Spatial Analysis of Landslide Vulnerability Using Weighted Overlay Based on GIS in Balik Bukit

Stefano Candra Wahyudi[1*], Azizah Dea Putri[1], Aprido Lumbanraja[1], Liana Sinaga[1], and Karyanto[2], Nandi Haerudin[2], Rahmat Catur Wibowo[2], Rahmi Mulyasari[2]

[1]*Student of Geophysical Engineering, Faculty of Engineering, Lampung University*
[2]*Lecturer of Geophysical Engineering, Faculty of Engineering, Lampung University*
Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung 35142, Indonesia

[*]*Email: 2315051069@students.unila.ac.id, 2315051084@students.unila.ac.id, 2315051076@students.unila.ac.id, 2315051092@students.unila.ac.id*

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Abstract

Balik Bukit District in West Lampung Regency is an area with high susceptibility to landslides, which are difficult to predict and pose significant threats to human safety. This study aims to comprehensively map landslide vulnerability zones as a foundation for mitigation strategies. The method used is the Weighted Overlay approach based on Geographic Information Systems (GIS), analyzing eight triggering parameters: slope steepness, slope aspect, slope length, lithology, distance from faults, soil type, soil depth, and rainfall. The research produced a risk map classifying the study area into three categories: low risk (4,878.442 ha), moderate risk (8,487.104 ha), and high risk (1,230.959 ha). Slope steepness was identified as the most dominant factor. This map is expected to serve as a strategic guide for the government and local communities in developing adaptive spatial planning and more effective disaster mitigation plans.

Keywords: *Balik Bukit, Disaster Mitigation, GIS, Landslide Susceptibility, Weighted Overlay.*

I. Introduction

Landslides rank as among the most frequently occurring types of natural disasters in Indonesia. From a geospatial perspective, it is identified that the area associated with Balik Bukit sub district falls within an area at risk due to its graphical features and respective geosoft structure, as well as rainfall intensity. Consequently, given the landslides which took place at the end of April 2025, there have been considerable damages caused at several infrastructures. Similar conditions have been reported in various mountainous regions in Indonesia, where the interaction between steep slopes, geological conditions, and high rainfall significantly increases landslide occurrence [1][2]. Recent meteorological studies suggest that changing rainfall patterns, specifically the increase in short-duration high-intensity storms, have become a critical trigger for slope instability in western Indonesia [3]. Recent Indonesian studies also confirm that rainfall-triggered landslides are strongly controlled by slope morphology and lithological conditions, particularly in tectonically active regions [4][5].

The establishment of Geographic Information Systems (GIS) using multi-criteria analysis, particularly the Weighted Overlay method, has been commonly applied for landslide risk and susceptibility mapping in various regions of Indonesia [6][7]. This approach allows multiple conditioning factors to be integrated into a single spatial model. However, most previous landslide susceptibility studies in Indonesia were limited to no more than seven main parameters, generally including slope, soil type, land use, and rainfall intensity. The use of a limited number of parameters may reduce the accuracy and representativeness of the resulting susceptibility models [8]. Several studies have emphasized that landslide susceptibility is governed by complex interactions among geomorphological, geological, and hydrological factors that cannot be fully represented using a simplified parameter set [9][10].

Despite the increasing number of landslide susceptibility studies in Indonesia, there remains a gap in research that applies a more holistic approach by incorporating a broader range of controlling parameters. Therefore, this study attempts to address this limitation by integrating eight critical factors, including slope steepness, slope direction, slope length, lithology, distance from geological faults, soil type, soil depth, and rainfall intensity. Previous Indonesian studies have demonstrated that the inclusion of additional morphometric and subsurface-related parameters significantly improves the reliability and predictive capability of landslide susceptibility models [11][12].

It is expected that the application of this comprehensive parameter integration will result in a more holistic spatial analysis of landslide susceptibility in the Balik Bukit Subdistrict. Furthermore, this research aims to (1) generate a landslide susceptibility map with improved accuracy and spatial precision, and (2) conduct a quantitative analysis of the relationship between contributing environmental factors and the resulting degree of landslide susceptibility.

