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Research Article

Landslide hazard assessments and their application in land management in Kendari, Southeast Sulawesi Province, Indonesia

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Abstract

Kendari is the capital of Southeast Sulawesi Province which is prone to landslides. Good land management needs to be done to minimize the impact of landslides. This study aimed to map the Kendari landslide hazard that can be used as an input into land management strategy, especially in vulnerable to the threat of landslides. The primary data used in this study were DEMNAS and Sentinel-2. Landslide detection was carried out using a Process Hierarchy Analysis (AHP) approach and validated by field surveys. Land capability analysis was based on landform analysis using land system data. Land management directions were carried out based on the integration of landslide hazard analysis with the ability of the land to be calibrated with actual land cover. The analysis showed that areas with high and very high landslide hazards reached 2654.09 ha (9.64%) and 4354.78 ha (15.82%). Capability class of VII is spread over structural hills to the north and south of Kendari with an area of 7,215.81 ha (26.21%). Land management in areas with very high landslide hazards and land capability class VII is to add cover crops on land that is not protected by a canopy. Cover crops that can be added are the grass type to minimize the danger of erosion that can trigger landslides.

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Introduction

Landslides are a natural process that occurs in various regions around the world. Landslide terminology can be defined as vertical ground movement caused by slopes (Hartono and Nasikh, 2017). The landslide process has a complex mechanism and highly depends on the geo-environmental conditions (Das et al., 2022). Several factors that trigger landslides are rainfall (Froude and Petley, 2018), soil (Djukem et al., 2020), geology (Bacha et al., 2018), landforms (Martinello et al., 2022), and land use (Abeysiriwardana and Gomes, 2022). The combination of these various parameters can initiate landslides of different magnitudes.

The phenomenon of landslides can cause changes in the morphology of an area and threaten human life and livelihoods. On the environmental aspect, landslides can affect the morphological and hydrological conditions of the surface and trigger other secondary disasters (Dabiri et al., 2019). Furthermore, landslides can also damage public infrastructure, settlements, bridges, and dams (Mu et al., 2020). Sujatha and Sridhar (2021) mentioned that landslides could also cause tremendous losses to socioeconomic conditions. The landslide mechanism influencing socioeconomic conditions usually occurs because the human component loses property or land and causes horizontal conflicts. Domino landslides can occur due to neglect, in that the community or the local government leaves the appearance of landslide initiation. This will undoubtedly cause small-scale landslides and can develop at a larger magnitude.

Systematic efforts to minimize the risk of landslide disasters, including landslide hazard mapping, need to be undertaken (Jam et al., 2021).

Landslide hazard mapping can be done in two main ways, namely: 1) direct on-site measurement; and 2) spatial approach. Direct measurement in the field is the most accurate way, but it takes much money, time, and effort and can endanger the safety of life. Measurement of landslide hazards using a geospatial information system (GIS) approach is the wisest way because it can be done easily, quickly, and efficiently (Neamat and Karimi, 2020). GIS provides the ability to spatially integrate the various factors that lead to landslides, allowing one to pinpoint areas where landslides are likely to occur (Dou et al., 2019).

Based on the various GIS approaches that can be used, process hierarchy analysis (AHP) is one of the most commonly used GIS-based landslide hazard assessment methods (Hadmoko et al., 2010; Panchal and Shrivastava, 2020). AHP is a multi-criteria parameter-based approach for various thematic mappings, including landslides. Through matrix-based pairwise comparisons, AHP allows users to determine the contribution of various factors that affect landslide magnitude (Mallick et al., 2018; Roccati et al., 2021). Kendari has a reasonably high landslide susceptibility because there are structural hills in some parts with a fairly steep slope.

Data from the Kendari Regional Disaster Management Agency (BPDB) states that in this decade, eight significant landslides have threatened people's lives and livelihoods (Saleh et al., 2019). Furthermore, Sejati et al. (2020) stated that more than 22% of areas from Kendari have a high landslide hazard, while 14% have a very high hazard class. Studies on Kendari landslides have been conducted by several previous researchers (Mangidi, 2013; Saleh et al., 2019; Amaluddin et al., 2020; Sejati et al., 2020), but unfortunately, the follow-up efforts from the results of the landslide study have received little attention. Landslide-based land management efforts with a land capability analysis approach need to be carried out to minimize the risk of landslides (Bachri et al., 2021).

