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Research Article

Spatio-temporal of landslide potential in upstream areas, Bali tourism destinations: remote sensing and geographic information approach

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Abstract

Upstream Bali has tourist destinations with beautiful natural panoramas such as mountains, forest areas, and lakes. Characteristics of the area with steep slopes, high rainfall, and altitude above 1,500 masl. The area is inseparable from the threat of disasters, such as landslides, especially in the Baturiti District. This area often experiences landslides but has not been mapped spatially. Mitigation efforts are needed to minimize the impact of landslides. This study aimed to determine the potential for landslides and their distribution in different periods, namely 2000, 2010, and 2020. The scoring method considers four parameters: rainfall, slope, soil type, and vegetation density, using ArcGIS 10.8 Apps. Parameters extracted from remote sensing data include Landsat with ETM+ and OLI sensors, rainfall from the CHIRPS satellite, and slopes from DEMNAS. Geographic Information System (GIS) data includes soil types. Another role of GIS is to quantify raster data to build a landslide potential prediction model. Baturiti District has a low to high potential for landslides, which are administratively distributed in Candikuning, Baturiti, Antapan, Batunya, and Bangli Villages. The landslide potential in the high category in 2000, 2010, and 2020 respectively, is 70.12 ha (1%), 597.05 ha (5%), and 39.12 ha (1%). Based on the findings of this study, the leading cause of landslides is high rainfall followed by reduced vegetation density. Other factors include steep slopes (>45%) and soil types of Andosol and Regosol.

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Introduction

The island of Bali has been known to domestic and foreign tourists as a world-famous tourist destination. Beautiful panoramas and landscapes become leading tourism destinations and increase the country's foreign exchange (Utama et al., 2020; Trimurti and Utama, 2021). Natural tourism in coastal areas that have been famous such as Kuta Beach, Pandawa, Sanur, Tanah Lot, Legian, Seminyak, etc. Other panoramas that are no less interesting are tourist destinations in the upstream area with highlands, such as Mount Agung, Batur, Bedugul/Candikuning, and lake destinations with cool air (Ismail, 2021). The area is inseparable from the threat of disasters, one of which is landslides that often occur in the Bedugul tourist destination, Baturiti District (Diara et al., 2022). A landslide is a natural mass transfer of soil and occurs in a short time with a large volume. This condition is a natural phenomenon; nature is looking for a new balance due to disturbances or factors that influence it and cause a reduction in shear strength and an increase in soil shear stress (Tebbens, 2020). Landslides and earth movements are increasingly occurring in Indonesia yearly, especially during the rainy season (Silalahi et al., 2019). Mitigation efforts are needed to minimize the impact of landslides. Landslides are generally caused by the influence of gravity on the weathered rock, which is located on topography with a steep to a very steep slope and is on the impermeable rock. Today, several landslides often hit the Bali area. Baturiti District is an area that has exceptionally high hills and steep to very steep slopes that have the potential for landslides. Baturiti District has various slopes, ranging from flat (0-8%) to very steep (>45%). Land with a very steep slope has the potential for landslides to occur, so the level of landslide hazard is also high.

Previous researchers stated that the Bedugul tourist destination area has moderate to high landslide-prone areas in the east and south. Most of the settlements affected by landslides are in Candikuning Village (Sunarta et al., 2018). Other researchers focused on mapping the potential for landslides on horticultural agricultural land, and the result was that around 2,369.11 ha of Baturiti agricultural area were in a landslide-prone area (Trigunasih and Saifulloh, 2022). In addition to horticultural agriculture, the main access road that crosses the Baturiti-Candikuning area is also in a high-category landslide potential area (Diara et al., 2022). Previous researchers modeled landslides with one-time series data without remote sensing data (Lee and Choi, 2004; Silalahi et al., 2019; Psomiadis et al., 2020; Wang G et al., 2020; Bachri et al., 2021).

