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SPATIAL STUDY OF LAND USE PLANNING GUIDELINES FOR LANDSLIDE DISASTER MITIGATION IN BONDOWOSO REGENCY

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Abstract. Natural disasters, such as landslides, can occur unpredictably, leading to significant damage to infrastructure, loss of life, and environmental degradation. In Indonesia, landslides are a major threat, particularly in mountainous and hilly regions with unstable soil and high rainfall. This study focuses on landslide risk assessment in Bondowoso Regency using a quantitative approach with data analysis tools such as Analytical Hierarchy Process (AHP) and Weighted Overlay Analysis. The study identifies vulnerability levels and classifies them into high, moderate, and low-risk areas. The findings reveal that 5,047.89 Ha of land fall under high-risk areas, while 50,358.61 Ha are classified as moderate risk, and 100,197.74 Ha are low-risk zones. The study recommends disaster risk mitigation strategies through spatial planning based on the PAR (Protection, Adaptation, Relocation) framework. Protection measures are suggested for low to moderate-risk areas, while adaptation and relocation strategies are proposed for high-risk zones. This research provides critical insights for reducing disaster risks and enhancing spatial planning to improve disaster resilience.

Keywords: Landslide risk; Spatial planning; Vulnerability assessment; AHP–Weighted Overlay; Disaster mitigation in Indonesia

I. INTRODUCTION

Natural disasters are phenomena that can occur at any time and in any place, posing significant risks to human life, infrastructure, and the environment. These disasters often result in substantial material losses and human casualties, disrupting economic stability and societal well-being (Nugroho et al., 2009). According to the Indonesian Disaster Risk Index (IRBI, 2013), disasters are categorized into three main types: natural disasters, non-natural disasters, and social disasters. The impact of disasters varies depending on the level of vulnerability of human settlements, environmental conditions, and the resilience of infrastructure (Himbawan, 2010). Among the various natural disasters affecting Indonesia, landslides are one of the most significant threats, particularly in mountainous and hilly regions with high rainfall and unstable soil conditions (Hadmoko et al., 2017).

Landslides are defined as the movement of slope-forming materials, including rocks, debris, and soil, which move downward or outward due to gravitational forces (SNI 13-7124-2005). Globally, landslides account for significant environmental damage, human fatalities, and economic losses. The World Bank (2018) reported that landslides cause an estimated 4,500 deaths annually worldwide, with Southeast Asia being one of the most affected regions due to its tropical climate and geomorphological characteristics (Petley, 2012). In Indonesia, landslides are the third most significant natural disaster after floods and tornadoes (BNPB, 2020). These events are often triggered by intense rainfall, seismic activity, deforestation, and human-induced land-use changes (Meisina et al., 2008).

The stability of a slope is influenced by various factors, including morphological conditions (particularly slope steepness), the composition of soil and rock, and hydrological processes (Guzzetti et al., 1999). Generally, landslides are caused by two primary factors: (1) driving factors, which influence the inherent condition of the material, such as weathering, soil composition, and tectonic activity; and (2) triggering factors, which cause the material to move, including heavy rainfall, earthquakes, and human activities such as deforestation and improper land use (Fell et al., 2008).

To mitigate the risks associated with landslides, effective spatial planning is essential. Spatial planning serves as a multidimensional development intervention that integrates structural and non-structural mitigation strategies to enhance disaster resilience (Godschalk, 1991, in Kaiser, 1995). In disaster-prone areas, spatial planning functions as an instrument for risk reduction, as it enables proactive measures before a disaster occurs. Furthermore, spatial planning plays a critical role in development policy by guiding land-use decisions to reduce exposure to hazards, eliminate vulnerabilities, and strengthen adaptive capacities (Brody, 2004, in Sagala and Bisri, 2011). Implementing risk-sensitive land-use planning, enforcing zoning regulations, and adopting

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sustainable environmental management practices can significantly reduce the occurrence and impact of landslides (Alexander, 2008).