A. Data Used

The data pertaining to administrative boundaries were obtained from the Geospatial Information Agency (BIG). Soil type and lithological information were acquired from the West Lampung District Development Planning Agency (BAPPEDA). Geological fault data were sourced from the Geological Survey Center. Topographic parameters were derived from Digital Elevation Model (DEM) data provided by the Indonesian Nad Tinya project through the Tanah Air portal. The utilization of high-resolution DEM data is considered essential in enhancing the accuracy of slope geometry extraction for landslide susceptibility modeling [13]. Historical rainfall data were collected from the Pesawaran Climatology Station of the Meteorology, Climatology, and Geophysics Agency (BMKG). Similar data sources and datasets have been widely applied in landslide susceptibility studies in Indonesia [14][15]. All spatial processing and modeling were conducted using ArcGIS 10.8.

B. Weighted Overlay Method

The Weighted Overlay method integrates eight variables: slope, direction, and length of the slope (derived from DEM); lithology and distance from faults; soil type and depth; and rainfall (interpolated using the Inverse Distance Weighted method). Each parameter and its sub-class is given a score and weight based on literature studies [16][17] and adjusted to local conditions. The weights used are: slope (30%), rock type (20%), rainfall (20%), soil type (10%), and 5% each for slope direction, slope length, distance from faults, and soil depth. Similar weighting schemes have been successfully applied in landslide susceptibility studies in several regions of Indonesia, demonstrating reliable spatial prediction results [18][19].

The linear relationship between the resulting landslide hazard map and each parameter was tested using Pearson's correlation analysis. Final validation was performed by comparing the risk map with historical landslide occurrence data and the Regional Spatial Plan (RTRW) map [20]. Previous studies indicate that the combination of statistical correlation testing and spatial validation enhances the robustness of landslide susceptibility assessment [21] [22].

Weighted Overlay technique was employed because it enjoys an advantage in combining different multi-criteria variables into a single comprehensive spatial model. Unlike boolean logic, which considers binary variables alone (1 = yes, 0 = no), Weighted Overlay technique considers assigning a weight value as a percentage value representing the contribution amount within each raster layer to be considered within the percentage value accounting for its contribution amount within landslide susceptibility level.

The weight here represents guidelines set forth per BNPB guidelines 2016 and modified within local conditions surrounding the area pertaining to an increase within relevance values emerging within an analysis result. Moreover, Pearson Correlation Test technique was employed within examination for ascertaining intention and degree within measuring relationship within two variables ranging in value as continuous variables. Within this analysis, it emerged with value ranging within an equation with value scaling within -1 and +1, approaching 1 with +1 sign defining relationship set within strong and highly positively related within variables measured, and approaching -1 sign defining relationship set within strong and highly negatively related within variables measured. A value approaching 0 eithersignologically positions within variables measured as no value within relationship as measured. The equation used in this study is expressed in Equation (1).

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2)(N\sum Y^2 - \sum X)^2)]}} \qquad (1)$$

Table 1. Relationship Strength Categories Based on Correlation Coefficient (r) [23].

Coefficient Value Range (r)	Correlation Strength Level
0	No Correlaton
0,01-0,20	Very Weak
0,21-0,40	Weak
0,41-0,60	Moderate
0,61-0,80	Strong
0,81-0,99	Very Strong
1	Perfect

II. Results and Discussions

The results of spatial analysis using the Weighted Overlay method based on Geographic Information Systems (GIS) show that the level of landslide vulnerability in Balik Bukit Subdistrict, West Lampung Regency, is greatly influenced by a combination of morphological, geological, soil, and rainfall factors. This area has a topography dominated by steep hills with volcanic lithology, which is naturally prone to mass land movements. Based on the spatial modelling results, the study area is divided into three risk classes, namely a low-risk zone covering 4,879 hectares, a medium-risk zone covering 8,486 hectares, and a high-risk zone covering 1,231 hectares, with the medium category dominating. The high-risk zone is concentrated on steep slopes in the central to northern parts of the study area, while the low-risk zone is generally found in flat areas and at the foot of slopes.

The major factor influencing landslide susceptibility, with a weight of 30%, is slope inclination. A slope with an inclination of more than 30% enhances shear stress and decreases shear strength. As a result, slope stability will be low. These findings are consistent with soil mechanics because, as the slope degree increases, there will be an increase in the force that drives landslides. Also, very steep slopes have low permeability. As a result, there may be surface runoff due to reduced infiltration capacity. Therefore, it will result in landslides [24][25].

