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GIS-Based Spatial Analysis of Landslide Risk in the Bango Sub-Watershed, Malang Regency

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ABSTRACT

Purpose of the study: This study aims to assess and map landslide risk zones in the Bango Sub-Watershed, Malang Regency, by integrating natural physical factors and human activities using a GIS-based spatial analysis to support effective disaster mitigation and regional planning.

Methodology: Primary data, including land use patterns, slope excavation, pond and drainage construction, and infrastructure development, were integrated with secondary data such as rainfall records (2005–2014), geological maps, soil type maps, land use maps, and historical earthquake data. Thiessen polygons and overlay techniques were applied in ArcGIS 10.1 to systematically quantify spatial variations in landslide susceptibility across the Bango Sub-Watershed.

Main Findings: The results show that most areas in the Bango Sub-Watershed are classified as low to medium landslide risk, while high-risk zones, associated with slopes greater than 40%, are confined to steep terrain with intensive human activity. The integration of environmental factors, including slope, rainfall, and soil type, with anthropogenic activities produces more detailed and reliable spatial risk maps, enabling targeted prioritization for mitigation measures and supporting improved disaster planning and management.

Novelty/Originality of this study: This research integrates multiple environmental and human activity datasets into GIS through the use of Thiessen polygons and overlay analysis, offering a more comprehensive and precise assessment of landslide risk than previous studies. The methodology provides a replicable framework for other similar watersheds, supporting enhanced disaster mitigation planning, informed land-use decisions, and evidence-based strategies for reducing potential damage in vulnerable areas.

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1. INTRODUCTION

A watershed is an essential ecosystem for managing water resources and the surrounding environment. Each watershed exhibits complex interactions between physical conditions, hydrology, and human activities [1], [2]. The Bango Sub-Watershed in Malang Regency is a tributary of the Brantas River with hilly terrain and steep slopes. These characteristics make the area highly susceptible to landslides, which can threaten communities and

infrastructure [3], [4]. Geographic Information System (GIS) technology provides a practical solution for mapping and analyzing landslide risks with precision and efficiency.

Landslides frequently occur in the Bango Sub-Watershed, particularly in areas with steep slopes and high rainfall. Such events can damage land, settlements, and critical infrastructure while posing a significant risk to human life. Currently, comprehensive risk maps are limited, making disaster management largely reactive [4], [5]. Communities and local authorities often have insufficient information about areas prone to landslides [6]. This situation highlights the need for a detailed and integrated spatial analysis of landslide risk in the watershed.

Previous studies have examined landslide risk using both conventional methods and GIS-based approaches. Many focused primarily on physical parameters such as slope, rainfall, and soil type [7]. However, few studies have combined multiple factors into a comprehensive spatial analysis at the scale of the Bango Sub-Watershed. Assessments that incorporate Thiessen polygons or overlays of rainfall and land-use data remain rare [8], [9]. These limitations indicate the importance of conducting a more integrated and structured analysis to support effective risk management.

In the Bango Sub-Watershed, current information about landslide-prone areas remains fragmented and limited. A more detailed spatial assessment is necessary to guide stakeholders in planning mitigation strategies [10], [11]. By combining data on rainfall, slope, land use, and human activities, this study provides a clearer picture of areas most at risk. Such analysis allows for targeted interventions to reduce damage and enhance safety [12], [13]. This approach aims to provide practical guidance that has not been previously available in the region.

Understanding the spatial distribution of landslide risk is essential for both community safety and sustainable planning. Accurate maps can inform local authorities and agencies in designing effective disaster mitigation measures [14], [15]. At the same time, residents can use this information to prepare and respond proactively. Detailed spatial analysis also helps in prioritizing areas for monitoring and preventive action [16]. Overall, this study contributes to a more evidence-based approach to managing landslide hazards.

This research integrates multiple environmental and human activity parameters into a GIS-based model to produce more detailed and reliable risk maps. By using Thiessen polygons and overlay techniques, the analysis identifies zones ranging from low to high landslide susceptibility [17], [18]. The approach highlights areas that have not been analyzed in previous studies, providing new insights for risk reduction. The results can support informed decision-making and better planning in the Bango Sub-Watershed. In this way, the study offers a fresh perspective on landslide risk management that can be applied to other similar watersheds.