The weakness of using single data in landslide investigations is not knowing past events in a time series. Such conditions are limited because they cannot be used as a basis for future mitigation plans (Aggarwal et al., 2020, 2022; Liu et al., 2022). Commonly, the occurrence of landslides depends on the variability of vegetation density and rainfall dynamics in an area (Van Beek and Van Asch, 2004; Reichenbach et al., 2014; Jeong et al., 2017; Chen et al., 2019; Kumar et al., 2019; Jia et al., 2020). The latest researchers found that the influence of climate change, such as El Niño and La Niña, is closely related to landslide events (Moreiras, 2005; Froude and Petley, 2018; Emberson et al., 2021).

To address this issue, this research used multi-temporal remote sensing data derived from Landsat satellite images with ETM+ and OLI sensors and rainfall data extracted from Rainfall Estimates from Rain Gauge and Satellite Observations (CHIRPS) satellite data for 2000, 2010, and 2020. Topographic data derived from the National Digital Elevation Model (DEMNAS). Topography data is a single series due to the limited time series topography data at the research location. Estimation of landslides by time series in this study uses integration between GIS and remote sensing.

Remote sensing techniques have been widely developed, among others, for disaster mitigation ranging from droughts, floods, land/forest fires, and landslides (Joyce et al., 2009). This technique has advantages in terms of temporal resolution, which can be used to change an object at different times. Geographic Information System (GIS) can facilitate the provision of spatial information, especially in determining the level of potential landslides in the Baturiti District.

This study aimed to analyze and map areas that have the potential for landslides in the Baturiti District in 2000, 2010, and 2020 and to quantify changes in the area of landslide potential in the Baturiti District.

Materials and Methods

Research location

The case study was carried out in Baturiti District, Tabanan Regency, Bali Province, with an area of 11,420 ha. Baturiti District is geographically located at 08º14"30"-08º38"07" south latitude and 114º59"00"-115º02"57" east longitude. Buleleng Regency borders the administrative area of Baturiti District in the north, Badung Regency in the south, Penebel and Marga Districts in the west, and in the east, Petang District, Badung. The map of the research location is presented in Figure 1.

The upstream area where the research case study is located has famous tourist destinations (such as the landscape of Lake Beratan, campsites, strawberry picking tours, and other man-made tours), (Sujarwo, 2019; Sunarta et al., 2019) with various supporting facilities such as villas, restaurants, and shopping areas. The upstream agro-tourism area indicates relatively high land degradation (Kartini et al., 2023). This phenomenon is caused by the excessive use of chemical fertilizers in agricultural land activities. Another problem in the upstream area is that the community cultivates on steep slopes, even though the area has relatively high rainfall. So it is prone to soil erosion rates, as in previous studies, which reached >480 t/ha/yr (Trigunasih and Saifulloh, 2023).

Tools and materials

The materials used in this study were CHIRPS data in 2000, 2010, and 2020 that were collected via Google Earth Engine platform (Gorelick et al., 2017; Bangsawan et al., 2021; Mehdi et al., 2021), Landsat 5, 7, and 8 images of 2000, 2010, and 2020 respectively, with path/row 118/65 that were downloaded from https://eartheexplorer.usgs.gov/, map of soil types in Baturiti Subdistrict scale 1:250.000 that was obtained BPDAS Bali Province, and the DEMNAS data with a resolution of 8 meters that was that were obtained from http://tides.big.go.id/DEMNAS/. Supporting tools for spatial analysis using ArcGIS 10.8 was used to process Landsat imagery, overlay, and layout maps.