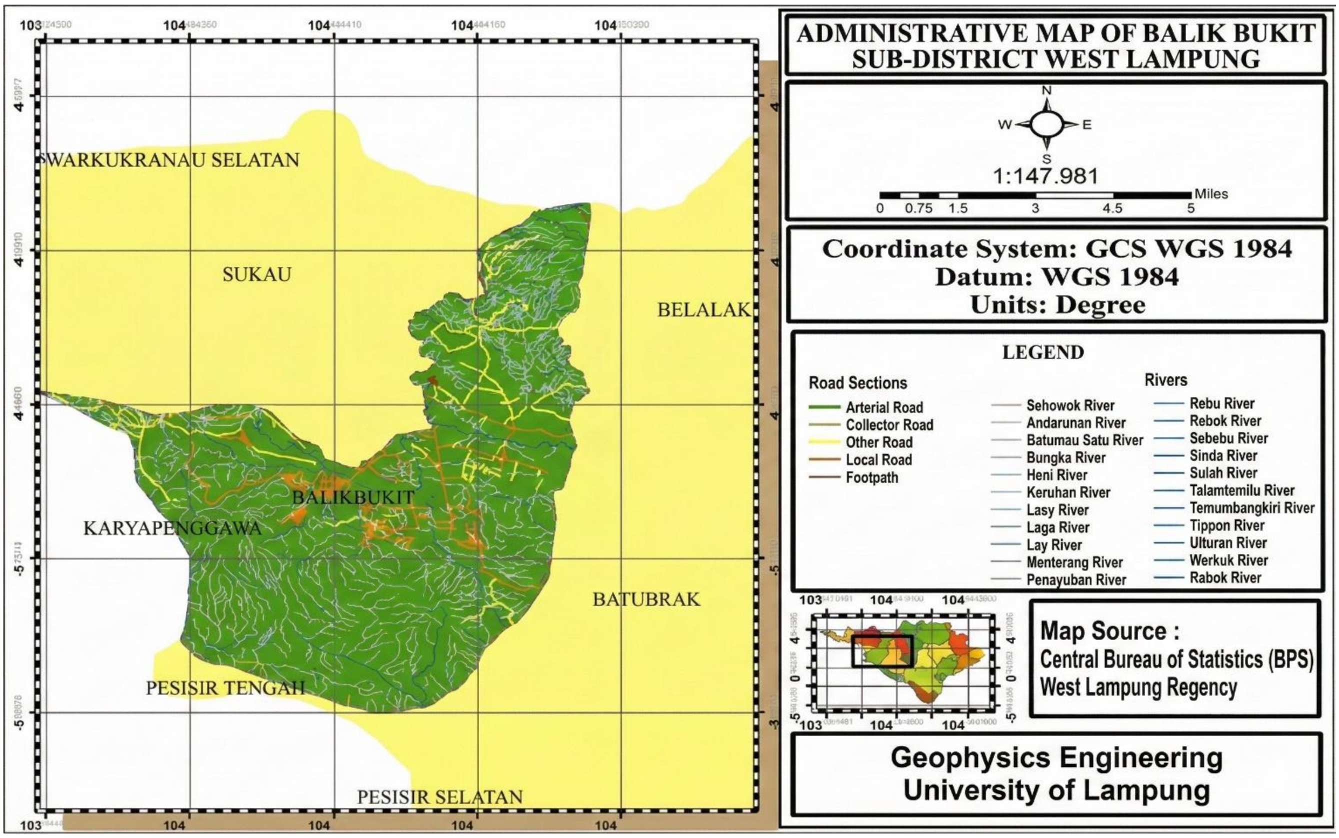

Figure 1. Administrative Map

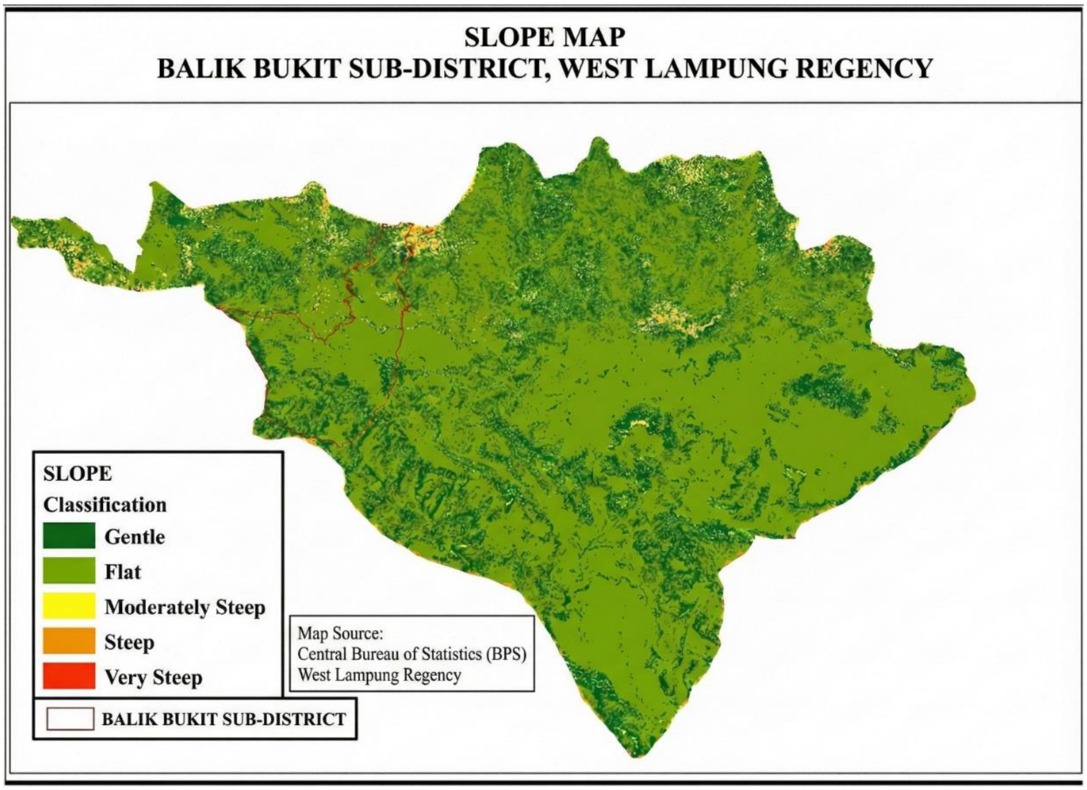

Figure 2. Slope Gradient Parameter Map

The rock type factor has an influence weight of 20% with a low correlation value (r = 0.042). These results hint that while rock is an important element in slope stability, at the investigation site, the influence is not of a dominant characteristic. The dominant rock types in this study area are volcanic rocks like breccia, lava, and andesitic-basaltic tuff, all easily subjected to weathering and producing much loose material. This process of weathering alters the physical properties of the rock to a more brittle constituent with reduced shear strength, particularly in steep slopes [26]. Thus, the influence of rock type is relatively indirect through the weathering products that become soil-forming materials.