2. RESEARCH METHOD

2.1. Study Area

The research was conducted in the Bango Sub-Watershed, a tributary of the Brantas River originating from the slopes of Mount Tunggangan. The river has a U-shaped rocky bed, with an approximate length of 11,061 meters and a width of 30 meters. The study area covers about 360.244 km² and is geographically located between 9,115,843 – 9,141,425 meters south and 672,794 – 696,354 meters east, based on the UTM 1983 projection with WGS84 datum, zone 49. This area was selected due to its steep slopes, varied topography, and high potential for landslides. Its diverse conditions make it suitable for a GIS-based spatial analysis of landslide risk.

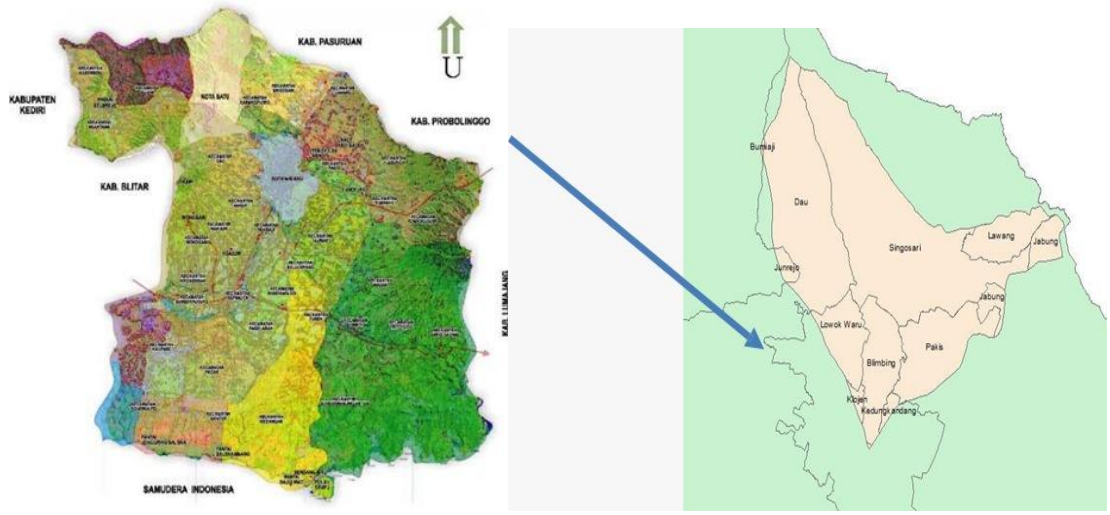


Figure 1. Study Area

2.2. Data Collection

The study utilized both primary and secondary data. Primary data included land use patterns, slope excavation, pond construction, drainage systems, infrastructure development, and local mitigation activities. Secondary data were obtained from rainfall records from 2005 to 2014, maps of the Bango Sub-Watershed, geological maps, land use maps, soil type maps, historical earthquake records, and population density. Integrating these datasets into a GIS database allowed for a comprehensive analysis of both natural and human factors affecting landslide susceptibility. Combining primary and secondary data ensures that the spatial analysis reflects real-world conditions accurately.

2.3. Data Processing

Rainfall data were first checked for consistency and anomalies using double mass curve analysis and inlier-outlier tests. This step was crucial to ensure reliable data for further spatial modeling. Verified data were then prepared for processing in ArcGIS 10.1, where GIS tools were used to create Thiessen polygons. These polygons distributed rainfall and other parameters across the study area, representing local variations effectively. This processing step allows each part of the watershed to be analyzed according to its specific environmental and human-influenced conditions.

