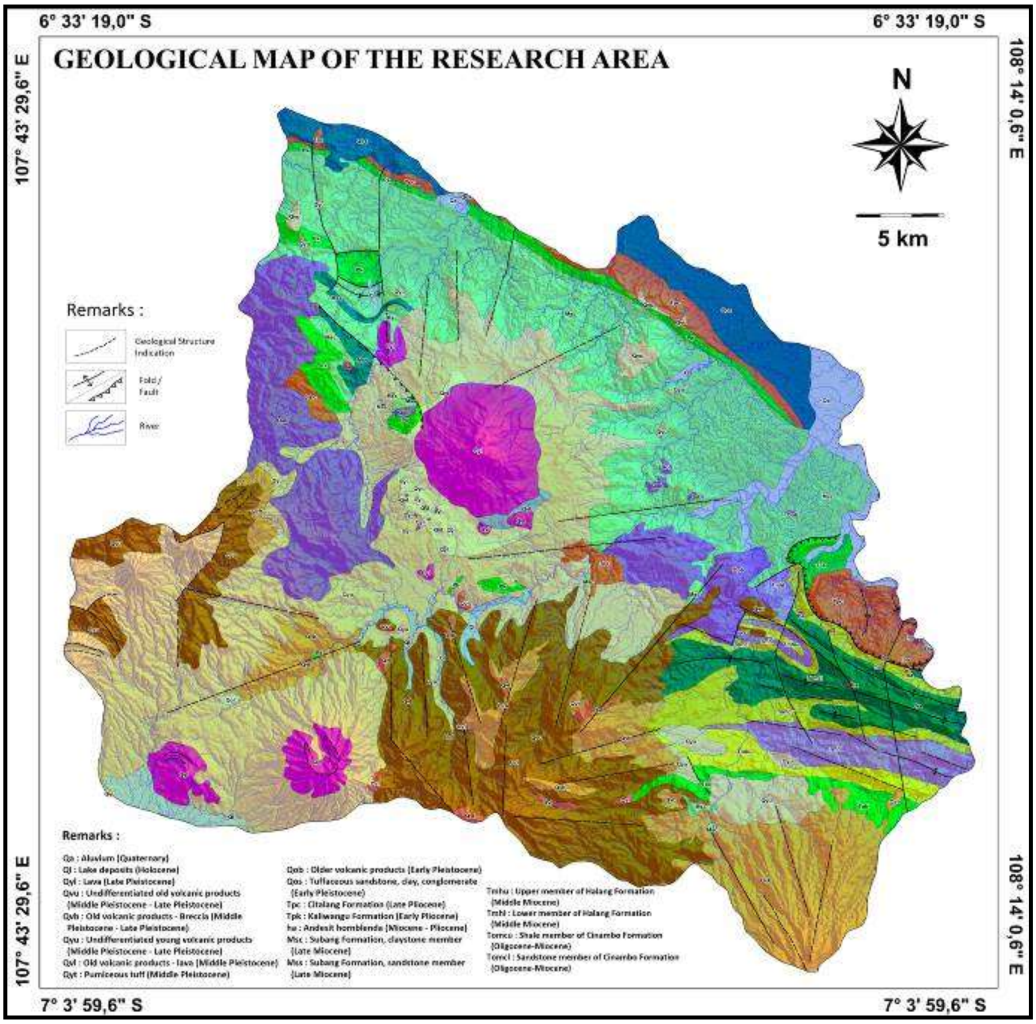

Fig. 2 - Geological map of the Sumedang Regency (Djuri, 1995; Silitonga, 2003) in (Rendra et al., 2025)

3.3 Historical Landslide Records

Based on landslide event data for Sumedang Regency (Figure 3), a Landslide Occurrence Map was developed to illustrate the locations, frequency, and spatial distribution of landslides that occurred between 2007 - 2014. The number of recorded landslide events during this period ranged from 0 - 59 across various subdistricts. Subdistricts experiencing more than 15 events include Cisitu (16 events), Tanjungkerta (17 events), Rancakalong (22 events), Jatinunggal (36 events), and South Sumedang (59 events). Areas with 6 to 15 recorded landslides include Cimanggung (8 events), Situraja (9 events), Cimalaka (9 events), Wado (10 events), Ganeas (12 events), North Sumedang (13 events), Pamulihan (14 events), and Jatigede (14 events). Subdistricts with fewer than 6 events include Jatinangor (0 event), Conggeang (1 event), Buahdua (2 events), Surian (2 events), Cisarua (3 events), Ujungjaya (3 events), Tanjungmedar (3 events), Sukasari (4 events), Darmaraja (4 events), Tomo (4 events), Paseh (4 events), Tanjungsari (5 events), and Cibugel (5 events). These patterns indicate that the majority of high landslide susceptibility areas are concentrated in the southern and southeastern parts of the study area. This spatial trend aligns with remote sensing analysis results, which reveal significant land use conversion occurring in the southern regions of Sumedang Regency.