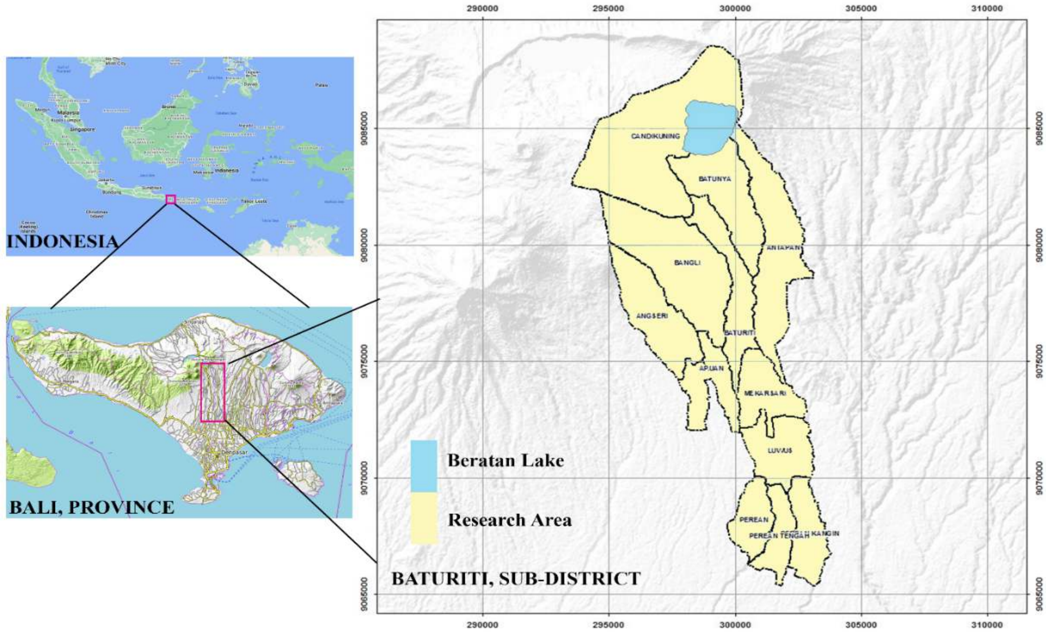

Figure 1. Research location viewed by global scale (left-above), regional scale (left-bellow) and local scale (right).

Research methods

This research was conducted in several stages, namely the preparation and data collection stage, the image processing stage, the thematic map-making stage, and data analysis techniques. Image processing was carried out in several stages: geometric correction, radiometric correction, pan sharpening, and Normalized Difference Vegetation Index (NDVI) transformation. Each image of Landsat 5 in 2000, Landsat 7 in 2010, and Landsat 8 in 2020 in multi-temporal and rainfall analysis using CHRIPS data using ArcGIS software. Determination of potential landslide susceptibility used Geographic Information System through the scoring method. The purpose of scoring was to determine or assess landslide potential in the research area. Scoring parameters that affect landslides include rainfall, slope, soil type, and vegetation density. The level of potential for landslides is indicated by the total value or overall score of each supporting parameter for the occurrence of landslides.

The method used in this study was a survey and scoring method. The survey method was carried out with the aim of checking/validating and documenting landslide events that have occurred. In addition, interviews with residents were also conducted to find out the locations of landslides that had occurred in the research location. The parameters used to predict the potential for landslides were based on the research of Khoiri et al. (2018), giving weights and scores referring to researchers in the same place against previous researchers (Diara et al., 2022; Trigunasih and Saifulloh, 2022). The method was modified by classifying the potential for landslides at predetermined intervals so that four classes of landslide potential are obtained by considering four parameters: rainfall, slope, soil type, and vegetation indices. Each parameter has a different weight and score. The score for each parameter starts from 1 to 5, which indicates the magnitude of the influence on the process of landslides. The scores for each class of each parameter are presented in Table 1. A score of 1 shows a tiny contribution to landslides, whereas a score of 5 substantially contributes to the process of landslides. The landslide potential level, which was carried out to obtain the landslide potential class interval, was further classified into four classes, namely high, medium, low, and not potentially presented in Table 2.

Results and Discussion

Factors causing landslides are divided into 2, namely, dynamic factors and static factors. The dynamic factor is a factor whose value tends to change according to the period of the year (rainfall and vegetation density). In contrast, the static factor is a factor whose value is difficult to change or tends to remain constant (soil type and slope).