Bondowoso Regency, located in East Java, Indonesia, is one of the areas frequently affected by landslides due to its steep terrain, high precipitation, and extensive agricultural activities on sloping land. The regency has experienced multiple landslide events, resulting in severe damage. For instance, a recent landslide buried approximately five hectares of newly planted rice fields, severely damaged a bridge and a prayer hall in Andungsari Village, and destroyed several homes, including one in Banyuwulu Village, Wringin District (BPBD Bondowoso, 2021). The increasing frequency and severity of landslides in Bondowoso highlight the urgent need for an integrated spatial planning approach to mitigate future disasters.

Based on these concerns, this study aims to analyze spatial planning directions to mitigate landslide risks in Bondowoso Regency. By evaluating current land-use patterns, geological vulnerabilities, and existing mitigation strategies, this research seeks to provide recommendations for sustainable spatial planning policies that enhance community resilience against landslides.

A. Landslides

Landslides or mass movements are closely related to scientific processes occurring in a particular landscape. A landscape is a natural formation on the Earth's surface, such as hills, mountains, plateaus, and valleys (Dwikorita, 2005). Landslides are one of the most common natural disasters in humid tropical regions. The damage caused by mass movements is not only direct, such as the destruction of public infrastructure, agricultural land, or loss of human lives, but also indirect, paralyzing economic activities and regional development (Hardiyatmo, 2006). According to Highland & Bobrowsky (2008), landslides account for significant economic losses worldwide, particularly in developing countries where mitigation efforts are often inadequate. Climate change, deforestation, and unregulated urban expansion further exacerbate the frequency and intensity of landslides (Guzzetti et al., 2012).

B. Disaster Mitigation

Disaster mitigation refers to a series of efforts to reduce disaster risks through physical development, awareness programs, and capacity-building initiatives. It plays a critical role in minimizing the impacts of disasters by reducing casualties and economic losses. The initial step in disaster mitigation is conducting a risk assessment of the affected region. This requires an understanding of three key factors: hazard, vulnerability, and disaster risk. Each of these factors has distinct definitions and implications for mitigation planning (UNDRR, 2020).

C. Hazard

A hazard is a natural or human-induced phenomenon with the potential to threaten human life, property, and environmental stability. Indonesia is located at the convergence of three tectonic plates: the Indo-Australian Plate to the south, the Eurasian Plate to the north, and the Pacific Plate to the east. The movement and collision of these plates result in frequent earthquakes, volcanic eruptions, and active fault lines (Cao et al., 2016). Landslides are often triggered by intense rainfall, seismic activity, and anthropogenic factors such as deforestation and uncontrolled land use (Kirschbaum et al., 2019).

D. Vulnerability

Vulnerability refers to the condition of a community or society that leads to an inability to cope with hazards. According to Djauhari Noor (2010) in "Pengantar Mitigasi Bencana Geologi," vulnerability is the inability to withstand the impact of external natural events. Socioeconomic factors, including poverty, lack of infrastructure, and limited access to emergency response resources, significantly influence a community's vulnerability to disasters (Cutter et al., 2003). Studies by Birkmann et al. (2013) highlight that effective land-use planning, governance, and community preparedness are crucial for reducing vulnerability.

E. Disaster Risk

According to the book "Pengantar Mitigasi Bencana Geologi," disaster risk is the estimated level of damage and losses from a natural event. It is determined by the interaction between hazard and vulnerability. According to BNPB Regulation No. 2 of 2012, disaster risk refers to potential losses caused by disasters in a given area and period, including fatalities, injuries, displacement, property damage, and disruption of societal functions. The United Nations Office for Disaster Risk Reduction (UNDRR, 2015) emphasizes that disaster risk reduction requires multi-sectoral collaboration, integration of early warning systems, and investment in resilient infrastructure.

F. Spatial Planning

The spatial study of spatial pattern planning is a process for determining spatial patterns, including the preparation and establishment of spatial plans (Law No. 26 of 2007 on Spatial Planning). Spatial planning also functions as a development policy (according to Brody, 2004, in Sagala & Bisri, 2011). Development policy decisions can be directed at reducing risk components by avoiding hazardous locations, eliminating vulnerabilities, and strengthening capacities. The more commonly used approaches are physical mitigation and emergency response preparedness. Physical mitigation includes the construction and reinforcement of embankments, as well as the installation of early warning system devices (Burby et al., 2000). According to Godschalk (2003), disaster risk reduction-based spatial planning benefits regional resilience against disasters, including landslides. A study by Cutter et al. (2008) emphasizes that integrating disaster mitigation into spatial planning policies can reduce disaster impacts through land use control and more adaptive infrastructure planning in response to environmental risks.