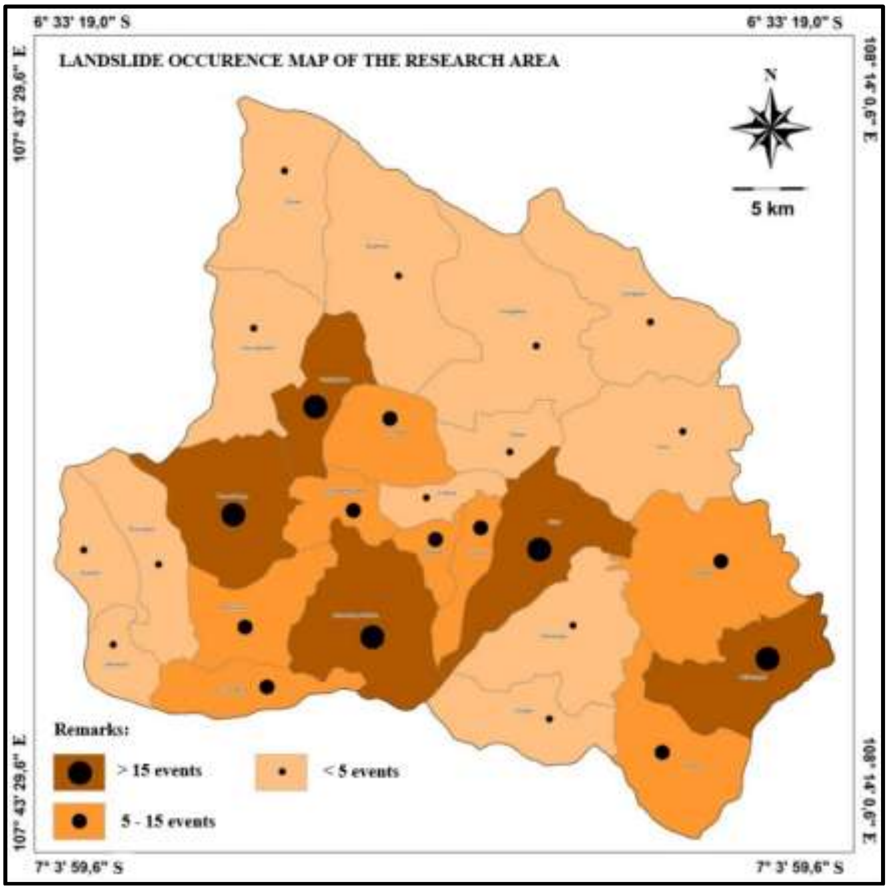

Fig. 3 – Landslide occurrence map of the Sumedang Regency

3.4 Correlation Between Slope Gradient and Volcanic Rocks

Variations in slope gradients across the study area can reflect differences in lithological composition. For example, steeper slopes in southern regions such as South Sumedang, Wado, and Situraja are largely associated with volcanic rock formations. Conversely, areas with lower slope angles, including parts of the north and localized zones in the south like Darmaraja and Buahdua, are typically underlain by sedimentary rocks such as sandstone and claystone. To evaluate the correlation between slope gradient and lithology, slope sampling and the assessment of volcanic rock proportions were undertaken. The analysis utilized slope angle and the proportion of volcanic rocks as variables (Tables 3 and Table 4). A simple random sampling method was applied in both northern and southern sections of the study area to ensure representative coverage and to capture the potential correlation between slope morphology and volcanic rock distribution. A total of 23 slope samples and 23 volcanic rock proportion measurements were selected for statistical analysis.

A polynomial trend with a correlation coefficient (r) = 0.875 (Figure 4) was obtained from a correlation analysis between the slope gradient and the percentage of volcanic rock, suggesting a very strong correlation between the two variables. This correlation's positive nature suggests that a larger percentage of volcanic rock typically accompanies slope gradients that are higher. The coefficient of determination ($r^2 = 0.765$) indicates that variations in slope gradient account for 76.5% of the variation in the proportion of volcanic rock, with r = 0.875 indicating a very strong correlation. Other variables like elevation, terrain morphology, and proximity to the eruption center are probably responsible for the remaining 23.5%.

Table 3 – Slope gradient sample data in the research area.