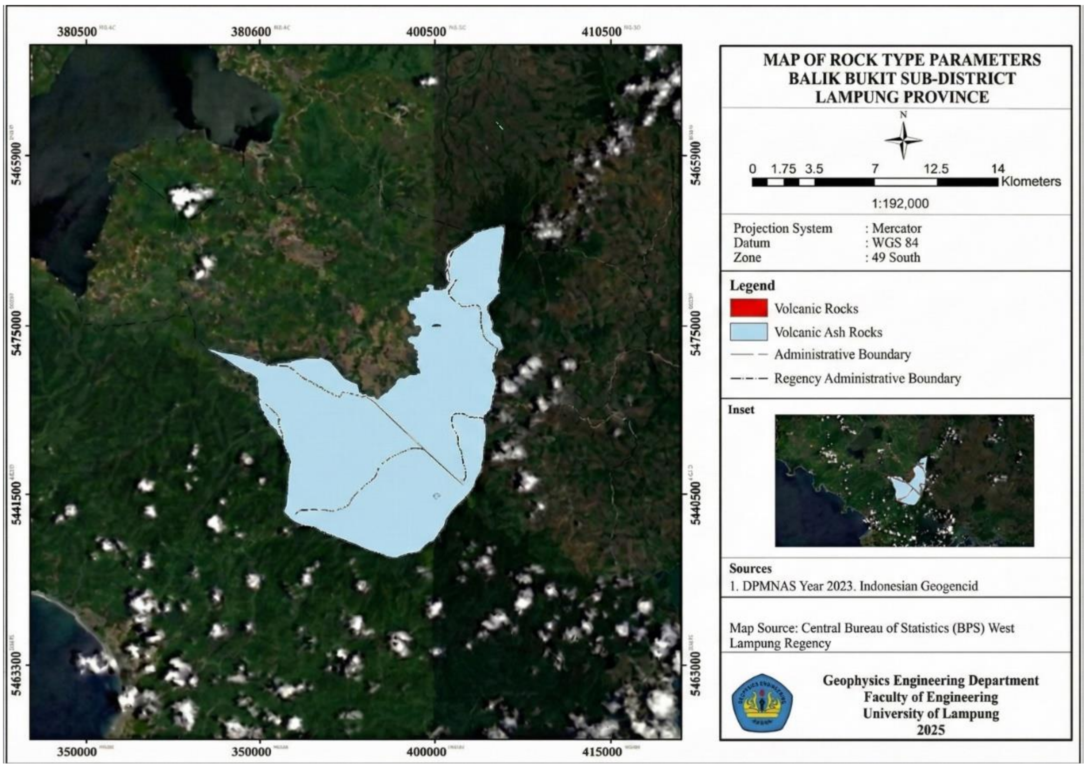

Figure 2. Rock Type Parameter Map

The parameter of the soil type is 10%, the correlation value (r = 0.051) shows that there is a very weak relationship between soil types and landslide potential. The clay and sandy soils, which are resulted from weathering volcanic rocks, dominate the study area. The clay soils are usually highly cohesive and have strong particle binding power, whereas they get saturated with water easily, whereas sandy soils have high infiltrability and tend to get unstable when fully saturated by water. Specifically, volcanic residual soils in Sumatra are known to exhibit a significant reduction in shear strength when the moisture content exceeds the plastic limit, accelerating slope failure [27]. These weak results are due to too general soil types classification and complex interaction between the soil factors, rainfall, and morphology.