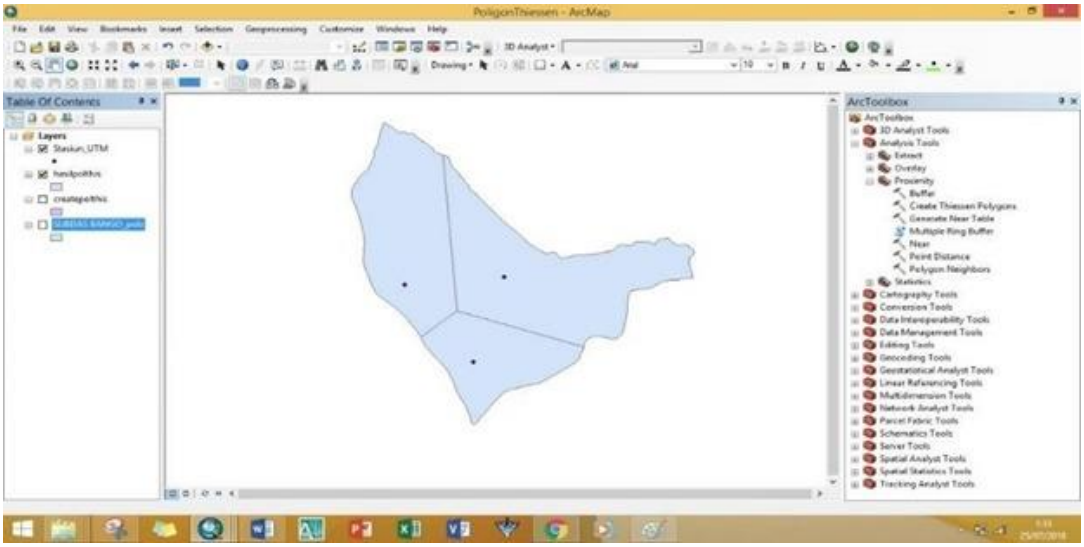


Figure 2. Poligon Thiessen overlay

The figure above illustrates how Thiessen polygons divide the watershed into sub-areas, each associated with a rainfall station. This method ensures that rainfall data are spatially distributed across the study area in a way that reflects actual variations. By using this approach, each polygon can be analyzed individually, which is critical for accurate hydrological and landslide risk modeling. Additionally, this overlay allows researchers to visualize patterns of rainfall distribution, identify high-risk zones, and plan further GIS-based spatial analyses efficiently.

2.4. Landslide Risk Scoring

Each Thiessen polygon was scored based on parameters from the Indonesian Ministry of Public Works Regulation No. 22 of 2007, including slope, rainfall, land use, and human activities. Scores were assigned from low to high risk to quantify the susceptibility of each zone. This scoring system provides a structured and comparable way to evaluate different areas within the watershed. By applying this method, the study can clearly identify areas that require prioritized attention and mitigation [19], [20]. The approach ensures that risk assessment is both systematic and applicable to practical disaster management.

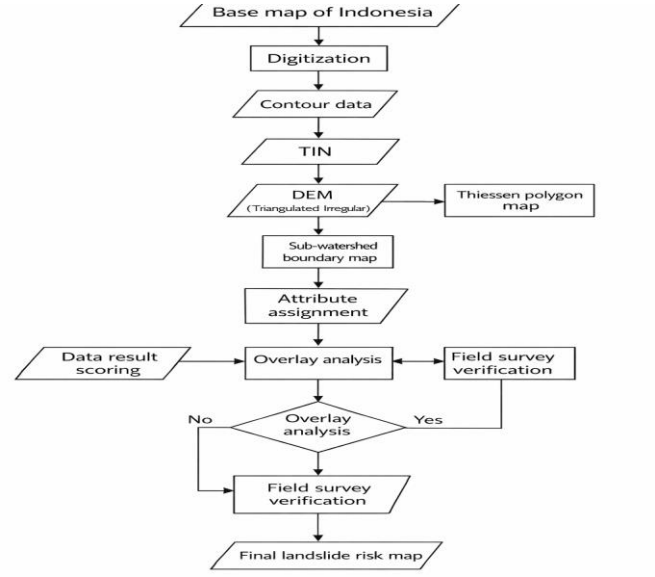


Figure 3. Scoring flowchart

The figure above shows the step-by-step process used to assign landslide risk scores to each Thiessen polygon. It illustrates how multiple parameters are integrated into a single risk value for each area. This visual representation helps readers understand the logical flow of the scoring system, from data input to final risk classification. By using this approach, it becomes easier to identify high-risk zones, plan mitigation strategies, and support decision-making in watershed management.

