

Analysis of Slopes and Their Impact on Settlements in Landslide-Prone Areas of Balikpapan City Using Geographic Information Systems (GIS) Methods

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Abstract

The city of Balikpapan is dominated by hilly topography, covering approximately 85% of its area, while the remaining 15% consists of flat land. These conditions greatly influence surface runoff patterns, slope stability, land-use changes, and urban development policies, particularly those related to settlement expansion and landslide risk management. This situation has encouraged communities to build settlements in hilly areas; however, development in such locations increases the potential for landslides, especially when combined with steep slopes, high rainfall, and unstable soil conditions. This study aims to map landslide vulnerability in Balikpapan City using a GIS-based weighted overlay method. In addition to mapping vulnerability, the study also assesses the level of settlement exposure within each vulnerability class and develops spatially based mitigation strategies to support disaster risk reduction. The results of this study are expected to serve as a basis for government recommendations in landslide management and mitigation. The parameters used include soil type, land cover, slope steepness, and rainfall intensity, each weighted and scored according to its influence on landslide potential. Through the weighted overlay process, a landslide vulnerability zonation map was produced. The results show that West Balikpapan, South Balikpapan, Central Balikpapan, and North Balikpapan districts have the largest areas of high vulnerability, although the assessment covers all six districts. A total of 177,174 housing units are located within landslide-vulnerable zones, with 168,989 units in the medium vulnerability class, while the remaining 8,185 units are distributed across low and high classes. This distribution indicates that exposure is largely concentrated in medium-risk zones. Mitigation recommendations include increasing public awareness, constructing retaining walls on steep slopes, establishing evacuation routes, and installing drainage systems on steep terrain.

Keywords: Landslide, Disaster Mitigation, Mapping, Weighted Overlay

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1. Introduction

Balikpapan City is 85% hilly and 15% plain (Rivaldi et al., 2021). The plains are located along the east and south coasts, while the hills are located within the city. The flat areas are densely populated, leading urban expansion to tend toward hilly areas. (Rivaldi et al., 2021). Furthermore, Balikpapan City has four zones of land susceptibility: very low, low, medium, and high. Disasters are events or series of events that threaten and disrupt the lives and livelihoods of communities caused by natural, non-natural, or human factors (Pradnyasari et al., 2019). The occurrence of disasters is due to the presence of threats and vulnerabilities without the capacity of the community to cope with them (Isnaini, 2019). Landslide are Landslides are a geological natural disaster that, when they occur, can cause loss of life and extensive material damage, including silting, disruption of traffic access, damage to agricultural land, residential areas, irrigation channels, and physical infrastructure (Hidayatush Sholikah et al., 2021). Landslide disaster are divided into two types deep landslides and shallow landslides. Shallow landslides are characterized by soil instability at a depth of 2-3 meters (Agusman et al., 2023). To ensure the sustainability of life, livelihoods, and community welfare, it is crucial to prioritize and promptly address the protection of communities from the dangers and threats posed by disasters (Nugraheni et al., 2025).

Population growth and distribution in a city can create a new problem: housing. Increased economic development in a region leads to increased demand for housing, including uninhabitable areas. The presence of residential areas on unsuitable land can increase the risk of natural disasters. Increasing growth and development have an impact on the increasing need for land for community living space in Balikpapan City. This situation has driven the development of building activities in areas unsuitable for residential use (Prasetia et al., 2022). In this case, space utilization becomes the main focus in landslide disaster control because the development of an are is very important ini minimizing casualties and physical, social, and economi losses (Fatmasari et al., 2021). Mitigation is carried out to reduce disaster risk, both through physical development and awareness and improvement in disaster preparedness. Mitigation involves deciding what and where to do things related to the health, safety, and well-being of the community, as defined and implemented as part of a disaster risk reduction program. This is a continuous effort to reduce risks to life and property, as well as their impacts (SUSANTI & Anggara, 2021).

