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LANDSLIDE VULNERABILITY MAPPING USING SPATIAL ANALYSIS METHODS, CASE STUDY IN WATULIMO SUB-DISTRICT, TRENGGALEK DISTRICT, EAST JAVA

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Abstrak

Penelitian ini bertujuan untuk menilai kerentanan tanah longsor di Kecamatan Watulimo dengan menggunakan Sistem Informasi Geografi (SIG). Metodologi yang digunakan adalah pendekatan kuantitatif berjenjang tertimbang terhadap beberapa parameter seperti curah hujan, kemiringan lereng, geologi, jenis tanah, dan penggunaan lahan. Hasil penelitian menunjukkan bahwa sebagian besar wilayah Kecamatan Watulimo diklasifikasikan sebagai daerah yang rentan terhadap longsor, dengan daerah yang sangat rentan berada di Desa Slawe, Dukuh, dan Watulimo. Bagian utara dan selatan kecamatan menunjukkan kerentanan yang lebih rendah. Faktor-faktor utama yang mempengaruhi kerentanan tanah longsor meliputi kecuraman lereng, curah hujan, dan penggunaan lahan. Pemetaan tingkat kerentanan tanah longsor memberikan informasi penting untuk pembuatan kebijakan yang bertujuan untuk mengurangi risiko bencana.

Kata kunci: *Tanah longsor, Kerentanan, Sistem Informasi Geografi, Trenggalek*

Abstract

This study aims to assess landslide vulnerability in the Watulimo sub-district using Geographic Information System (GIS)-based analysis of landslide susceptibility factors. The methodology employed a weighted tiered quantitative approach to various parameters including rainfall, slope, geology, soil type, and land use. The results indicate that the majority of the Watulimo sub-district is classified as vulnerable to landslides, with highly vulnerable areas concentrated in Slawe, Dukuh, and Watulimo villages. The northern and southern parts of the sub-district exhibit lower vulnerability. Key factors influencing landslide susceptibility include slope steepness, rainfall patterns, and land use practices. Mapping landslide vulnerability levels provides essential information for policymaking aimed at mitigating disaster risks.

Keywords: Landslide, Vulnerability, Geographic Information System, Trenggalek

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Introduction

Climate change is defined as a change in climate due to natural or human activity over time (IPCC, 2007). Climate change affects seasonal shifts and changes in the hydrological system that caused hydrometeorological disasters. One of the most common hydrometeorological disasters in Indonesia is landslides. Analysis of climate change is important in developing countries that are prone to disasters, such as Indonesia (Haines, 2004). Landslide is the movement of a mass of rocks, soil, or rubble down a slope (Cruden, 1991). Landslides can occur due to high rainfall. Changes in rain patterns lead to increased rain intensity which has an impact on increasing surface runoff and erosion (Nearing et al., 2004). The increasing amount of infiltration will have an impact on the saturated soil, then the soil porosity will become easily destroyed and soil aggregation becomes weak so that soil resistance decreases. In addition, water saturated soil can add to the burden of soil that will trigger avalanches.

Mapping the level of landslide vulnerability is one of the solutions to reduce the risk of disasters, aimed at private, public, government, researchers (Shahabi and Hashim, 2015). This mapping utilizes GIS in its creation. GIS plays a role to facilitate the presentation of spatial information related to the level of landslide vulnerability in a region (Effendi and Hariyanto, 2016). Landslide hazards that can be identified quickly through geographic information systems by stacking or overlaying methods on the parameters of landslide causes such as: slopes, rainfall, altitude, soil type, and land cover (Geological Agency, 2010).

Trenggalek district is a potential area for landslide hazards. Based on Badan Pusat Statistik (2020), from 2016 to 2020, 408 landslides occurred in Trenggalek Regency. According to Riadi, et al. (2019), Watulimo sub-district has a high vulnerability to landslide hazard in Trenggalek District. Therefore, this study aims to produce a landslide vulnerability map of Watulimo Subdistrict based on landslide factors using GIS, thus it will increase coping capacity in watulimo district.