3. RESULTS AND DISCUSSION

3.1. Rainfall Data Analysis

Rainfall data for the Bango Sub-Watershed was obtained from three stations during the 2005–2014 period. Station locations were validated through field surveys and Google Earth to ensure coordinate accuracy. Double mass curve analysis was conducted to detect anomalies or data inconsistencies. The results indicate that all three stations showed no significant deviations, thus the rainfall data is reliable for landslide potential analysis.



Figure 4. View of the Bango Sub-DAS in Google Earth

This map shows the location of the rainfall stations used for data analysis in the Bango Sub-Watershed, which were validated through field surveys to ensure coordinate accuracy.

3.2. Determination of Landslide-Prone Areas

Landslide-prone areas were identified based on natural physical factors and human activities. Physical factors include slope gradient, soil type, geology, rainfall, vegetation, and earthquake history. Slopes with >40% gradient are categorized as high-risk zones, 15–40% as medium-risk zones, and <15% as low-risk zones. Human activities affecting landslide risk include slope excavation, construction, and land use patterns. The combination of these factors produces a preliminary landslide hazard map.



Figure 5. Bango Sub-DAS Slope Map

This map highlights that areas with slopes greater than 40% are concentrated in specific zones and represent the highest potential for landslides. The visualization helps to identify locations where mitigation measures and careful land management are most needed.

3.3. Scoring of Landslide-Prone Areas

Each factor was assigned a score following the guidelines of Permen PU No.22 of 2007. Total scores determine risk levels:

- Zone A (High): score >2, priority for mitigation.
- Zone B (Medium): score 1.89–2.145.
- Zone C (Low): score <1.805.

The scoring shows that the combination of physical and human factors spatially determines the level of landslide risk.

Table 1. Factor Scores And Risk Categories

Factor	Weight	Zone A Score	Zone B Score	Zone C Score
Slope	0.3	>2	1.89–2.145	<1.805
Soil	0.2	>2	1.89–2.145	<1.805
Human Activity	0.3	>2	1.89–2.145	<1.805
Rainfall	0.2	>2	1.89–2.145	<1.805

3.4. Landslide Hazard Map Results

Overlaying physical aspects and human activities shows the distribution of Zones A, B, and C. Most areas fall under low and medium risk, while high-risk zones are limited to steep slopes with intense human activity. This map serves as a basis for prioritizing disaster mitigation efforts.

Table 2. Distribution of Landslide Risk Zones in SubDAS Bango

Zone	Slope Range	Risk Level	Area (km²)	% of Total Area
A	>40%	High	5.82	1.62
B1	30-40%	Medium	57.60	15.99
B2	15-30%	Medium	43.53	12.08
C1	8-15%	Low	54.00	14.99
C2	3-8%	Low	47.14	13.09
C3	0-3%	Low	127.17	35.30
Total	–	–	360.24	100.00

3.5. Interpretation and Analysis of the Map

The analysis of the landslide-prone areas in the SubDAS Bango shows that most of the area is classified as low-risk, followed by medium-risk and a small portion as high-risk. The distribution of each risk level is summarized in Table 1 below.

Table 3. Distribution of Landslide-Prone Areas in SubDAS Bango

Potential	Area (km²)	Percentage (%)
Low	203.59	56.51
Medium	150.84	41.87
High	5.82	1.62
Total	360.24	100.00

From the table, it is evident that the majority of the SubDAS Bango area falls under the low-risk category (56.51%), while high-risk zones are minimal (1.62%). To visualize this distribution clearly, a pie chart or bar chart can be used, which will help readers quickly understand the proportion of each risk level.

Suggested Figure:

- Create a pie chart using the percentages: Low (56.51%), Medium (41.87%), High (1.62%).
- Label it as Figure 5 – Distribution of Landslide-Prone Areas in SubDAS Bango.