This research was conducted to map landslide susceptibility by focusing on land management in Kendari. Landslide susceptibility-based land management directives can be used as consideration for revising regional regulations related to regional spatial planning. This effort is urgently carried out to minimize the impact caused by landslides so that active landslide activities do not threaten aspects of people's lives and livelihoods.

Materials and Methods

The focus of this research was conducted in Kendari City, Southeast Sulawesi Province, Indonesia. Kendari City is the center of government and is the capital city of Southeast Sulawesi Province, Indonesia (Figure 1). Astronomically, Kendari is located between 3°54'40" - 4°5'5" South Latitude and 122°26'33" - 122°39'14" East Longitude with an area of 267.37 km^2. Kendari city center is located in the center, composed of fluvial material and flanked by structural hills on the north, west, and south. In the east, Kendari City center is directly opposite the Kendari Strait, a busy trade route throughout the year. The structural hills surrounding Kendari are composed of various geological formations vulnerable to landslide hazards (Saleh et al., 2019).

Landslide hazard mapping was carried out in three stages: 1) data preparation, 2) data analysis and 3) presentation of hazard maps. The data preparation stage was carried out by preparing geospatial data sourced from secondary data and validated in the field. The raw geospatial data used in this study came from the National DEM data (DEMNAS) sourced from the Geospatial Information Agency (BIG) (8 meters resolution) and Sentinel-2 Image from the United States Geological Survey (USGS) (10 meters resolution). DEMNAS was prepared to extract slope and landform data, while Sentinel-2 was used to extract land use data. Additional data are geological maps and maps of soil types sourced from the Ministry of Energy and Mineral Resources and the Ministry of Agriculture. Measurement of landslide hazard was measured using the AHP approach and considered the landslide hazard index (LHI). The LHI formula refers to the equation developed by Hadmoko et al. (2010) with modifications to adjust the Kendari geo-environmental condition setting. The parameters used are landform, slope, geology, soil, and land use. A simple GIS-based overlay analysis was carried out to produce land units that would later be filled with landslide hazard classes. The LHI formula is presented in equation 1, while the weights and criteria are presented in Table 1. The landslide hazard map in this study is classified into five classes: very low, low, medium, high, and very high. The basis for grading uses a Likert Scale, where the highest value is divided by the lowest value and distributed into five classes.

$$LHI = 0.36LANDF + 0.36SLOP + 0.07GEOL + 0.14SOIL + 0.07LU \quad \text{........ (1)}$$

Areas with flat relief characterize a very low class, and no landslides have occurred. The landslide hazard class is very high, characterized by mountainous relief and frequent landslides. A ground check was carried out in 2021 to see the distribution of existing landslides at the research site. The following research stage was to compile a land capability map to evaluate the relationship between the land capability class and the landslide hazard. The land capability class assessment parameter refers to the criteria developed by Arsyad (2006) with modifications. Changes to several parameters of land capability criteria were made to adjust data availability with the required criteria. The data source used as a land capability database is a land system map sourced from the Geospatial Information Agency. In detail, the land capability assessment criteria used in this study are presented in Table 2.