Methods

Watulimo sub-district lies within longitude 111°38’41” to 111°46’41” and latitude 8°8’31” to 8°23’01” and covers an area 154.44 km². This sub-district has 12 villages consist of Karanggandu, Prigi, Tasikmadu, Watulimo, Margomulyo, Sawahan, Hamlet, Slawe, Gemaharjo, Pakel, Ngembel and Watuagung, as depicted in

Figure 1. Watulimo sub-district is dominated by hills and coastal landforms (BPS, 2020). In this study, the data consisted of landslide parameters according to Riadi, et al., (2019) such as slope, geology, lithology, rainfall, and land use. Geologic factors only contain geology formation. Slope and lithology that were used in this study represent the topographic factor, meanwhile rainfall and land use represent environmental factors.

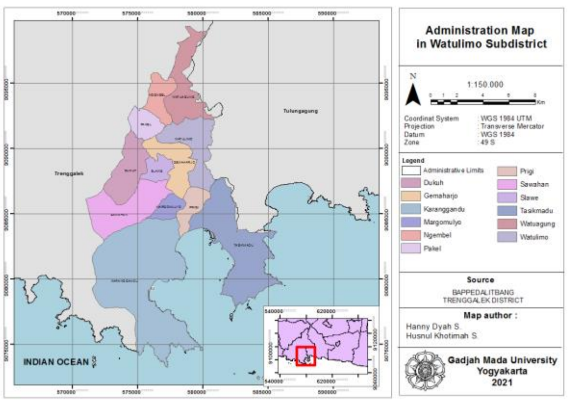


Figure 1. Administration Map in Watulimo Subdistrict

Slope is an important parameter for analyzing the assessment of slope stability (Wu, et al., 2016). The slope map in this study shows that most of this area has more than 25%. The increase of slope affects increases in landslide events. Geology and lithology can also influence landslides by the thickness of soil solum and the weathering material. Thicker soil solum and more weathering affects material to move (Riadi, et al., 2019). Lithology is shown as the land type map. Rainfall has a positive correlation with landslides by its intensity (Yu and Chen, 2020). Higher rainfall intensity results in a higher occurrence of landslides. The last parameter used in this study is land use which takes effect of landslides by the presence of vegetation. Land use at a non vegetated site would have higher risk of landslide.

The research flowchart is shown in **Figure 2** representing the steps and processes involved in this study. Slope were derived from DEM SRTM 90 m by Badan Informasi Geospasial (BIG). The spatial resolution of this data is 0.27-arcsecond and uses the EGM 2008 vertical datum. Meanwhile, geology, lithology, rainfall, and land use maps scale 1:50.000 were obtained from Bappedalitbang Trenggalek District.

