

GEOSPATIAL-GEOTECHNICAL STUDY AS A BASIS FOR MICRO-SPATIAL PLANNING USING A 3D LANDSLIDE RISK MAP IN WARA BARAT DISTRICT

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Abstract

Wara Barat District is a hilly area of Palopo City with recurrent landslides and growing land-use pressure. This study integrated slope geometry, rock-weathering conditions, soil shear parameters, and three-dimensional geospatial visualization as a basis for micro-spatial planning. Field observations were carried out at 15 points in Battang, West Battang, Lebang, Padang Lambe, and Tomarundung. Laboratory data consisting of water content, cohesion, and internal friction angle from five documented samples. The corrected dataset contained seven very-high, three high, and five moderate points. Battang showed the highest mean slope (80.51%; 36.65°) and had high mean water content (54.82%) with a relatively low internal friction angle (25.5°). Integrated interpretation placed Battang in the very-high class, West Battang in the provisional high-to-very-high class, Lebang in the moderate-to-high class, and Padang Lambe and Tomarundung mainly in the moderate class with local high-susceptibility pockets. The revised 3D map provides an initial basis for protection, restricted-use, and conditionally developable zones.

Keywords : Geotechnics; Landslides; Micro-Spatial Planning; Three-Dimensional Mapping; West Wara .

INTRODUCTION

Landslides are one of the most frequent geological hazards in hilly areas when slope gradient, material conditions, and water work together. West Wara District is located in the western part of Palopo City, with a landscape dominated by undulating to steep slopes. The recapitulation of events used in the research proposal shows 17 landslides between 2014 and 2024. A major event in January 2019 caused significant damage to homes, casualties, and economic losses. These records demonstrate that the landslide problem in West Wara cannot be addressed solely after a disaster has occurred. Management efforts that have previously focused on retaining structures and drainage improvements remain necessary, but they are insufficient without controlling spatial use. City-scale spatial plans provide general direction, while decisions regarding building locations, road openings, cliff cuts, and land cover changes occur at a more detailed scale. In these situations, geological information and slope shape need to be translated into easily understood micro-spatial guidelines that can be applied at the village or slope unit level. Geographic information system-based landslide mapping has been widely used to assess slope, land cover, rainfall, and other factors through a multi-criteria approach (Kinanti et al., 2022; Chaabane et al., 2024). Slope morphology methods also help identify potential areas in regions with limited data (Latue et al., 2023). However, zoning that relies solely on regional spatial data often fails to reflect the state of the material in the field. On slopes of the same steepness, the degree of weathering, water content, cohesion, and angle of internal friction can produce different stability responses.

Previous studies on the West Ring Road in Palopo City showed that rock characteristics and slope geometry are directly related to landslide potential (Gawing et al., 2023). Subsequent developments have led to the integration of more diverse data sources, including multi-criteria approaches and multimodal frameworks for regional risk analysis (Caporale & Rinaldi, 2025; Pollock & Wartman, 2025). For West Wara, the integration of geospatial and geotechnical data is crucial so that maps are not merely color displays but can also explain the technical rationale behind each vulnerability class. This study aims to analyze variations in slope geometry, weathering conditions and early signs of landslides, and geotechnical soil parameters; develop vulnerability zones in three-dimensional visualization; and formulate micro-spatial planning guidelines. The term "risk" is retained in the title to adhere to the proposed research framework, while the resulting analysis primarily describes physical vulnerability. A comprehensive risk analysis still requires information on population exposure, buildings, infrastructure, loss values, and mitigation capacity.

METHOD

2.1. Research Location and Design

The research was conducted in Wara Barat District, Palopo City, in five sub-districts: Battang, Battang Barat, Lebang, Padang Lambe, and Tomarundung. Each sub-district was represented by three observation points, resulting in a total of 15 slope geometry points. The research approach was descriptive-quantitative, combining field measurements, engineering geology observations, laboratory test results, geographic information system processing, and three-dimensional visualization.

Primary data consists of location coordinates, slope top and bottom elevations, slope length, rock weathering level, slope surface conditions, and initial signs of landslides. Secondary data includes elevation models, topographic maps, administrative boundaries, and landslide event records, which serve as context for interpretation. Position measurements were performed using GPS, while slope geometry was obtained from elevation and horizontal length measurements at predetermined points.