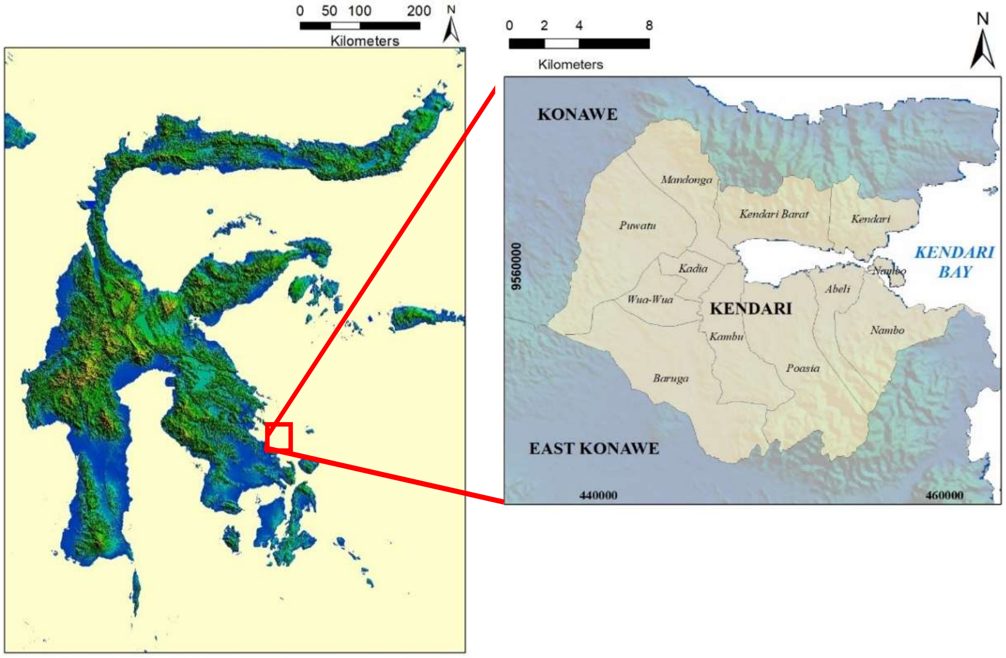

Figure 1. Study site.

Table 1. The weight and score of each parameter used in landslide analysis.

Parameters	Variables	Weight	Score
Landform	Af6Q, Bf6Q, Am6Q	0.36	1
	Cs8Q, Bs7Q, Cs2Q, Cs4Q, Bs3Q		2
	Cs7Q, Cs6Q		3
	Ds3Q, Ds1Q		4
	Es5T		5
Slope	0<8%	0.36	1
	8≤15%		2
	15-25%		3
	25-45%		4
	≥45%		5
Geology	Alluvium Deposit (Qa); Conglomerate and Sandstone (Qpa)	0.07	1
	Coral Reef, Conglomerate and Sandstone (Ql)		2
	Sandy Clay, Sandy Marble and Sandstone (Tmpb)		3
	Conglomerate, Sandstone, Shale and Chalcarenite (Tml)		4
	Filite, Slate, Malic Sandstone and Quartzite (TRjm)		5
Soil	Alluvial, Cambisol	0.14	1
	Podzolic		2
	Gleysol		3
	Mediterranean		4
	Latosol		5
Land Use	Forest	0.07	1
	Plantation		2
	Shrubs		3
	Moorfields, Rice fields		4
	Settlements, Bareland		5

Source: Hadmoko et al. (2010) with modifications.

Table 2. Criteria for assessing land capability.

Limiting factor	Land Capability Class							
	I	II	III	IV	V	VI	VII	VIII
Soil texture	t_1, t_2, t_3	t_1, t_2, t_3	t_1, t_2, t_3	t_1, t_2, t_3, t_4	(*)	t_1, t_2, t_3, t_4	t_1, t_2, t_3, t_4	t_3
Surface slope	A	B	C	D	E	F	G	(*)
Drainage	d_0/d_1	d_2	d_2	d_3	(**)	(*)	(*)	(*)
Effective soil depth	k_0	K_1	k_2	k_2	(*)	k_3	(*)	(*)
Erosion rate	e_0	e_1	e_2	e_3	(**)	e_4	e_5	(*)
Gravel/rock	b_0	b_0	b_1	b_2	b_3	(*)	(*)	b_4
Flood threat	O_0	O_1	O_2	O_3	O_4	(*)	(*)	(*)

Notes: (*) Can have inhibiting factor values of lower classes, (**) The ground surface is always flooded with water.