G. Disaster Risk Reduction

Disaster risk reduction can be carried out in both pre-disaster and post-disaster phases. Risk reduction in the pre-disaster phase can be achieved through disaster mitigation efforts. In the context of spatial planning, disaster mitigation activities aimed at reducing disaster risks within spatial planning are categorized as passive mitigation, which involves disaster risk assessment and analysis (Schneiderbauer & Ehrlich, 2006). From a temporal perspective, mitigation includes all actions taken before a disaster occurs (pre-disaster actions), which encompass long-term disaster risk reduction measures.

II. RESEARCH METHOD

A. Analytical Hierarchy Process (AHP)

AHP is an analytical method used to identify factors influencing landslide vulnerability. AHP, in essence, is a decision-making process that operates based on a functional hierarchy with human perception as its primary input. By utilizing a hierarchical structure, complex and unstructured problems are broken down into groups and then arranged into a hierarchical format (Falatehan, 2016:1). This method is used to determine the priority factors affecting landslide vulnerability, which include physical, social, economic, and environmental aspects. The respondents involved in this analysis consist of three stakeholder groups: academia, government, and the general public. The weighting scale used in the calculations follows the 1-9 scale (Saaty, 1993).

B. Weighted Overlay Analysis

The next stage in formulating vulnerability analysis is the weighted overlay, which aims to generate a vulnerability map based on different levels of vulnerability (low to high). The analysis technique used is the overlay technique, where each vulnerability indicator is layered based on the weighting results from the AHP analysis. This process produces maps for physical, social, economic, and environmental vulnerability. Subsequently, an overlay of these individual vulnerability maps (physical, social, economic, and environmental) is performed using the weights derived from the AHP analysis to generate an overall landslide vulnerability map. The analytical tool used in this process is the Geographic Information System (GIS) software, specifically ArcGIS 10.3. The final stage involves determining landslide risk areas in Bondowoso Regency. The data used for risk assessment is based on the interaction (multiplication) between hazard (H) and vulnerability (V), which are analyzed using the Map Algebra technique with the Raster Calculator function. This function allows for computational operations, particularly multiplication, on raster data (hazard and vulnerability data) according to the formula:

$$R = H \times V$$

C. Recommendation Analysis for Spatial Planning in Landslide Risk Areas in Bondowoso Regency

The disaster aspect serves as the basis for analyzing and providing recommendations for spatial planning to mitigate landslide hazards in Bondowoso Regency. The data used to develop these recommendations consists of the landslide risk level map and the spatial planning map for the 2011-2031 period. These datasets undergo an overlay analysis to identify areas that require spatial planning recommendations to address and anticipate landslide disasters proactively. This process ensures that future spatial planning incorporates disaster risk reduction considerations.