2.2. Geometry Measurement and Slope Classification

The height difference is calculated from the difference in elevation between the top and bottom of the slope. The slope percentage and slope angle are calculated using the following equation:

$$\text{Slope gradient (\%)} = (\Delta h/L) \times 100$$

$$\theta = \arctan (\Delta h/L)$$

with Δh as the height difference and L as the horizontal length of the slope. The slopes are grouped into very low ($\leq 8\%$), low ($>8-15\%$), moderate ($>15-25\%$), high ($>25-45\%$), and very high ($>45\%$). This classification is used consistently at all points after calculations and coordinate identities are rechecked.

2.3. Field Condition Observation and Geotechnical Testing

Field observations recorded the degree of rock weathering, material compaction, cracks, seepage, saturation zones, erosion, root uplift, and landslide scars. Field scores in the research data were used as supporting indicators, not as a sole risk index. These values were interpreted in conjunction with slope geometry to avoid mismatching steep slopes with relatively fresh rock with steep slopes that had weathered and exhibited deformation.

Laboratory testing included moisture content and direct shear. From available test documentation, five samples could be verified. Four samples could be definitively attributed to Battang and Lebang, while one sample only listed the Wara Barat District without a village name. Samples without village identification were not included in the village-by-village synthesis to avoid misattribution.

2.4. Data Integration and Three-Dimensional Mapping

Geometry, field conditions, and geotechnical data were integrated through a multi-level synthesis. Slope geometry served as the initial basis, and classes were then strengthened or maintained by considering weathering, instability signs, water content, cohesion, and internal friction angles. Because overlay weights and parameter rasters were not available in the research data, spatial class boundaries on the map were treated as indicative zoning. Three-dimensional visualizations were constructed on top of the topographic model to demonstrate the relationship between relief and vulnerability patterns. The final results were then simplified into protection zones, restricted use zones, and conditional development zones as the basis for micro-spatial planning.

RESULTS AND DISCUSSION

3.1. Variations in Slope Geometry

The correction results show that seven of the 15 points are in the very high class, three points in the high class, and five points in the medium class. No points fall into the low or very low class. The average slope of all points reached 46.14% with an average angle of 23.34°. These values indicate that the study area is generally composed of medium to steep morphology, but the level of vulnerability is not uniform across villages.

Table 1. Recapitulation of slope geometry and vulnerability class per sub-district

Ward	Average slope (%)	Average angle (°)	Three-point composition	Integration result class
Batang	80.51	36.65	3 very high	Very high
West Battang	62.56	31.78	3 very high	High-very high*
Hole	33.39	18.03	1 very high; 2 moderate	Medium-high
Lambe Field	31.57	17.47	2 tall; 1 medium	Medium; local high

Ward	Average slope (%)	Average angle (°)	Three-point composition	Integration result class
Tomarundung	22.65	12.75	1 high; 2 medium	Medium; local high

Battang has the highest average slope, at 80.51%, with an average angle of 36.65°. Battang 2 reaches 133.33%, or 53.13°, the highest value of all locations. The slope percentage exceeding 100% is not a calculation error because it is a ratio of height difference to horizontal distance, not the magnitude of the angle. All points in Battang and West Battang are classified as very high based on geometry. This condition indicates that changes in slope shape, additional loads, or cliff cuts in both villages can significantly increase the driving force.

Lebang shows the most pronounced variation. One point reached 56.53% and is considered very high, while the other two points are in the moderate category. Padang Lambe consists of two high points and one moderate point. Tomarundung has the lowest average, but one point is still in the high category. This pattern confirms that village averages are insufficient for site-level decisions. Steep slope units still need to be separated from gentler sections, as is the slope morphology approach used in landslide potential mapping (Latue et al., 2023).

3.2. Rock Weathering and Indications of Instability

Field conditions highlight differences not entirely apparent from the geometry. Battang and West Battang exhibit Grade IV-V weathering, loose soil, easily disintegrated rock, longitudinal cracks, erosion, uplifted roots, landslide scars, and water-saturated zones. The average field condition score is 81.5-85, categorized as high. These findings indicate that vulnerability in Battang stems not only from slope shape but also from material degradation and signs of developing deformation.