Results and Discussion

Kendari landslide hazard analysis

Slope and landform factors significantly contribute to the landslide phenomenon in Kendari. Structural hills south and north of the Kendari area have a very high landslide hazard. Slope analysis using a GIS approach shows that the structural hills on the north and south sides of Kendari have a slope of more than 45%. Such a large slope allows water to flow quickly, causing natural erosion and developing into trench erosion. When the trench has developed, and the surface area is wet due to the influence of water, the implications for the slope load become heavy. Heavy loads on the slopes can trigger slope instability which leads to landslides. The distribution of landslides in Kendari can be seen in Figure 2. Interestingly, on land with very steep slopes, the land cover is still dominated by dense vegetation. The effect of dense vegetation is good enough to withstand the rate of landslides compared to other land covers. That is why in areas with very steep slopes in Kendari, the phenomenon of landslides tends to be less than in other areas. However, further investigation is needed on how the mechanisms of plants in the southern and northern regions of Kendari respond to water in the local hydrological cycle. This is based on the fact that some plants can store water in their root system, which can overload the slopes and trigger landslides. Land management in areas with high and very high landslide hazards can be given through the land capability approach.

The overlay results between the land capability map and the landslide hazard map are used as input for modifying physical land factors and land management. The results of the overlap between the land capability map and the landslide hazard map are used as input for modifying physical land factors and land management.

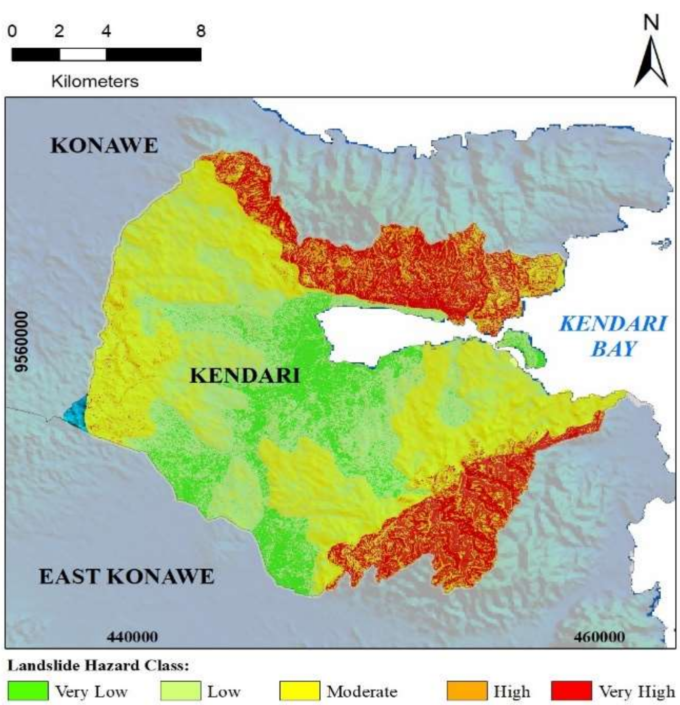

Figure 2. Distribution of landslide hazard in Kendari.

The results of this study indicate that the analysis results differ from previous studies, which were conducted in Kendari. Amaluddin et al. (2020) concluded that the structural hills in southern Kendari are in moderate danger. It is suspected that the cause of the difference in the analysis is that Amaluddin et al. (2020) research added the annual rainfall factor, while this study did not use the annual rainfall factor as the basis of the analysis. This study prefers to use a landform approach because the landform provides a complete picture of the edaphic and climatic processes of the research location. Furthermore, Martinello et al. (2022) and Bachri et al. (2021) also highlight that landforms are closely related to the landslide phenomenon.

Statistically, the area in Kendari, which has a high-hazard class, is 2654.09 ha (9.64%), while the very high-hazard class has an area of 4354.78 ha (15.82%) (Table 3). The area occupies land units to the north and south of Kendari. Typical land with high and very high class is characterized by land with a 25-45% slope and >45%. This finding is in line with Fata et al. (2022), who stated that active landslides mainly occur on land with a slope of >45%. Sub-districts with a high risk of landslides are found in Kendari, West Kendari, Poasia, Abeli, Mondonga, and Nambo. The landslide hazard map is validated in areas with high and very high landslide hazards by considering the affordability of the landslide location.