Data from the Indonesian Disaster Information Center (2025), under the auspices of the National Disaster Management Agency, states that in the year 2024, from January to December, there were at least 207 landslide disaster events out of a total of 3,472 disasters that occurred in Indonesia. Data from the Balikpapan City Disaster Management Agency reveals that in the past five years, there have been three years with the highest scale of landslide and ground movement disasters: 2021 with a total of 61 events, 2022 with a total of 69 events, and 2024 with a total of 93 events. The landslide disaster caused by a ground subsidence of over 1 meter on Jl. Sungai Wain, Karang Joang Village, on November 1, 2021, resulted in 12 houses being severely damaged (Inibalikpapan.com, 2021). Heavy rainfall and unstable soil conditions caused 31 houses to be affected by landslides in several districts in the city of Balikpapan (News.okezone. 2022). On August 9, 2024, a landslide disaster occurred on Jl. Gunung Sari Ulu, Balikpapan Central District, caused by high rainfall intensity starting from 03:00 WITA early morning until morning, resulting in one fatality and another person suffering from broken bones due to being hit by landslide debris (Detiksulsel. 2024). In the same year, a landslide also occurred on September 30, 2024, caused by high rainfall intensity and ground movement on Jl. Gunung Sari Ulu, Balikpapan Central District, resulting in damage to two houses (Kaltimpost.id.2024).

In anticipation of landslide events, it can be done through mapping and landslide disaster risk analysis. Risk analysis is a method for developing mitigation plans and can be used to take

action to address the occurrence of a disaster (Kinanti et al., 2022). Geographic Information Systems can be used to map landslide-prone areas. Mapping landslide-prone areas can be done using mapping application analysis (Susetyo et al., 2023). Geographic Information Systems can be used to map landslide-prone areas by utilizing spatial information such as soil type, rainfall, slope gradient, and land cover, which will be analyzed and presented in the form of maps to provide a clear picture of the factors that can cause landslides (Erfani et al., 2023). Rainfall, soil type, slope gradient, and land cover will be the parameters in this study. Rainfall is one of the main parameters in determining the occurrence of landslide disasters; high rainfall intensity will greatly influence this, as it will increase the potential for landslides (Yassar et al., 2020). The type of soil in the topography also influences the occurrence of landslides types that are easily eroded, such as sand, will worsen the risk of landslides (Kambri & Saitakela, 2025). The slope gradient is one of the triggering factors for landslides and erosion. Landslides can occur in areas with steep slopes. Therefore, slope factor is always associated as one of the main factors in the occurrence of landslide disasters because the steeper the slope, the higher the risk zone (Nurfaiz Fathurrahman Yasien et al., 2021). A landslide is an event where a mass of soil, rocks, trees, sand, and other materials slides down. A landslide occurs when the stability of the soil and rocks that make up a slope is disrupted, causing the mass of soil, rocks, or a combination of soil and rocks to move and fall or break away from the slope wall (Hamida & Widayasamratri, 2019).

Previous research on landslide-prone area classification using the Davies-Bouldin index analysis by (Ulfah et al., 2023) only classified landslide-prone areas in Balikpapan City without analyzing the factors causing landslides. This research offers something new because it not only analyzes the factors causing landslides but also identifies landslide-prone areas, the number of settlements in those areas based on landslide risk classification, and landslide disaster mitigation based on landslide hazard class classification. The purpose of this research is to identify landslide-prone areas and the number of settlements within landslide-prone areas in each sub-district of Balikpapan City based on landslide classification, and to create disaster mitigation based on landslide hazard class classification. This study uses the weighted overlay method in ArcGIS Maps 10.8 thru spatial information analysis such as rainfall, slope, soil type, and land cover. Residential areas within disaster-prone zones can be identified using building footprint shapefile data and shapefile data for each disaster-prone classification, processed with the overlay tool, and then spatially joined in ArcGIS Maps 10.8.

2. Method

The research location is situated in the city of Balikpapan, East Kalimantan Province, which consists of six sub-districts: West Balikpapan, Balikpapan City, South Balikpapan, East Balikpapan, Central Balikpapan, and North Balikpapan.