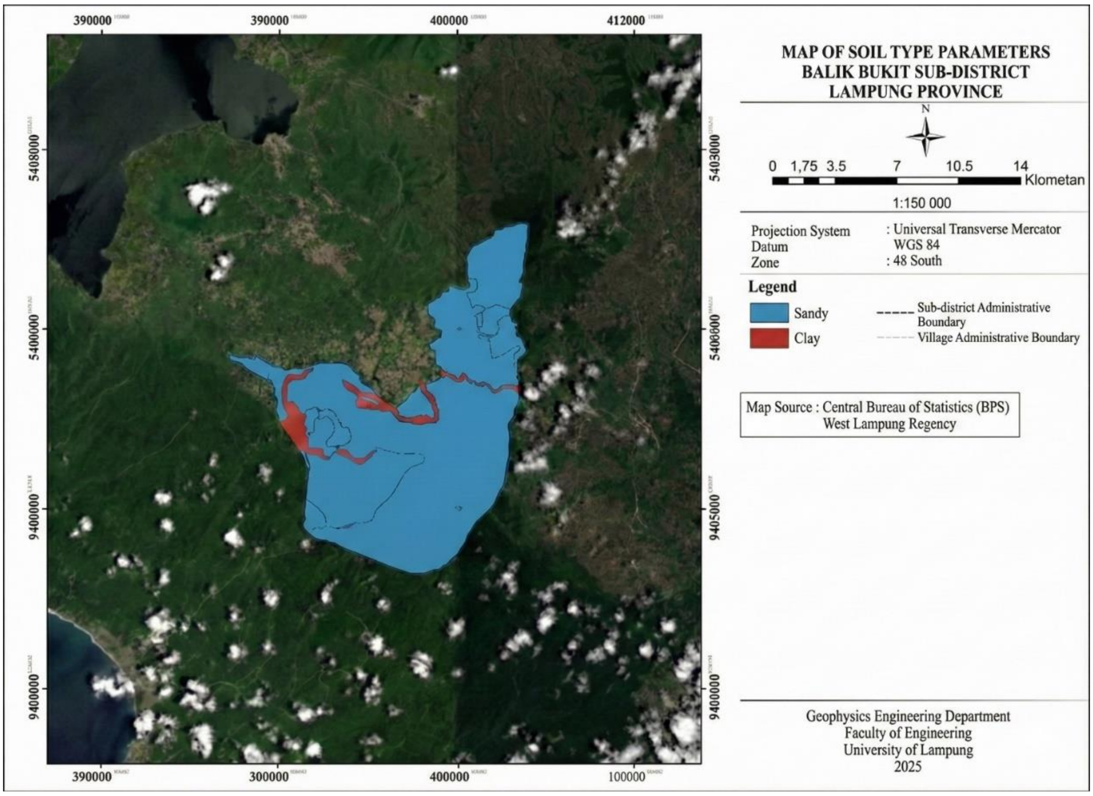

Figure 3. Soil Type Parameter Map

The rainfall variable with a weightage of 20% presents a low. Although rainfall represents a major landslide-triggering factor, annual rainfall records, as adopted in this analysis, are not comprehensive enough with regard to short-term changes in rainfall intensity, which can be a major landslide-triggering factor. Rains here receive an average annual rainfall ranging from 2,000 mm to 3,000 mm [28]. Rainfall here exhibits high values, mainly on the northern and western sides, with steep terrain. The relationship here regards rainfall and landslides as interactive. A high rainfall intensity would be an important factor if it occurs on a slope with steep terrain and soils that can be readily soaked with rainwater.

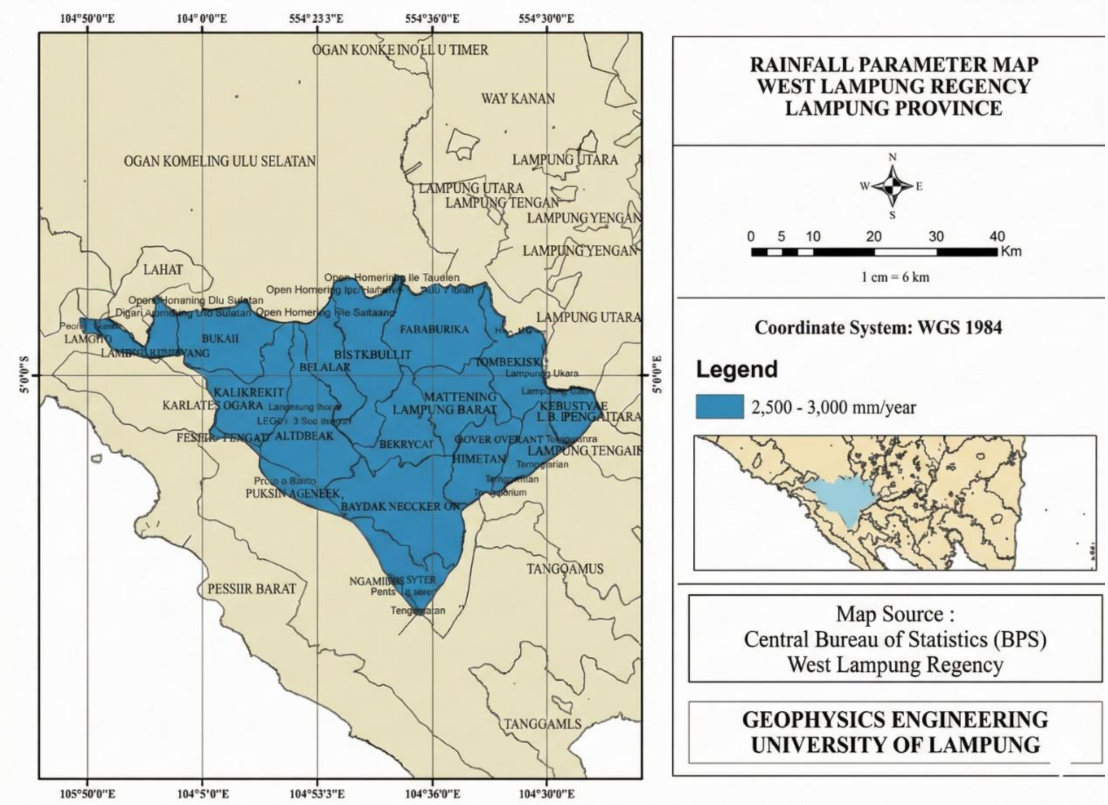

Figure 4. Rainfall Map

The integration of all parameters produced a landslide hazard zoning map, which depicted the distribution of risk levels in the study area. High hazard zones were identified to be located mainly in the central and northern parts of the Balik Bukit Subdistrict, with an area characterized by steep slopes, weathered volcanic rocks, and high rainfall intensity. In contrast, moderate hazard zones are scattered in the middle hills and partly cover the residential area. Low hazard zones are generally located within the lowland areas with very low slope inclination and more or less stable soil conditions.