No	Sample	Slope gradient (°)
1	Ujg	0.77
2	Srn	2.77
3	Tm	7.57
4	Cgg	9.70
5	Psh	10.27
6	Bda	11.09
7	Drj	11.34
8	Jtl	13.61
9	Jtd	16.21
10	Jtr	19.57
11	Cbg	19.87
12	Wd	19.97
13	Tjd	20.41
14	Skr	20.75
15	Pmh	21.71
16	Tjr	21.89
17	Rcl	23.20
18	Smt	23.68
19	Cmk	25.44
20	Gns	26.15
21	Cmg	26.57
22	Sml	29.36
23	Stj	29.60

Table 4 – Volcanic rocks proportion sample data in the research area.

No	Sample	Volcanic rocks proportion (%)
1	Ujg	1.17
2	Srn	17.27
3	Tm	15.18
4	Cgg	36.46
5	Psh	58.18
6	Bda	43.75
7	Drj	61.06
8	Jtl	30.90
9	Jtd	5.76
10	Jtr	73.59
11	Cbg	98.13
12	Wd	100.00
13	Tjd	71.79
14	Skr	100.00
15	Pmh	98.78
16	Tjr	100.00
17	Rcl	99.92
18	Smt	98.14
19	Cmk	100.00
20	Gns	91.81
21	Cmg	90.77
22	Sml	96.45
23	Stj	100.00

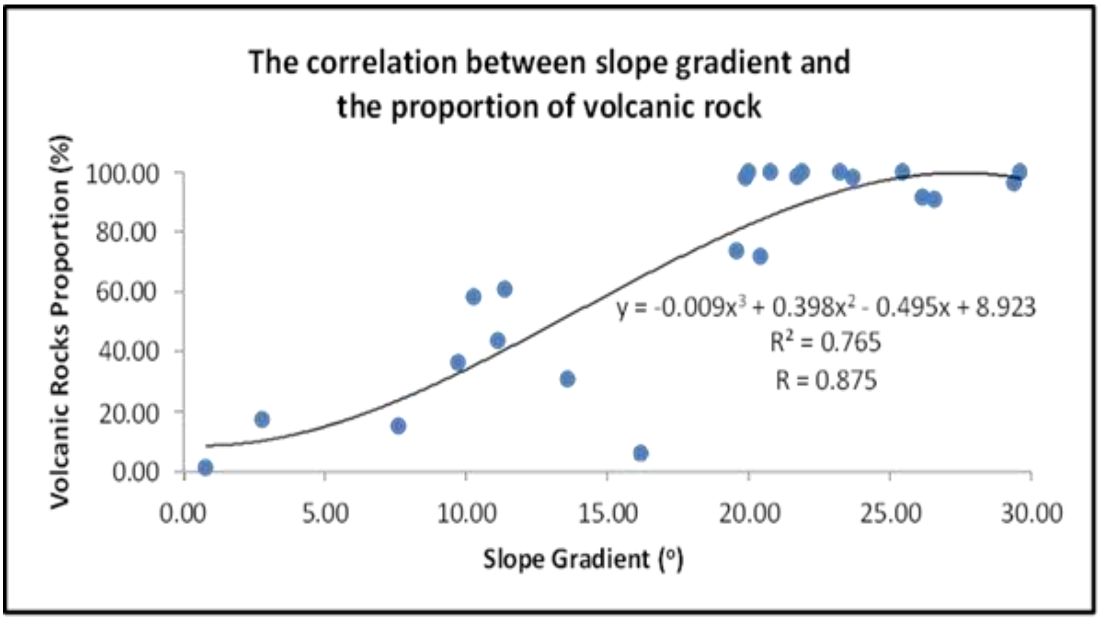

Fig. 4 – The correlation between slope gradient and the proportion of volcanic rock is represented by a polynomial trend, defined by the equation $y = -0.009x^3 + 0.398x^2 - 0.495x + 8.923$, with a correlation coefficient (R) = 0.875

4. Conclusion

The potential for landslides in Sumedang Regency is closely associated with slope gradient and its relationship to volcanic rock formations. Steep slopes are inherently more prone to gravitational failure due to the reduced stability of surface materials. Analysis of slope data within the study area reveals a very strong correlation between slope gradient and the proportion of volcanic rocks, as shown by a polynomial trendline represented by the equation $y = -0.009x^3 + 0.398x^2 - 0.495x + 8.923$ ($r = 0.875$). This high correlation indicates that areas with steeper slopes tend to coincide with a greater presence of volcanic rock, which may contribute to increased landslide susceptibility. The results highlight the critical role of terrain steepness in landslide hazard assessment, especially in volcanic landscapes such as Sumedang.

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