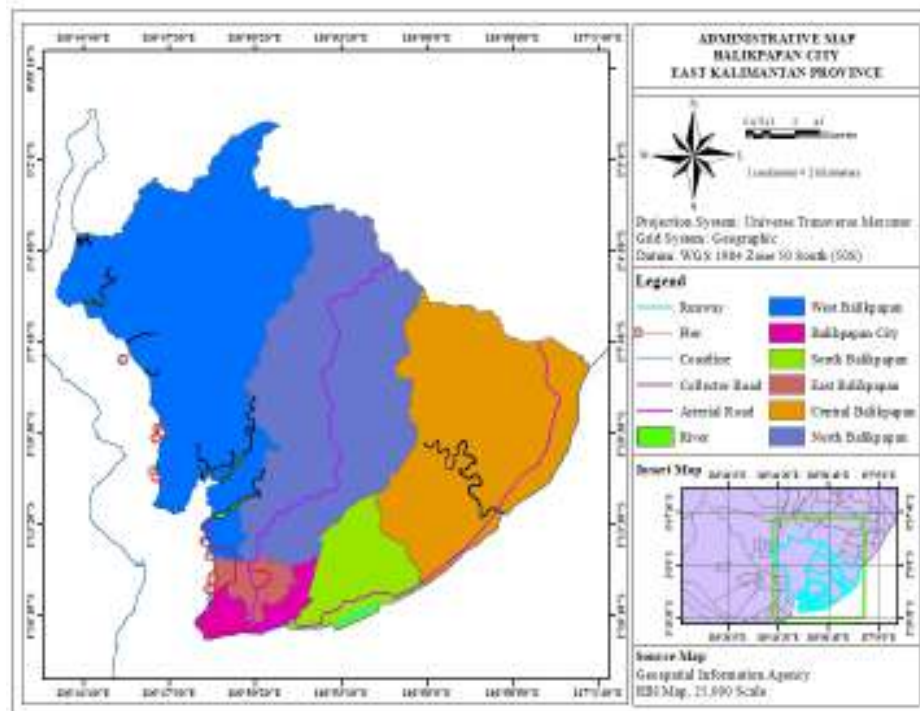


Figure 1. Research Location

The data used in the research is secondary data, including slope gradient data sourced from DEMNAS from the Geospatial Information Agency and soil type data sourced from FAO (Food and Agriculture Organization), annual rainfall data obtained from the rainfall measurement station in Balikpapan City, RBI map data at a scale of 1:25,000 obtained from BIG (Geospatial Information Agency), and SHP (Shapefile) building parcel data obtained from open street maps. The method used to create the landslide-prone map is the scoring weight method on the parameters that will be used in the data processing for landslide-prone map analysis or weight overlay. The number of settlements included in the landslide-prone area was obtained through the overlay tools, then selecting spatial join, resulting in building parcels that fall within the landslide disaster-prone area. The landslide parameters used will be overlaid with the intersect method to obtain the landslide potential. From the weight overlay results, the total score will be calculated using the following equation.

$$S_t = B_1(S_1) + B_2(S_2) + \dots + B_n(S_n) \quad (1)$$

Explanation:

St = Total score
 B1,B2,...,Bn = Weight of each parameter
 S1,S2,...,Sn = Score of each parameter
 N = Number of parameters

The total score results were then classified into three categories: low, medium, and high, according to the guidelines of the National Disaster Management Agency (BNPB), which are low, medium, and high potential. These classifications have different values: low classification category with a value of 2-15%, medium classification 15-40%, and high classification > 40%.

Table 1. Weight and Score Slope Gradien

Slope Gradient	Slope Class	Weight (30%)	Score
0-2 %	Flat		1
2-15%	Gentle		2
15-40%	Somewhat Steep		3
>40%	Steep		4

Source: Badan pusat statistik, 2023

Table 2. Weight and Score Rainfall

Rainfall	Description	Weight (30%)	Score
<1000 mm/years	Very Low		1
1000- <2000 mm/years	Low		2
2000 - 2500 mm/years	Moderate		3
2500 - <3000 mm/years	High		4
>3000 mm/years	Very High		5

Source: Jaduk Arief, 2023

Table 3. Weight and Score Soil Type

Soil Type	Description	Weight (20%)	Score
Aluvial	Insensitive		1
Sand	Senstive		2
Redyellow Podzolic	Sensitive		3