The spatial analysis of the Bango Sub-Watershed indicates that most areas fall under low to medium landslide risk, while high-risk zones are limited to steep slopes with intensive human activities. Rainfall data validated through field surveys and double mass curve analysis confirm the reliability of precipitation patterns for modeling landslide potential. Slope analysis shows that areas with gradients above 40% are concentrated in specific locations, emphasizing the need for careful monitoring. Integration of human activity parameters such as excavation, construction, and land use patterns further refines the identification of susceptible zones. Overall, the results provide a detailed understanding of spatial variation in landslide risk across the watershed.

The scoring system applied using the guidelines from Permen PU No. 22 of 2007 effectively classified the Sub-Watershed into Zones A, B, and C corresponding to high, medium, and low landslide susceptibility. Zone A, representing only 1.62% of the total area, requires priority mitigation measures. Medium-risk zones occupy approximately 28% of the area, while low-risk zones dominate with 56.51%. These findings are consistent with the overlay maps produced through GIS, illustrating the combined effects of physical and anthropogenic factors. The visualizations provide clear insights for risk prioritization and planning.

Despite the detailed analysis, existing studies in similar watersheds often focus solely on physical parameters such as slope, soil type, and rainfall. Few investigations have combined multi-factor GIS-based spatial analysis with both natural and human-induced parameters at this scale. This gap in previous research highlights the novelty and necessity of integrating comprehensive datasets for more accurate risk assessment. Comparisons with prior studies show that considering human activities significantly alters risk distribution maps. Therefore, the current research addresses a key limitation in the literature by providing a more holistic spatial assessment.

The novelty of this study lies in its integration of multiple environmental and human activity datasets through GIS, which has not been extensively applied in the Bango Sub-Watershed. By employing Thiessen polygons and overlay techniques, the research identifies localized variations in rainfall, slope, and land use that affect landslide susceptibility [21], [22]. This approach produces more precise and actionable risk maps compared to conventional methods. The study demonstrates a practical methodology for combining diverse spatial data for disaster mitigation planning [23]. Additionally, it offers a replicable framework for other watersheds with similar geomorphological and socio-environmental characteristics [24].

The findings have important implications for disaster management and regional planning. Accurate identification of high-risk zones enables local authorities to prioritize mitigation efforts such as slope stabilization, land-use regulation, and community awareness programs [25], [26]. Residents can use the maps to prepare and respond proactively to potential landslide events. Furthermore, the study supports evidence-based decision-making for infrastructure development and environmental management [27], [28]. In this way, the research contributes to reducing potential damage and enhancing community resilience.

Nevertheless, the study has some limitations that should be acknowledged. The analysis relies on historical rainfall data from 2005–2014, which may not capture recent climate variability or extreme weather events. Human activity data may also change over time, potentially altering current risk patterns [29]. Certain micro-scale features, such as small drainage channels or local excavation, were not included due to data availability constraints. Future research could incorporate real-time monitoring, updated land use changes, and higher-resolution terrain data [30]. Despite these limitations, the study provides a solid foundation for informed landslide risk management in the Bango Sub-Watershed.

4. CONCLUSION

This study demonstrates that GIS-based spatial analysis can effectively identify landslide risk zones in the Bango Sub-Watershed, integrating both natural factors such as slope, rainfall, and soil type, and human activities including land use and construction. The results indicate that most areas fall under low to medium risk, while high-risk zones are confined to steep slopes with intensive human activity, providing a clearer basis for prioritizing mitigation efforts. By combining multiple datasets through Thiessen polygons and overlay techniques, the research produces more detailed and reliable risk maps than previously available, addressing gaps in earlier studies that focused on single parameters. The findings offer practical applications for local authorities and communities, such as informed land-use planning, targeted disaster preparedness, and early warning strategies. Furthermore, the methodology can be applied to similar watersheds, allowing future studies to incorporate dynamic factors like updated land use and climate change impacts to enhance predictive accuracy.

Overall, this study contributes to evidence-based decision-making and supports proactive disaster risk reduction in hilly and vulnerable watersheds.

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