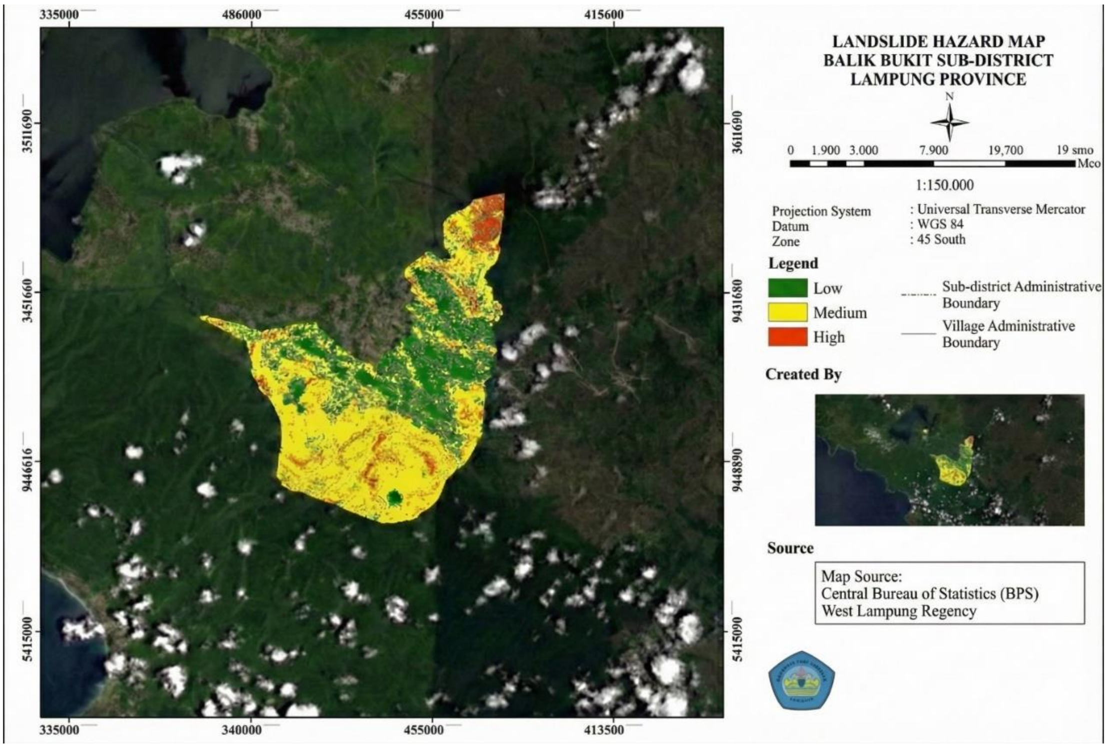

Figure 5. Landslide Hazard Map

Overall, the study results demonstrate that the GIS-based Weighted Overlay method is effective in integrating various physical parameters to obtain a landslide vulnerability map that is spatially accurate. This map not only depicts the distribution of hazards but also serves as a basis for mitigation planning. The proposed strategic recommendations include planting deep-rooted vegetation on steep slopes, improving drainage systems, developing monitoring and early warning systems, and increasing community awareness and participation in managing landslide-prone areas. The implementation of these measures is expected to enhance the resilience of Balik Bukit District against landslide threats while supporting safe, adaptive, and sustainable spatial planning.