Table 2. Summary of field conditions

Ward	Degree of weathering	Main indications	Score	Field category
Batang	Grade IV-V	Cracks, erosion, landslide scars, saturated zones	81.5	Tall
West Battang	Grade V	Loose soil, easy to collapse	85	Tall
Hole	Grade III	Small cracks and puddles	62	Currently
Lambe Field	Grade I-II	Hard rock; no indication of landslides	30	Low
Tomarundung	Grade II	Rocks are relatively compact; there is seepage	48	Medium-low

Lebang has Grade III weathering, with a mixture of soil and rock that is beginning to decompose. Small cracks and water puddles indicate infiltration pathways and water accumulation in certain locations. At Padang Lambe, the rock remains hard and relatively intact, and no signs of landslides are found. This difference explains why the two slopes at Padang Lambe, geometrically classified as high, were not immediately placed in the very high class. Tomarundung also shows no prominent cracks, but the presence of seepage indicates that conditions can change when prolonged rainfall occurs or surface drainage is disrupted.

These results align with the principle that steep slopes don't always respond equally. Weathered, fractured, and saturated materials are more susceptible to strength loss than compacted rocks. Therefore, mapping using only slope risks over-expanding the red zone or, conversely, overlooking gentler slopes with water and weathering issues. The integration of field data is a key component of the novelty of this research approach.

3.3. Geotechnical Characteristics of Soil

Verifiable laboratory test results included two Battang samples, two Lebang samples, and one sample that only included the West Wara District. The last sample was not used to generate values per village. A summary of the test results is shown in Table 3.

Table 3. Water content and direct shear parameters

Sample location/code	Ward	Water content (%)	Cohesion c (kg/cm ²)	Shear angle in ϕ (°)
ST.1	Lambe Field	15,508	0.00	31
ST. 2	West Battang	53,314	0.01	26
ST. 3	Battang	56,334	0.01	25
ST. 4	Tomarunding	18,747	0.00	31
ST. 5	Hole	19,436	0.00	30

Battang has an average water content of 54.82%, a cohesion of 0.01 kg/cm², and an average internal friction angle of 25.5°. Lebang has an average water content of 19.09%, a cohesion of 0 kg/cm², and an internal friction angle of 30.5°. The significant difference in water content confirms the observations of the saturated and infiltration zones in Battang. Water adds weight to the soil mass and, as pore water pressure increases, reduces the effective stress acting between grains. At the same time, the internal friction angle in Battang is lower than in Lebang, resulting in lower frictional resistance.

The cohesion values for all samples were very low. Under these conditions, the shear strength of the material depends more on intergranular friction and effective stress. The decrease in effective stress due to saturation can have a greater impact than the cohesion difference of 0.01 kg/cm². The combination of steep slopes, weathered material, high water content, and low internal friction angles are the technical reasons for placing Battang in the very high class. In contrast, Lebang data shows drier material and a higher internal friction angle, although the steep slope section still requires restrictions on its use.

3.4. Vulnerability Zoning and Suitability of Three-Dimensional Maps

The revised three-dimensional map places the very high zone primarily in Battang and the steep parts of West Battang. The high zone develops in other parts of West Battang, pockets of steep slopes in Lebang, and certain parts of Padang Lambe and Tomarunding. The moderate zone is more dominant in the central to southern parts of the region, while the low zone occurs only to a limited extent on gentler slopes and relatively good rock conditions.