Table 1. Analysis Objectives, Techniques, and Results

Target	Analysis Objectives	Analysis Techniques	Analysis Method	Validation Method	Results
Identify the level of vulnerability influencing landslide disasters in Bondowoso Regency.	- Determine the weight of each factor influencing landslide vulnerability in Bondowoso Regency. - Identify vulnerability zone classifications based on vulnerability levels, ranging from low to high, by overlaying maps of influencing factors.	- AHP (Analytical Hierarchy Process) - Weighted Overlay	- Determine the weight of each factor affecting landslide vulnerability. - Classify vulnerability zones based on physical, social, economic, and environmental aspects, ranging from low to high vulnerability by overlaying maps of influencing factors.	- Once the hierarchical process of variables is structured, assessments are conducted to compare criteria for weighting to achieve the research objectives. - Overlay maps of physical, social, economic, and environmental aspects based on weighted vulnerability factors.	- Table of Factors Affecting Landslide Vulnerability - Landslide Vulnerability Map of Bondowoso Regency
Determine the distribution of landslide disaster risk levels in Bondowoso Regency.	Identify landslide disaster risks in Bondowoso Regency by multiplying the hazard zone map with the vulnerability zone map.	- Map Algebra using Raster Calculator	- Using GIS software (Geographic Information System), access the spatial analysis tool (Raster Calculator) and apply Map Algebra by multiplying the hazard zone map with the vulnerability zone map.	- This stage involves multiplying hazard data with vulnerability data. The result is a risk map, which is then reclassified to determine landslide disaster risk levels in Bondowoso Regency.	Landslide Disaster Risk Map of Bondowoso Regency
Provide recommendations for spatial planning regarding landslide disaster risk areas in Bondowoso Regency.	Provide spatial planning recommendations for landslide disaster risk areas in Bondowoso Regency based on disaster aspects.	- Descriptive Analysis - Overlay Analysis	- Combine the landslide disaster risk map with the spatial planning map of Bondowoso Regency. - Provide recommendations using the PAR (Protection, Adaptation, Relocation) model.	- Delineate areas on the overlaid maps to facilitate disaster-based spatial planning recommendations.	Spatial Planning Recommendation Map

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III. RESULTS AND DISCUSSION

Identifying the Level of Vulnerability That Affects Landslide Disasters

A. Factors Causing Landslides

Factors causing landslides in the process have a weighting that comes from the perceptions of stakeholders, to obtain the weighting of the criteria, the AHP analysis tool is used assisted by the Expert Choice 11 software. The weighting of each indicator includes:

Figure. 2. AHP results of weighting variables in landslide causative factors

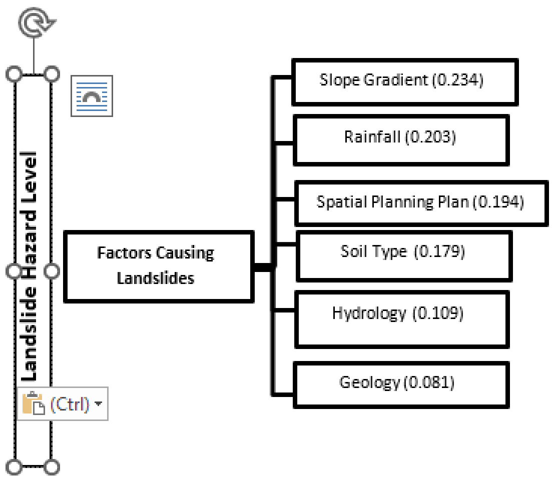

Figure. 2 . Hierarchical Tree of the Research

B. Physical Vulnerability

The vulnerability level of houses is measured based on the total residential area in relation to the hazard level. The number of housing units is determined according to the Decree of the Minister of Housing and Regional Infrastructure No. 403/Kpts/M/2002 on Technical Guidelines for the Construction of Simple Healthy Houses, which states that the ideal housing area is 200 m² per unit (assuming one housing unit accommodates four people).

C. Critical Facilities

The vulnerability zoning of critical facilities in the study area is considered zero because critical infrastructure, such as airports and ports, is generally built on flat, low-risk areas. As a result, the critical facilities in the study area fall under the low vulnerability category.

D. Public Service Facilities

The vulnerability level of public service facilities is measured by the number of facilities such as education, healthcare, and other public services. The number of facilities is then multiplied by the unit cost of each facility. A higher total cost (in currency) indicates a higher level of vulnerability.

Based on the classification of vulnerability levels, most districts in the study area fall into the high vulnerability category.

E. Formula for Physical Vulnerability:

Physical Vulnerability =[(0.4×housing score)+(0.3×public service facility score)+(0.3×critical facility score)] Physical Vulnerability

=[(0.4×housing score)+(0.3×public service facility score) +(0.3×critical facility score)]

F. Social Vulnerability

1) Population Density

Population density vulnerability is measured by the number of residents per village. The higher the population density, the greater the vulnerability.

2) Gender Ratio

Gender-based vulnerability is measured by the ratio of the male population to the female population, multiplied by 100%. A higher gender ratio corresponds to higher vulnerability.