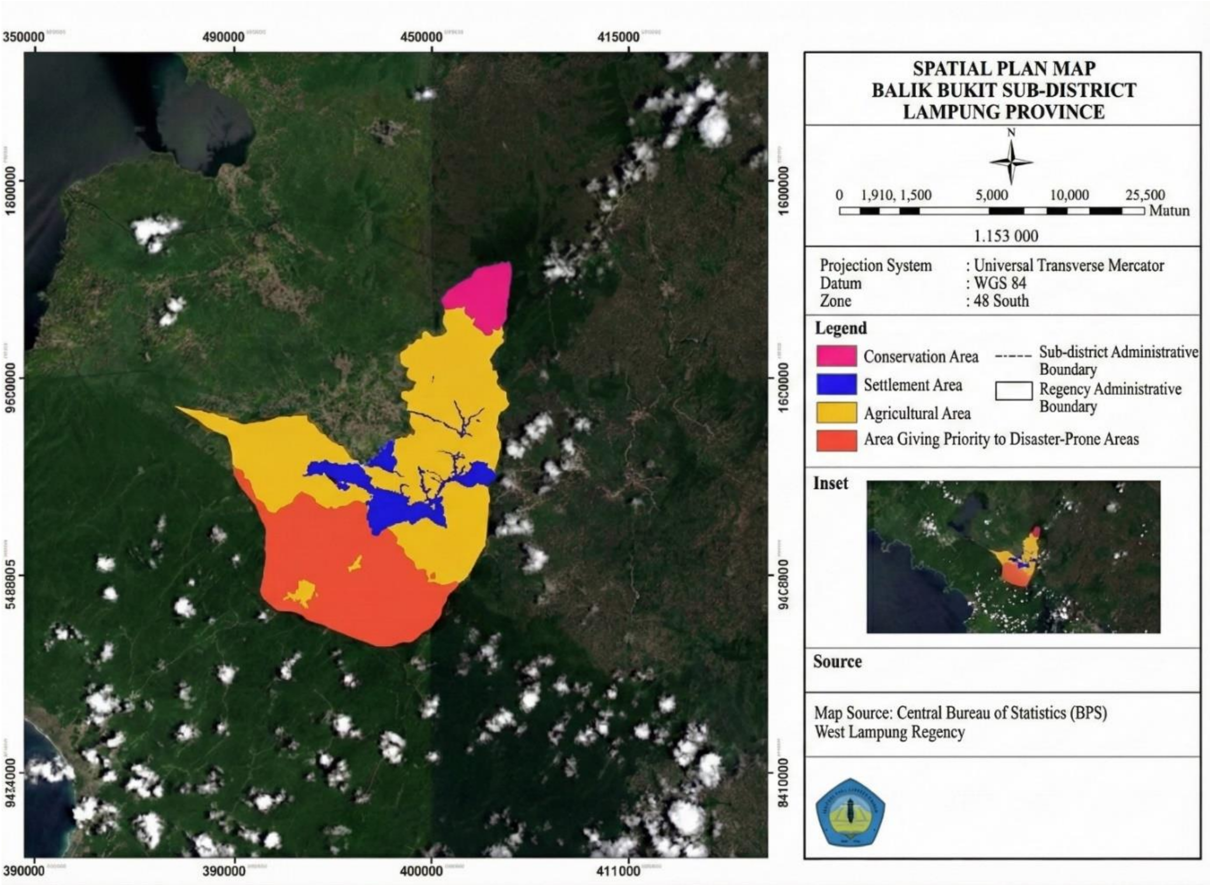

Figure 6. RTRW Map

These findings are consistent with previous studies conducted in Balik Bukit Subdistrict that applied a GIS-based Weighted Overlay approach for landslide hazard assessment [21]. Both studies identify slope inclination as the most influential parameter, followed by rock type, rainfall, and soil characteristics, while other factors exhibit relatively minor contributions. Moreover, the spatial distribution and extent of landslide hazard zones show strong similarities, with moderate hazard zones dominating the study area and high hazard zones concentrated on steep slopes composed of volcanically derived materials. This consistency confirms the robustness and reliability of the Weighted Overlay method in representing actual field conditions and supports its applicability as a scientific basis for landslide mitigation strategies and risk-informed spatial planning in landslide-prone regions.

III. Conclusions

The Weighted Overlay method on GIS spatial analysis for landslide vulnerability mapping in Balik

Bukit Subdistrict generated three zones, namely high, medium, and low with an area of 1,230.959 ha, 8,487.104 ha, and 4,878.442 ha, respectively. Of the eight factors considered in GIS, it was determined that

Slope inclination dominated with a weightage of 30%, followed by rock and rainfall with a weightage of 20% each, which clearly shows that slope inclination contributes greatly as a factor for landslides, and additionally, factors like rock and rainfall contribute as geological and hydrological factors. It has been made clear that combining all factors would be more reliable and authentic compared to previous research, and thus, it would be applicable as a scientific reference for disaster control and minimization as an approach for disaster control and minimization via enhancement of vegetation and soil bioengineering, management of drainage systems, enhancement of early warning systems, review of spatial planning, and enhancing community participation and awareness for making areas more resilient towards landslides. Integrating local wisdom and active community engagement in early warning protocols has been proven to significantly reduce casualty risks in disaster-prone rural areas [29].

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