Source : Sandri dan Erfani, 2022

Table 4. Weight and Score Land Cover

Land Cover	Weight (20%)	Score
Airport, Water Body, Primary Mangrove Forest, Secondary Mangrove Forest, Dryland Forest, Secondary Dryland Forest, Primary Plantations, Dryland Agriculture, Mixed Shrub Dryland Agriculture, Plantation, Pond		1
Swamp, Open Land		2
Settlement, Shurb, Swamp Shurb		3
Swampy Thickets		4
Mining, Rice Fields		5

Source: Permata Prasindya, 2019

3. Result and Discussion

A. Mapping Parameters of Landslide-Prone Area

1) Rainfall

Rainfall is one of the parameters for determining landslide-prone areas (Sholikhah et al., 2019). The rainfall map of Balikpapan City was obtained through data processing using ArcGISMap 10.8, utilizing annual rainfall data sourced from rainfall measurement stations, and then analyzed using the IDW interpolation method.

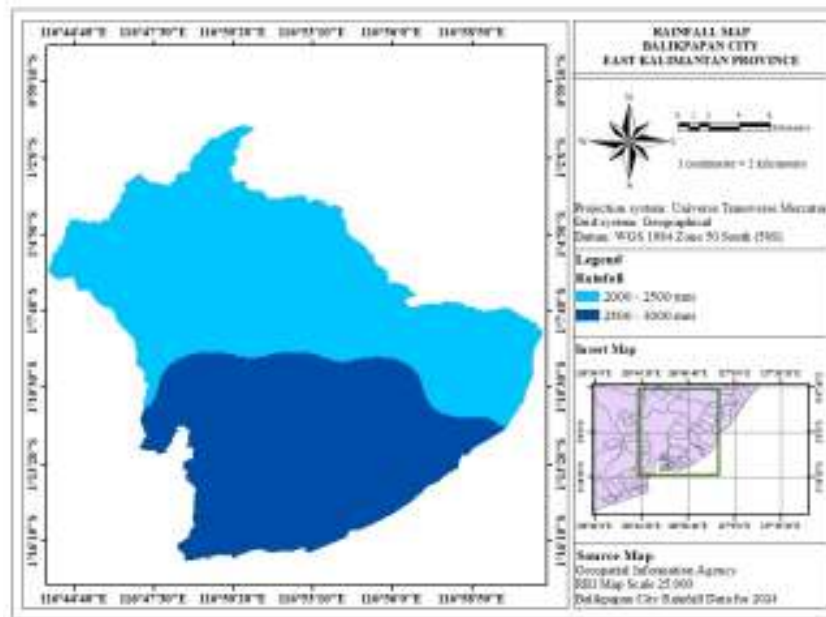


Figure 2. Rainfall Map

2) Soil Type

Various types of soil found in Indonesia have their own characteristics and properties that differentiate one type of soil from another (Dani et al., 2022).