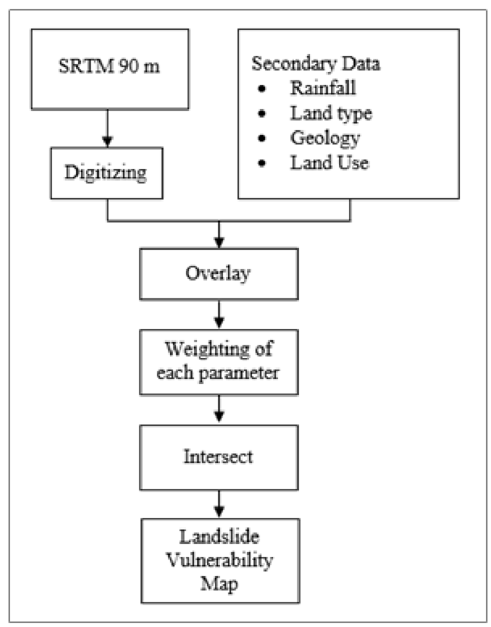


Figure. 2 Flow diagram of this study

Landslide vulnerability map was

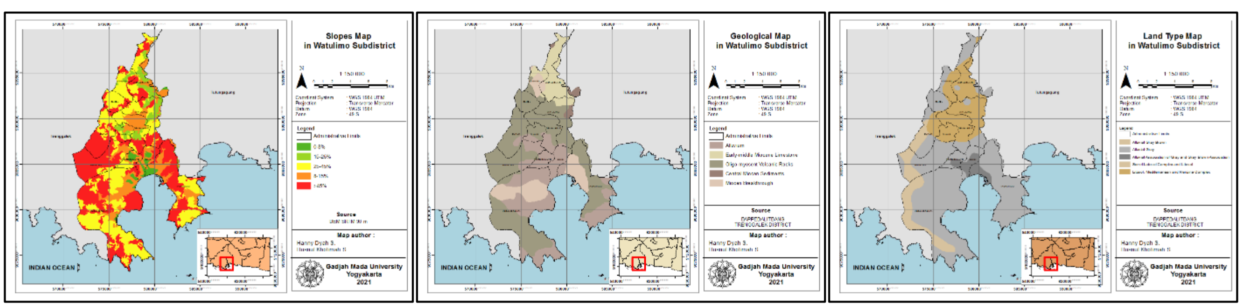
obtained by overlaying slope, geological, soil, rainfall, and land use map (Arifin, et al., 2010). Using this method, each parameter is weighed using a tiered quantitative approach. The weight of each parameter is graded based on their importance. The weights that were used in this study derived from the previous research which can be seen in **Table 1** (Lestari, 2008; Taufik and Suharyadi, 2008; Taufik and Firdaus, 2012). The following step consists of calculating each score by multiplying the weight of each parameter with its classification. **Figure 3** depicts all the landslide parameters after each has been weighted. Afterward, all the scores were summed to obtain the final result (Sani, et al., 2018).

All processes were conducted using ArcGIS. Model Builder is the feature in ArcGIS that facilitates geoprocessing through a flowchart, thereby simplifying the process (Wiles and Mallard, 2008). Overlaying maps in this study utilized the Intersect and Calculate Field tools. The Intersect tool was

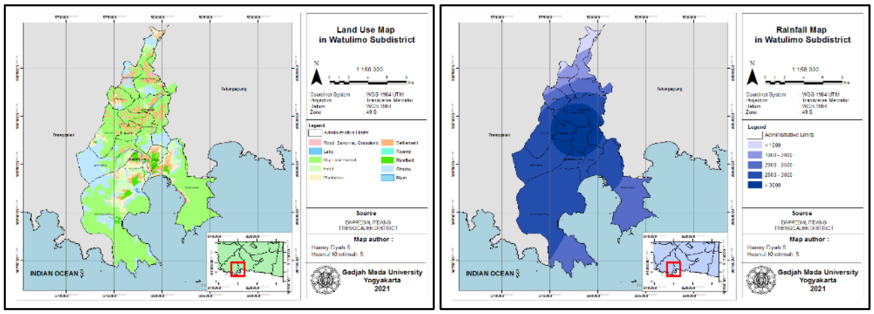
Table 1. Parameters Weight

No.	**Parameters**	**Weight**
1	Slope	3
2	Rainfall	2
3	Land use	2
4	Geology	1
5	Land type	1

employed to overlap each parameter map, including its attribute table that contains the weight of each classification. Subsequently, the Calculate Field tool was used to determine the final weight. The landslide vulnerability map was exported using Model Builder, resulting in four classifications: non-vulnerable, slightly vulnerable, vulnerable, and very vulnerable.