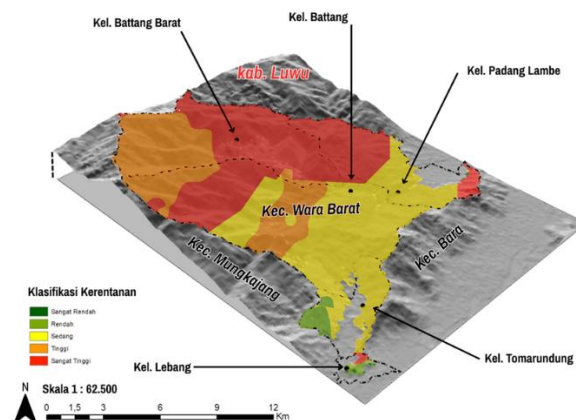


Figure 1. 3D landslide vulnerability map of West Wara District after adjustment based on corrected data

The pattern in Figure 1 is more consistent than the initial map, which displayed red zones almost evenly distributed across the subdistrict. The point data indicate that the very high class accounts for seven, or 46.67%, rather than the entire area. Conversely, the initial map also displayed a fairly extensive green zone around West Battang, even though all three geometric points in that subdistrict were considered very high. The revised zoning reduces both of these discrepancies: red is concentrated in areas with the strongest data support, while areas with more diverse evidence are presented as a mosaic of moderate to high levels.

Battang was prioritized because all available parameters were trending in the same direction. West Battang was placed in the high-very high class, but this was provisional due to the lack of adequate weathering observations and geotechnical testing. Lebang was in the medium-high class with one very steep area. Padang Lambe and

Tomarundung generally fell into the medium class, with high zones in steeper areas or those experiencing water problems. This approach aligns with multicriteria analysis, which emphasizes the importance of combining several indicator groups rather than using a single parameter (Chaabane *et al.*, 2024).

3.5. Implications for Micro-Spatial Planning

The five-class zoning on the map translates into three spatial directions. Very high zones are treated as protection or high-risk zones; high zones as strictly limited-use zones; and medium to low zones as conditional development zones with varying levels of control. This simplification is intended to allow technical results to be used in discussions of site plans, roadways, drainage, and building locations.

Table 4. Directions for the use of micro space based on vulnerability class

Vulnerability class	Space zone directions	Main technical directions
Very high	High risk/protection zone	Avoiding new development; slope conservation; water control; crack monitoring and stabilization of existing infrastructure.
Tall	Strictly restricted zone	Construction only after geotechnical investigation; cutting and filling restrictions; drainage and slope reinforcement mandatory.
Currently	Conditional development zone	Density regulation; runoff control; load limitation and geometry changes; verification of soil conditions at building sites.
Low-very low	Conditional relative safety zone	May be considered for development, but still requires site inspection and drainage system protection.

In Battang, new development should be avoided on slopes that show signs of cracking, landslide scars, and saturation. West Battang requires field verification before zone boundaries can be used as a basis for permits. In Lebang, controls should focus on pockets of steep slopes and water accumulation areas. Lambe and Tomarundung still have room for limited use, but drainage changes or cliff cuts could shift the previously moderate conditions to higher elevations.

3D visualizations help demonstrate the relationship between zone positions and terrain features, making them more communicative for spatial planning discussions than stand-alone two-dimensional maps. However, these maps cannot yet be used as parcel boundaries. Complete raster data for parameters, measured rainfall, land cover, interpolation methods, overlay weights, slope safety factors, and landslide validation coordinates are not yet available. The number of geotechnical samples is also limited and not representative of West Battang, Padang Lambe, and Tomarundung. These limitations need to be acknowledged so that the maps can be used as a basis for initial screening, not as a substitute for site investigations.

CONCLUSION

Geospatial-geotechnical studies indicate that landslide susceptibility in West Wara District has a non-uniform pattern. Of the 15 geometric points, seven are classified as very high, three are high, and five are moderate. Battang is the most vulnerable area because it has an average slope of 80.51%, Grade IV-V weathering, clear signs of instability, an average water content of 54.82%, and an average internal friction angle of 25.5°. West Battang also has a very steep geometry, but the high-very high class is still provisional because field and geotechnical data are incomplete. Lebang is in the medium-high class, while Padang Lambe and Tomarundung are dominated by the medium class with high pockets.

The revised 3D map has more focused red zones in Battang and the steep section of West Battang, and displays moderate to high variations in other sub-districts. The map can be used as a baseline for determining protection zones, restricted zones, and conditional development zones. Application at the site scale still requires additional geotechnical sampling, safety factor analysis, rainfall and land cover data, and validation with landslide coordinates.

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