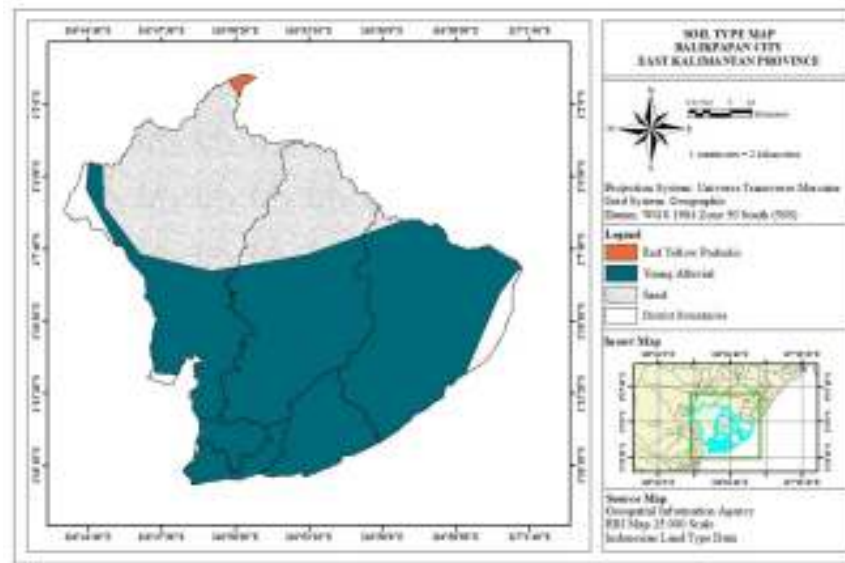


Figure 3. Soil Type Map

Soil type maps can be used to identify the landslide vulnerability levels in Balikpapan City. Based on the soil type distribution map, it can be determined that there are three types of soil in Balikpapan City: alluvial, red-yellow podzolic, and sand.

3) Slope Gradient

Slope inclination is the angle formed by the difference in land surface elevation (relief), which is between the flat land surface and the horizontal plane, and is generally calculated in percentage (%) (Manabung et al., 2021).

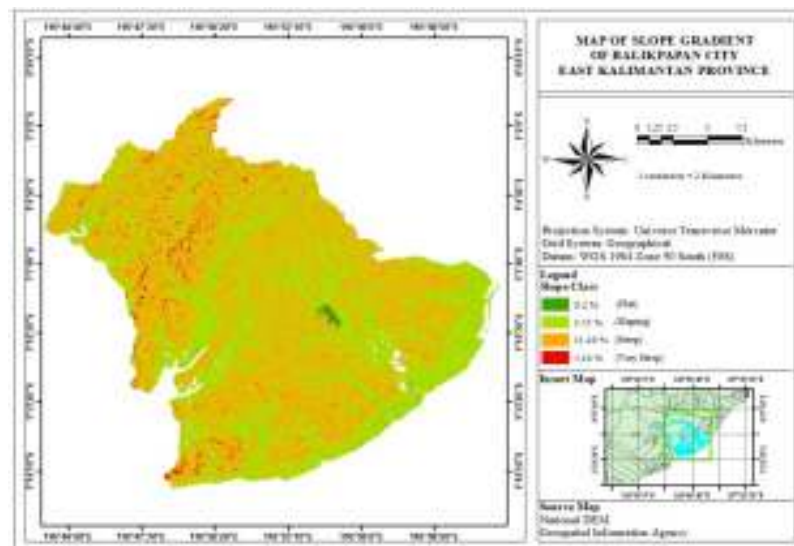


Figure 4. Slope Gradient Map

Steep slope categories have a high risk of landslides. The slope inclination map of Balikpapan City, with the majority of slope inclinations being moderately steep at a percentage of 15-40%, indicates the potential for landslide disasters.

4) Land Use

Land cover is a physical material feature on the Earth's surface where land cover illustrates the relationship between natural processes and social processes. Land cover can provide important information for modeling purposes and for understanding natural phenomena occurring on the Earth's surface (Cahyono et al., 2019).

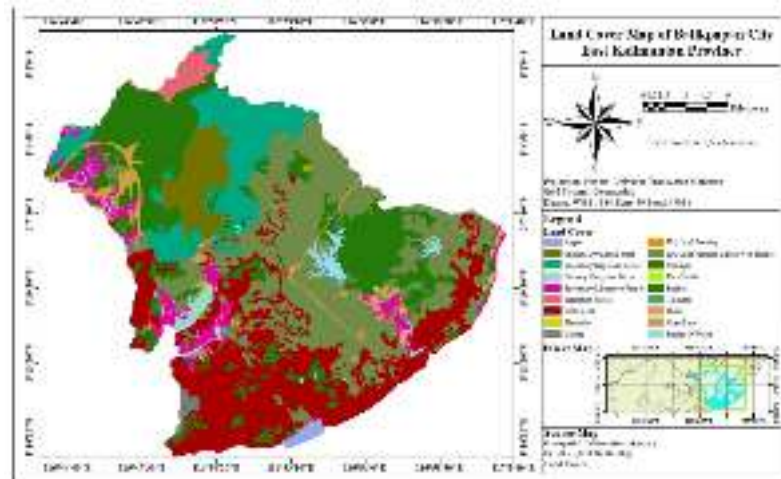


Figure 5. Land Use Map

Land use maps will show the load on soil stability levels. The vegetation depicted in land use maps is also related to the level of landslide disaster risk; vegetation that is not affected by land use changes will slow down erosion caused by rainwater and soil material, preventing them from moving down slopes and causing landslides.