Validation in 2021 shows at least 30 active landslide points in Kendari. Most of the landslides were in West Kendari and Mondonga. Landslide points are often found in areas with a very high hazard class with land cover in the form of vacant land. Most of the landslides in the research location occurred because the land was abandoned due to not being processed and caused natural erosion, which developed into ditches and partly led to the phenomenon of landslides.

Table 3. Percentage of landslide hazard class in Kendari.

Landslide Hazard Class	Area	%
Very Low	3165.62	11.50
Low	7444.89	27.04
Moderate	9908.51	35.99
High	2654.09	9.64
Very High	4354.78	15.82
Total	**27527.91**	**100**

Kendari land capability analysis

Measuring land capability as a series of sustainable land management efforts is essential. According to Abd-Elmabod et al. (2019), the essential data used for measuring land capability is land system data, which contains complete information about the characteristics of the land. Land capability in Kendari is classified into six classes: I, II, III, IV, VI, and VII (Figure 3). Slope and soil factors play an essential role in categorizing land capability in Kendari. This is in line with the findings of Yohannes and Soromessa (2019), which state that the association of slope and soil factors significantly influences the value of land capability in an area.

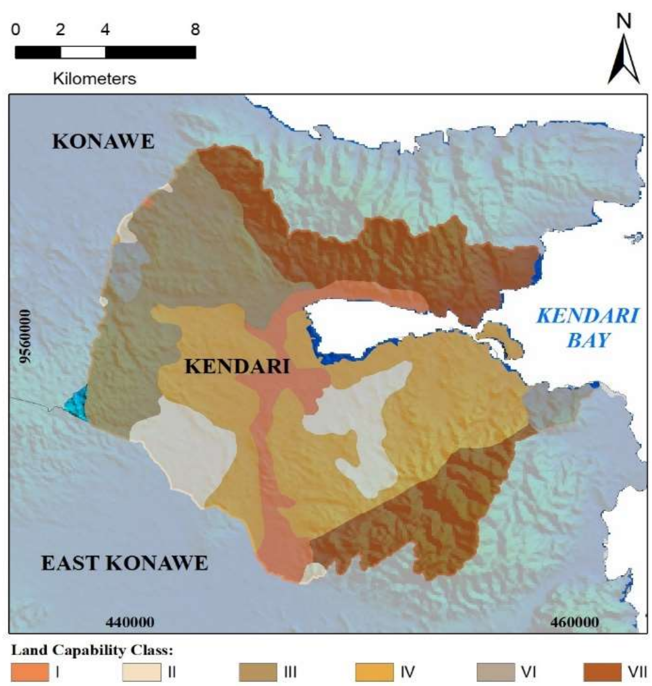

Figure 3. Overview of land capability distribution in Kendari.

The spatial distribution of areas with VI and VII land capability is spread over the structural hills north and south of Kendari. Soil classification in this area is composed of Latosol soil. Latosol soil is a super thick soil with a loamy soil texture of silty clay (Ramadhani and Lukito., 2021). Priyono and Elly (2021) added that Latosols are highly vulnerable to landslides. Interestingly, this area has high rainfall, which can increase the vulnerability to landslides.

The inhibiting factors in land use efforts in the structural hills in northern and southern Kendari are the slope and erosion factors. The average slope that dominates this area is a slope of >45%. Land with a slope of >45% is only suitable for forest areas and plantations with limited use. This area's built-up land and agricultural cultivation efforts must be limited given the high slope instability. Furthermore, although this area is dominated by land cover in the form of forests, erosion is also relatively high. The cloudy color of the water pieces of evidence this in the river that originates in the structural hills. Some intermittent rivers that flow when it rains also have a cloudy color on the beach. This phenomenon can be a problem for the silting of several rivers in the Kendari basin area, triggering inundation floods.

The percentage of land capability with class VII is also quite dominant in Kendari. The area with land capability class VII reaches 7215.81 ha (26.21%). The area includes the Districts of Mondonga, West Kendari, Kendari, Nambo, Abeli, and Poasia. Land capability with class VI in Nambo Sub-district should also get serious attention because the results of manual detection on Sentinel-2 imagery show that some of the areas have been cleared of land. The light brown to dark hue on Sentinel-2 indicates that the area has been explored for use in non-vegetative activities. The percentage of Kendari land capability class can be seen in Figure 4.