(a) (b) (c)



(d) (e)

Figure 3. Landslide parameter maps: (a) Slope Map; (b) Geological Map; (c) Land Type Map; (d) Landuse Map; and (e) Rainfall Map

Results and Discussion

The results of the landslide vulnerability assessment in Watulimo reveal that almost all areas are vulnerable, as depicted in **Figure 4**. The areas classified as very vulnerable are located in the central zone of the Watulimo sub-district. These highly vulnerable areas include Slawe, Dukuh, and Watulimo. The most influential parameter for landslide vulnerability is slope, with these areas mostly characterized by steep slopes (>25%). The steeper the slope, the higher the vulnerability to landslides (Taryana, et al., 2023; Diara, et al., 2022). Additionally, rainfall intensity in these regions exacerbates the vulnerability to landslide, as mentioned by Isnaini, et al. (2022). Intense rainfall saturates the soil, increases water pressure within the soil pores, and triggers erosion processes, all of which weaken soil stability and contribute to heightened landslide risk (Aristizábal, et al., 2022; Feranie, et al., 2021). Despite these factors, other parameters such as soil type and land cover also influence landslide susceptibility, albeit to a lesser extent.

In contrast to the previous condition, the northern and southern parts of Watulimo sub-district are mostly classified as non-vulnerable and slightly vulnerable to landslides. While slope and rainfall intensity are the most influential factors, land use in these areas has a lesser impact. These regions are predominantly covered by plantations, dryland forests, and shrubs, contributing to their lower vulnerability. The presence of this vegetation cover helps stabilize the soil and