B. Mapping of Landslide-Prone Area in Balikpapan City

Based on the landslide-prone area mapping results, the city of Balikpapan has four sub-districts that fall into the landslide-prone areas, namely Balikpapan City Sub-district, West Balikpapan Sub-district, South Balikpapan Sub-district, and North Balikpapan Sub-district. Each sub-district has different areas and percentages of landslide danger, ranging from low, medium, to high. This is influenced by the topographical conditions of each sub-district, which are hilly with steep slopes, soil types, and land movement, which are also factors in the occurrence of landslide disasters. Based on the data processing results of the research conducted using the weight overlay method, the classification of landslide-prone areas in Balikpapan City is divided into three classifications: low, medium, and high. The results can be presented with an output map of the landslide-prone areas.

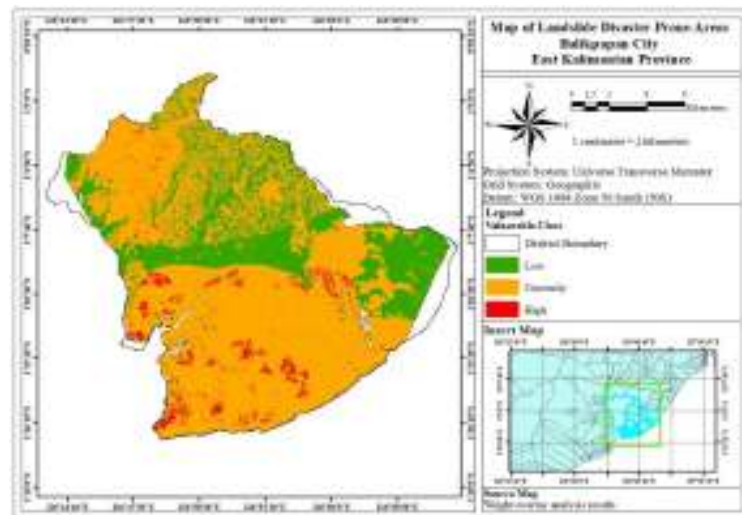


Figure 6. Map of Landslide-Prone Area in Balikpapan City

The area and percentage of landslide disaster risk zones obtained from the data processing in ArcGIS Maps 10.8 are classified into three categories: low, medium, and high.

Table 5. Landslide Area Size

No.	Subdistrict	Landslide Area Size		
		Low	Moderate	High
1.	West Balikpapan	843,3	13205,9	3018,0
2.	Balikpapan Cit		1129,9	169,5
3.	South Balikpapan	13,5	3036,8	292,0
4.	Central Balikpapan		996,9	116,2
5.	East Balikpapan	1729,3	9192,3	137,7
6.	North Balikpapan	1410,9	12689,6	529,3
Total		3997	40251,4	4262,7
Percentage		8%	83%	9%

Landslide disasters are also influenced by soil type, rainfall, land cover, and steep slope gradients, which contribute to the occurrence of landslide events. The steep slope gradient certainly has significant soil instability, therefore, land use experts conducting assessments on steep slope gradients will increase the potential for landslides. This is relevant to the research by (Goma et al., 2022) that steep slope inclinations are prone to landslides, especially under unstable slope conditions.

C. Settlement Conditions in Areas with Low Landslide Risk

Areas with low landslide susceptibility have a low population of residential settlements with buildings that are not too large, so the ground surface is not burdened by building materials that cause landslides. Additionally, the distance between houses is not too close, and they are built on slopes with a low gradient of 0-2%. In low landslide susceptibility areas, some still have land cover in the form of wet and dry forests that are well-preserved to support water absorption during high rainfall intensity and do not cause landslides. No landslide incidents were found in low landslide susceptibility areas because these regions have wet and dry forest land cover and relatively flat residential development. The number of settlements classified as low disaster risk

areas in each sub-district is relatively small, and even in two sub-districts in Balikpapan City, there are no settlements classified as low disaster risk.