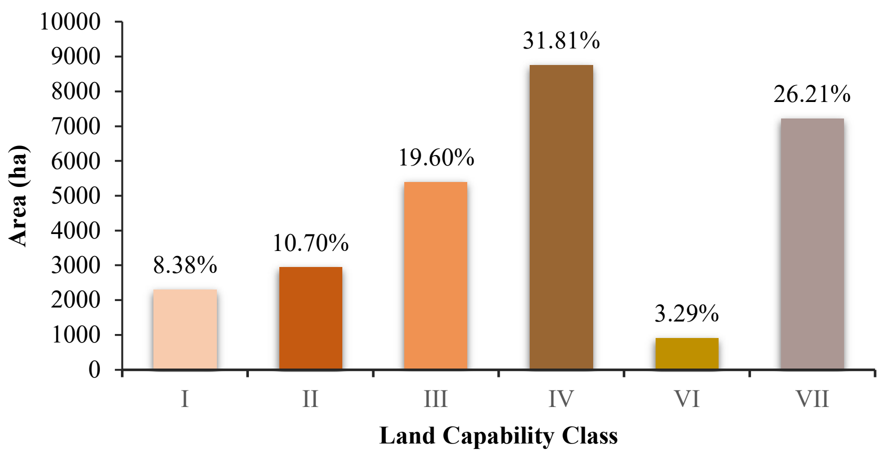

Figure 4. Percentage of land capability distribution in Kendari.

Land management direction based on landslide hazard and Kendari land capability

Analysis of landslide hazard and land capability in Kendari shows that the structural hills in the northern part of Kendari have a high to very high hazard, with a land capability class of VII. Referring to Chauhan et al. (2020), vulnerability class VII is suitable for forest and wildlife life. Existing conditions in Kendari indicate that the structural hills in the northern part of Kendari are covered with wilderness. The condition of the forest in the area is quite good because the area is designated as a Nature Reserve Park. This condition makes land use change occur slowly because rules protect it based on law. Furthermore, the structural hills in the southern part of Kendari also have a land capability class of VII with a landslide hazard in the high to very high class. This area is also dominated by wilderness cover in good condition because the government has designated this area as a protected area and water catchment area. This stipulation has the consequence that every person or institution that wants to change land use must have a permit so that land use changes occur slowly. Regarding the management of landslides, the government has also made various efforts to make community-based approaches. One of the educational efforts is to install signs indicating that the area has a high landslide hazard (Figure 5). Landslide danger signs can provide an understanding for the community not to carry out strenuous activities that can trigger slope instability in landslide-prone areas. This effort is quite effective in Kendari, considering that from the records of landslide events, the damage and losses caused by landslides in Kendari tend to be small. However, conservation efforts against erosion need to be increased in this area. An additional effort that might be made is to provide additional protective plants for the surface soil so that erosion can be minimized, especially in spots that are not protected by a canopy of vegetation.

Figure 5. Signs as markers of landslide-prone areas in Kendari.

Conclusion

A landslide is a natural phenomenon that occurs naturally. The existence of landslides can threaten human life and livelihoods if not taken seriously. Landslide hazard-based land management efforts with a land capability analysis approach can be a solution to minimize the risk of landslides. The results of this study indicate that the structural hills in the north and south of Kendari have a high to very high landslide threat. Furthermore, this area has land capability class VII, which means this area must be used as a conservation area.

This area is used as a nature reserve with different statuses. The law protects the area, so land use changes can slowly cause landslides. Land allocation in areas with high and very high landslide risk is considered appropriate. A feasible land management effort is to provide supplemental cover crops, especially on land not protected by a canopy. This is done to reduce the rate of erosion and maintain the environmental quality in the protected area.

Efforts are needed to scrutinize the landslide process and provide a complete picture of site-level landscaping. In addition, Kendari recommends performing large-scale landslide mapping, especially on high-risk structural hills. This survey can be conducted in vulnerable areas adjacent to settlements and public facilities such as roads and bridges.

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