Based on the calculations, the gender ratio in the study area falls into the high vulnerability category. This is because the ratio is below 100, indicating that the female population is larger than the male population. A higher number of females in an area is associated with increased vulnerability.

3) Poverty Rate

The vulnerability level related to poverty is assessed based on the economic well-being of residents. It is calculated using the ratio of low-income residents to the sum of middle- and high-income residents, multiplied by 100%. A higher ratio indicates greater vulnerability.

According to the calculations, one district in the study area falls into the high vulnerability category due to a high number of middle- and upper-class residents.

4) Disabled Population

Vulnerability based on the presence of disabled individuals is measured by the ratio of the disabled population to the non-disabled population, multiplied by 100%. A higher ratio indicates higher vulnerability.

5) Age Group

The level of vulnerability based on age group is measured by the ratio between the number of non-productive population compared to the number of productive population multiplied by 100%. The higher the ratio, the higher the vulnerability. Based on the calculation results above, the ratio of age groups in the research area is included in the high class category. Social vulnerability is obtained based on the following formula:

Social Vulnerability = [(0.6*population density score) + (0.1*gender score) + (0.1*poverty score) + (0.1*disability score) + (0.1*age score)].

G. Economic Vulnerability

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The level of vulnerability of productive land is measured by the area of productive land, namely rice fields and plantations. Then the area of land is converted into rupiah. Based on the calculation results above, the vulnerability of productive land in the research area is included in the high class category.

Economic vulnerability is obtained based on the following formula:

Economic Vulnerability = [(0.6*productive land score) + (0.4*GRDP score)]

H. Environmental Vulnerability

Landslide Vulnerability Level Zoning

Landslide vulnerability level zoning illustrates the vulnerability level of landslide disasters in the research area. The vulnerability level zoning is categorized from low to high vulnerability zones based on the overlay results of the formed variables. Below are the steps involved in zoning the vulnerability level:

1) Data Processing and Input

This stage provides a general description of the vulnerability level variables, including physical, social, economic, and environmental aspects. Raster processing is performed for each aspect.

2) Reclassifying Data

In this stage, the data in raster form is classified into levels for each variable. The classification for each variable has been completed. Scale 1 represents a low level, scale 2 indicates a medium level, and scale 3 signifies a high level.

3) Data Overlay

This stage involves zoning each vulnerability level variable that has been reclassified and then conducting zoning to determine the overall vulnerability level. This process uses a weighted sum with weighting according to BNPB Regulation No. 02 of 2012. Based on the calculations above, from all the vulnerability aspects in the research area, the landslide vulnerability can be determined using the following formula:

Landslide Disaster Vulnerability = [(0.4*social vulnerability score) + (0.25*economic vulnerability score) + (0.25*physical vulnerability score) + (0.1*environmental vulnerability score)]

Based on the results of the weighted overlay analysis that has been carried out, the level of landslide disaster vulnerability in the research area is divided into 3 levels, namely high, medium, and low vulnerability levels.

I. Landslide Disaster Risk Level Analysis

Disaster risk refers to the level of damage and losses that have been calculated from a natural event or disaster. The disaster risk is determined based on the multiplication of hazard and vulnerability factors. Hazard is the probability and magnitude of a natural event that can be anticipated, while vulnerability is influenced by physical, economic, social, and environmental factors. The following widely used formula is applied to calculate disaster risk, which is the multiplication of two factors:

Risk = Hazard × Vulnerability

In formulating the landslide disaster risk level, the researcher performed an overlay of the hazard map and the vulnerability map that were created in the previous analysis. To analyze and formulate the landslide disaster risk level, the researcher used ArcGIS 10.1 software with the map algebra analysis method.

Based on the analysis results of the landslide disaster risk level, it was found that an area of 5,047.89 Ha falls into the High-Risk category, which includes Klabang District, Taman Krocok District, Tegalampel District, and Wringin District. An area of 50,358.61 Ha is categorized as Medium Risk, which includes Binakal District, Botolinggo District, Cermee District, Curahdami District, Pakem District, Prajekan District, Pujer District, Sempol District, Sukosari District, Sumberwringin District, and Tlogosari District. An area of 100,197.74 Ha falls into the Low-Risk category, which is spread across all research areas.