Table 6. The Number of Disaster-Prone Settlements

No	Subdistrict	The number of settlements affected by the disaster	Class
1.	West Balikpapan	115	Low
2.	South Balikpapan	11	Low
3.	North Balikpapan	530	Low
4.	East Balikpapan	1.375	Low
5.	Balikpapan City	0	Low
6.	Central Balikpapan	0	Low

The East Balikpapan District has relatively low deforestation in its forests, resulting in a low landslide disaster risk level. This is influenced by land cover in the form of wetland forests and two types of urban forests that contain various large trees such as acacia, mahogany, trembesi, and angkana, making the soil structure relatively stronger. This strength allows it to hold back soil and surface water flow, which can cause landslides. The use of land for mixed plantations in the lowlands of this area does not have an impact on the occurrence of landslides. This is in line with the research by (Firdaus & Yuliani, 2022) that mixed gardens fall into the low-level land use classification in terms of causing landslide disasters.

D. Settlement Conditions in Areas with Moderate Landslide Risk

The moderate landslide vulnerability class for residential areas in the South Balikpapan and North Balikpapan districts has a slope gradient of 15-40%, with some hilly topography conditions, wetland forest cover, and a high distribution of settlements. The total number of residential areas affected by moderate disaster risk in the city of Balikpapan is 168,989 settlements, with a landslide area percentage of 83%. The residential areas in this region are not significantly affected by landslides because, in the moderate risk category, no landslide incidents have been found near the residential areas.

Table 7. The Number of Disaster-Prone Settlements

No	Subdistrict	The number of settlements affected by the disaster	Class
1.	West Balikpapan	15.571	Moderate
2.	South Balikpapan	35.769	Moderate
3.	North Balikpapan	49.271	Moderate
4.	East Balikpapan	23.834	Moderate
5.	Balikpapan City	21.609	Moderate
6.	Central Balikpapan	22.935	Moderate

The condition of buildings in landslide-prone areas is currently dominated by office buildings, shopping centers, residential areas, and schools that are centrally located in the city, with structures that relatively use heavy materials and have wide building areas. This, along with the construction of good drainage systems and water absorption areas, has contributed to the reduced occurrence of landslide disasters. This is in line with the research by (Hidayat et al.,

2023) that drainage is constructed on slopes to prevent surface erosion and reduce infiltration, and it is important to maintain slope stability to prevent landslides.

E. Settlement Conditions in Areas with High Landslide Risk

The West Balikpapan District has the highest landslide-prone area among other districts, covering 445.5 Ha, with residential buildings in this area still using wooden materials as the foundation. The houses are built close together and on a large scale on steep slopes, with unstable soil conditions. The hilly topography of the area and the lack of drainage and water absorption influence the occurrence of landslides. The city of Balikpapan has 6,151 settlements that fall within high-risk landslide zones.

Table 8. The Number of Disaster-Prone Settlements

No	Subdistrict	The number of settlements affected by the disaster	Class
1	West Balikpapan	606	High
2	South Balikpapan	2.586	High
3	North Balikpapan	739	High
4	East Balikpapan	20	High
5	Balikpapan City	840	High
6	Central Balikpapan	1.360	High

The high landslide disaster-prone class in Balikpapan City, which has a high number of affected settlements, namely the South Balikpapan and Central Balikpapan districts, is influenced by the hilly topography with land cover dominated by shrubs, leading to landslides. Additionally, settlements built on hilly topography with steep slopes greater than 40% on a large scale without any initial disaster mitigation contribute to this issue.

The lack of information regarding the development of residential areas on land that does not meet the criteria for the safety level of residential development, including the safety aspect of buildings from natural disasters. This is in line with the research by Prasetya et al. (2022), which states that the construction and development of residential areas should consider land use functions so that land utilization is appropriate as it should be. This is supported by the occurrence of landslides in high-risk disaster areas. The areas with high landslide vulnerability in the city of Balikpapan are the North Balikpapan, Central Balikpapan, and South Balikpapan districts. The South Balikpapan District and the Central Balikpapan District have hilly topography, unstable soil conditions, and densely populated settlements with buildings relatively made of heavy construction materials. The large building sizes and the close proximity between buildings mean that the heavy construction materials cause the soil to be unable to bear the load and reduce water absorption. Additionally, settlements built on slopes with an inclination greater than 40% lead to landslides.