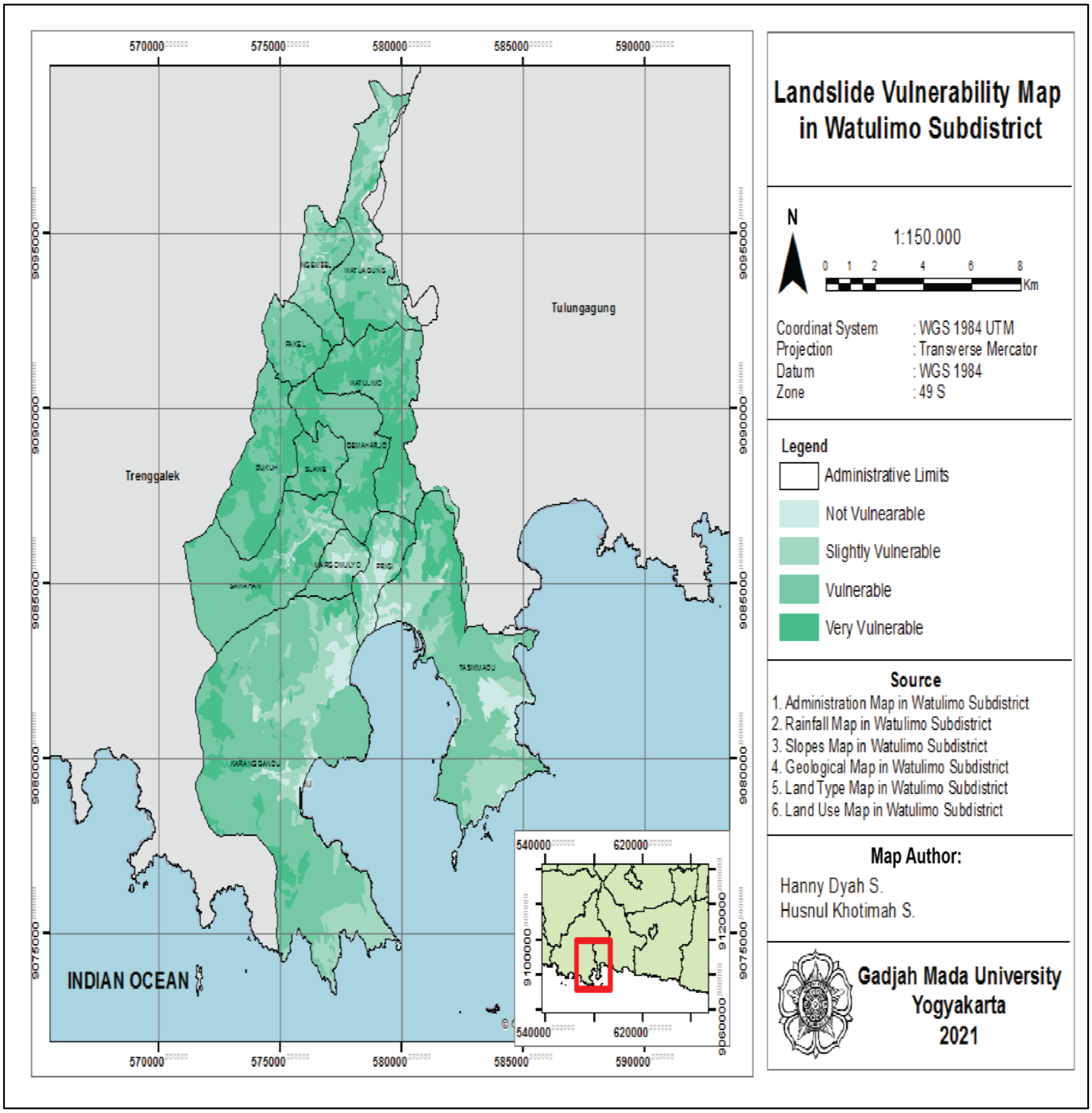


Figure 4. Landslide Vulnerability Map in Watudimo Subdistrict

reduce the likelihood of landslides by absorbing and filtering water from heavy rainfall (Asada and Minagawa, 2023). Therefore, land use plays a significant role in reducing landslide vulnerability, especially in steep areas, as indicated in previous research where changes in land use have been shown to significantly affect landslides in Trenggalek (Maulana and Taufik, 2020).

The distribution of landslide vulnerability in the Watulimo sub-district from this research shows similarities to previous studies conducted by Riadi et al. (2019) and Maulana and Taufik (2020), indicating that the area remains predominantly vulnerable to landslides. However, slight differences in distribution were observed, likely attributable to variations in rainfall data. Changes in rainfall patterns have been found to significantly influence the distribution of landslide vulnerability, as noted by Asada and Minagawa (2023). They highlighted that increased frequency of heavy rainfall events, influenced by climate change, escalates the risk of landslides. Therefore, understanding and monitoring these rainfall patterns are crucial for effective landslide risk management strategies in the Watulimo sub-district.

The mitigation strategies for landslides play a crucial role in reducing risks, especially given changing weather patterns. Proactive measures such as comprehensive land use planning, slope stabilization techniques, and early warning systems are essential. Implementing sustainable land management practices, such as reforestation and soil conservation, can enhance soil stability and reduce landslide susceptibility (Sudmeier-Rieux, et al., 2019). Community involvement in landslide mitigation programs is crucial for increasing awareness among residents. Moreover, government investment in resilient infrastructure strengthens resilience against landslide hazards. By integrating these strategies, stakeholders can effectively mitigate the adverse impacts of landslides exacerbated by climate change, ensuring the safety and sustainability of vulnerable regions.

Conclusions

The landslide vulnerability map of Watulimo sub-district in this study reveals that most of all areas are vulnerable to landslides. The highest vulnerability is concentrated in the central part of the sub-district, with less vulnerable areas situated in the northern and southern regions. Slope steepness emerged as the most influential parameter, alongside rainfall patterns and land use practices. Climate change-induced alterations in weather patterns have further exacerbated landslide vulnerability in Watulimo sub-district. Therefore, it is important to implement effective mitigation strategies to enhance resilience against landslides.

Recommendation

Building on this research, it is recommended to delve deeper into specific factors influencing landslide vulnerability using primary data. Further studies could explore the temporal and spatial dynamics of rainfall patterns and their correlation with landslide occurrences. By doing so, future research can complement the existing findings and contribute to a more comprehensive understanding of landslide assessment in Watulimo sub-district.

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