J. Analysis of Spatial Planning Recommendations for Landslide Disaster Risk Areas

In providing recommendations for spatial planning in landslide disaster risk areas, the analysis conducted includes descriptive analysis and overlay analysis. Descriptive analysis is used to depict the conditions in the research area, which serve as the basis for making recommendations and handling areas at risk of landslide disasters. The steps for describing the existing conditions are as follows:

Division of Blocks for Landslide Risk Area Spatial Planning Recommendations In this study, the researcher delineated the division of blocks based on the landslide disaster risk level, using the spatial planning conditions that had been overlaid into 3 sections: (KRB 1, KRB 2, KRB 3).

Table 2. Basis for Determining the Delineation Blocks for KRB 1, 2, 3

Basis for Determination	KRB 1	KRB 2	KRB 3
Block: - KRB 1 - KRB 2 - KRB 3	KRB 1 is a central urban activity area with residential, trade and service, and education functions located in Bondowoso, Tenggarang, Curahdami, Grujugan, Maesan Districts. Tamanan, Pujer, Sukosarri, Wonosari, Jambersari DS, Sukosari, Tamankrocok.	KRB 2 is an area supporting urban activities with residential, trade and service, and plantation functions located in Binakal, Pakem, Wringin, Klabang, Tegalampel Districts.	Sub BWP III is an area with residential, industrial and dry land agricultural functions located in Sumberwringin, Botolinggo, Tlogosari, Cermee Districts.
Function of KRB 1, 2, 3	Designated as the urban center and center of activities of the Regency Bondowoso	As a supporter of the urban center of Bondowoso Regency	As a supporter of the urban center of Bondowoso Regency
Carrying Capacity and Capacity	The carrying capacity of +70% of the space can be utilized and the carrying capacity is directed towards medium – high density.	Space carrying capacity +80% (but influenced by physical characteristics) and the carrying capacity is directed towards medium density	Space carrying capacity +85% (development direction) and capacity is directeduntuk kepadatan rendah

Basis for Determination	KRB 1	KRB 2	KRB 3
Provisions of RTRW of Bondowoso Regency 2011-2031	Cultivation (settlement, trade and services, education, wetland agriculture) and Protection (RTH)	Cultivation (settlement, trade and services, wetland agriculture, and plantations) Protection (RTH)	Cultivation (settlement, wetland agriculture, and plantation) Protection (Protected Forest, Green Open Space)

Source: Analysis Results, 2019

Based on the above criteria for determining KRB, it can be concluded that KRB 1, which includes the districts of Bondowoso, Tenggarang, Curahdami, Grujugan, Maesan, Tamanan, Pujer, Sukosari, Wonosari, Jambersari DS, Sukosari, and Tamankrocok, represents the urban centers and activities for Bondowoso Regency with a dominant low landslide disaster risk level. Meanwhile, KRB 2, which includes the districts of Binakal, Pakem, Wringin, Klabang, and Tegalampel, serves as the urban supporting centers of Bondowoso Regency with a moderate landslide disaster risk level. KRB 3, which includes the districts of Sumberwringin, Botolinggo, Tlogosari, and Cermee, represents the high-risk urban supporting centers for Bondowoso Regency with a high landslide disaster risk level. This block division was made to facilitate the researcher in recommending spatial planning directions for landslide disasters in Bondowoso Regency.

Sumber : Penulis, 2019

Figure. 3. Raster Calculator Tool for Formulating Landslide Disaster Risk Levels

K. Spatial Planning Recommendation Directions

In addressing the spatial planning recommendation directions for landslide disasters in Bondowoso Regency, in order to achieve a safe and comfortable life aligned with the spatial planning directions outlined in the Bondowoso Regency RTRW 2011-2031, we must understand the natural environment and the speed of changes occurring on Earth. It is essential to adapt to the characteristics of these natural changes so that disaster-based spatial planning does not result in fatalities or significant losses (Spooner & Lambert, 2021). The integration concept of disaster risk reduction, as explained in the book "Measuring Vulnerability to Promote Disaster-Resilient Societies and Enhance Adaptation: Discussion of Conceptual Frameworks and Definitions" (IPCC, 2014), includes PAR (Protection, Adaptation, and Relocation) for landslide disaster planning recommendations and handling, which are as follows:

1) *Protection:*

When the landslide disaster risk is low to medium, socialization of disaster response should be conducted for the surrounding community as part of pre-disaster preparedness. Vegetation planting, such as teak and mahogany, can be done to prevent landslides (Yoshimoto et al., 2020). Protection efforts, especially in residential areas, should include building anchor structures and piling to prevent soil erosion, with the condition of low building density. Terracing of drainage channels (in case of rainfall) should be implemented, and no buildings should be constructed on slopes or unstable land (landslide-prone areas) (Rahman et al., 2019).

2) *Adaptation:*

When the landslide disaster risk is moderate to high, no residential development should be allowed. Only disaster-related infrastructure, such as mitigation routes (evacuation route diversions/land cuts during disasters) and early warning systems (e.g., placing landslide-prone area signs), should be permitted (Cousins et al., 2018). If heavy rainfall occurs, it is advised to be cautious and anticipate landslides, preparing for immediate evacuation of victims to designated evacuation zones (Krausmann et al., 2021).

3) *Relocation:*

When the landslide disaster risk is high and has already occurred, relocation is preferable (without changing the land use to residential buildings). This involves avoiding areas that have already experienced landslides. Residential land should be converted into forest or plantation areas, and it is recommended to plant sturdy, deep-rooted trees, such as teak and mahogany, to prevent soil movement (due to unstable soil conditions). Productive trees, such as durian, petai, and jackfruit, can also be planted (Teixeira et al., 2020). This approach aims to address and anticipate landslide disasters in advance, contributing to future planning while still considering disaster risk factors (Muller & Geyskens, 2019).

4) *Spatial Planning Directions Based on (KRB – 1,2,3 Area Block) with Low to Moderate Landslide Disaster Risk Level*

After analyzing the spatial planning based on the low to moderate landslide disaster risk levels, the delineated block areas of KRB-1, KRB-2, and KRB-3 have been identified to facilitate the provision of spatial planning directions. Specifically, for KRB-1, the spatial planning is based on the low to moderate risk levels, helping to guide the implementation of appropriate strategies. Similarly, for KRB-2, the spatial planning directions are based on the same risk levels, providing clarity in the development process. In the case of KRB-3, the spatial planning takes into account a range of risk levels, from low and moderate to high, ensuring a comprehensive approach to disaster risk reduction and spatial planning for the area. These divisions are crucial in facilitating the effective development of disaster-resilient spatial planning strategies.

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IV. CONCLUSIONS

Natural disasters, including landslides, can occur anytime and anywhere, causing damage to property and loss of life. Landslides happen due to disturbances in slope stability influenced by morphological, soil, and hydrological conditions. The causes consist of driving factors (material characteristics) and triggering factors (factors that initiate material movement). The weighted overlay analysis classifies the landslide vulnerability levels in the research area into high (6 districts), moderate (8 districts), and low (9 districts). Meanwhile, the map algebra analysis shows that 5,047.89 Ha fall into the High-Risk category (Kecamatan Klabang, Taman Krocok, Tegalampel, Wringin), 50,358.61 Ha into the Moderate-Risk category (11 districts), and 100,197.74 Ha into the Low-Risk category, which is spread across the entire region. Risk mitigation is carried out through spatial planning based on the PAR (Protection, Adaptation, Relocation) concept. In low to moderate-risk areas (KRB 1), protection is implemented through disaster response socialization, vegetation planting, and the construction of soil retention structures. In moderate to high-risk areas (KRB 2), adaptation is applied by restricting settlement development, building mitigation routes, and installing early warning systems. Meanwhile, in high-risk areas (KRB 3), relocation is recommended, especially in Kecamatan Binakal, Tegalampel, and Wringin, by converting residential land into forest or plantation areas with hard and productive trees. These efforts aim to reduce disaster risk and create spatial planning that considers disaster-related aspects.

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