Landslides occurred in the Balikpapan City District, resulting in ten houses suffering minor damage and two houses suffering major damage, affecting a total of forty-six people. Two houses were affected, and access roads were blocked, along with fallen trees in the South Balikpapan District, influenced by high rainfall intensity and landslides. The areas with high landslide vulnerability in the city of Balikpapan are the North Balikpapan, Central Balikpapan, and South Balikpapan districts. The South Balikpapan District and the Central Balikpapan District have hilly topography, unstable soil conditions, and densely populated settlements with buildings relatively made of heavy construction materials. The large building sizes and the close proximity between buildings mean that the heavy construction materials cause the soil to be

unable to bear the load and reduce water absorption. Additionally, settlements built on slopes with an inclination greater than 40% lead to landslides. Landslides occurred in the Balikpapan City District, resulting in ten houses suffering minor damage and two houses suffering major damage, affecting a total of forty-six people. Two houses were affected, and access roads were blocked, along with fallen trees in the South Balikpapan District, influenced by high rainfall intensity and landslides. There was a landslide incident in North Balikpapan District that caused one house to be severely damaged and one house to be lightly damaged, influenced by residential buildings constructed in a landslide-prone area and steep slope inclines.

F. Efforts and Mitigation of Disasters in Landslide-Prone Area

Mitigation is a series of efforts to reduce disaster risk, both through physical development and the enhancement of capabilities to face disaster threats. The classification of landslide disaster risk levels affects actions and efforts in disaster mitigation. Disaster mitigation efforts become crucial in addressing disasters with the aim of reducing the risk of casualties and material and infrastructure losses caused by disasters. Disaster mitigation based on classification levels is as follows:

- 1) *Disaster mitigation in areas with low classification levels*
 - a) Conducting socialization for the community regarding the dangers of landslide disasters.
 - b) Building drainage and irrigation systems on slopes.
 - c) Providing information and disaster maps related to the distribution of landslide-prone areas.
 - d) Limiting construction to prevent land use changes in disaster-prone areas.
 - e) Creating signs or gathering point boards in safe areas from landslide disasters.
- 2) *Disaster mitigation in areas with moderate classification levels.*
 - a) Establishing regulations regarding construction bans around slope inclinations.
 - b) Forming disaster response agencies and community disaster response groups.
 - c) Installing danger markers in landslide-prone areas on steep slopes.
 - d) Monitoring soil conditions and environmental sustainability.
 - e) Strengthening building structures and environmental infrastructure.
- 3) *Disaster mitigation in areas with a high classification level*
 - a) Building retaining walls to prevent landslides on steep slopes or roads.
 - b) Relocating communities living in high-risk disaster areas to safe areas away from landslides.
 - c) Creating evacuation routes to facilitate evacuation activities in disaster-prone locations.
 - d) Establishing regulations regarding activity and construction limits that could burden the slopes.
 - e) Installing early warning systems as a marker for landslide danger.

4. Conclusion

Based on the research results, the classification of disaster-prone areas in Balikpapan City is divided into three classes: low, medium, and high vulnerability. The research findings indicate that the highest potential landslide disaster-prone areas are in three sub-districts with a high potential landslide disaster hazard area, namely Balikpapan Barat Sub-district (3018.0 Ha), Balikpapan Selatan Sub-district (292.0 Ha), and Balikpapan Utara Sub-district (529.3 Ha). The results from processing building parcel shp data with disaster-prone area shp data found a total of 177,174 affected settlements, which are classified into low, medium, and high disaster vulnerability classes. Disaster mitigation that needs to be carried out by the Balikpapan City government for areas with landslide disaster potential includes building retaining walls to hold back landslides on steep slopes, installing early warning systems as a marker for landslide

danger, and relocating communities living in high-risk disaster areas to safer locations. The limited parameters used in this study can serve as a foundation for future research to incorporate more parameters in mapping landslide-prone areas.

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