Factors and parameters

Based on the results of the analysis of rainfall data in 2000 in the Baturiti District, it was found that the rainfall index range was from 2,404.90 to 2,859.82

mm/year. Rainfall in 2010 was 3,129.77 to 3,579.47 mm/year, while in 2020, it was 2,026.38 to 2,503.50 mm/year. The highest annual rainfall was in 2010, which was >3,000 mm/year (very high). This is in line with Meteorological, Climatological, and Geophysical Agency (BMKG) data, 2010 that of the two active rainfall recording stations in Tabanan Regency, the highest rainfall in 2010 occurred in January, April, and September to December. Figure 2 (a, b, and c) presents the spatial distribution of annual rainfall.

Table 1. Score and weight of each parameter to predict landslide susceptibility.

No	Criteria	Score	Weight (%)
	Rainfall (mm/yr)		
1	<1,000	1	35
2	1,000-2,000	2	
3	2,000-2,500	3	
4	2,500-3,000	4	
5	>3,000	5	
	Slope (%)		
1	Flat (<8%)	1	20
2	Sloping (8-15%)	2	
3	Slightly Steep (15-25%)	3	
4	Steep (25-45%)	4	
5	Very Steep (>45%)	5	
	Soil types		
1	Alluvial, Gleisol, Planosol, Hydromorph gray, Lateric groundwater	1	15
2	Latosol	2	
3	Brown forest soil, Non-calcic brown, Mideteranian	3	
4	Andosol, Laterik, Grumosol, Podsol, Podsolic	4	
5	Regosol, Litosol, Renzina	5	
	Vegetation Indices (NDVI)		
1	High (0.19 s/d 1)	1	30
2	Moderate (0.25 s/d 0.36)	2	
3	Low (0.15 s/d 0.25)	3	
4	Very Low (-0.11s/d 0.15)	4	
5	Barren/ Urban/ Cloud Cover, Water (-1 s/d -0.11)	5	

Table 2. Landslide potential level.

No	Landslide Potential Level	Threshold
1	No Potential	115-211
2	Low	211-307
3	Moderate	307-404
4	High	404-500

Based on the image processing results in 2000, it is known that the lowest vegetation density index value is -0.46 while the highest index value is 0.88. The lowest vegetation index in 2010 was -0.35, while the highest index value was 0.55. The 2020 vegetation index is -0.31, while the highest index value is 0.50. Spatially, the vegetation index in 2000, 2010, and 2020 dominated with an area of 48%, 38%, and 37%, respectively (Figure 2d,e,f). The decrease in vegetation density in the study area occurred because of the conversion of land functions caused by changes to land in the form of forests turning into non-rice fields and agricultural land in the form of fields, plantations, and shrubs. The type of soil that dominates the research area is yellowish-brown Latosol, with an area of 4,602.96 ha (41%), and the lowest is gray Regosol, with an area of 1,864.90 ha (17%), and gray brown Andosol, with an area of 4,279.10 (38%). The yellowish-brown Latosol soil type was evenly distributed in the southern part of the study area (Figure 2g). The slope influences the occurrence of landslides; the more inclined the slope of a place is, the more potential the area is for landslides (Çellek, 2022; Kawamura et al., 2019). The slope class with the flat category dominates the research area covering an area of 3,102.34 ha (28%), while the very steep slope class is the slope class with the lowest area in the study area with an area of about 1,146.19 ha (10%) (Figure 2h).

Spatio-temporal of landslide potential

Based on the analysis and overlay of each parameter, four classes of landslide potential were obtained, namely high, medium, low, and no potential for each year. The spatiotemporal distribution from 2000, 2010, and 2020 shows the potential for landslide changes in the area, starting from an increase or decrease in the potential area in each class of landslide potential. The level of landslide potential has increased and decreased from 2000 to 2020.

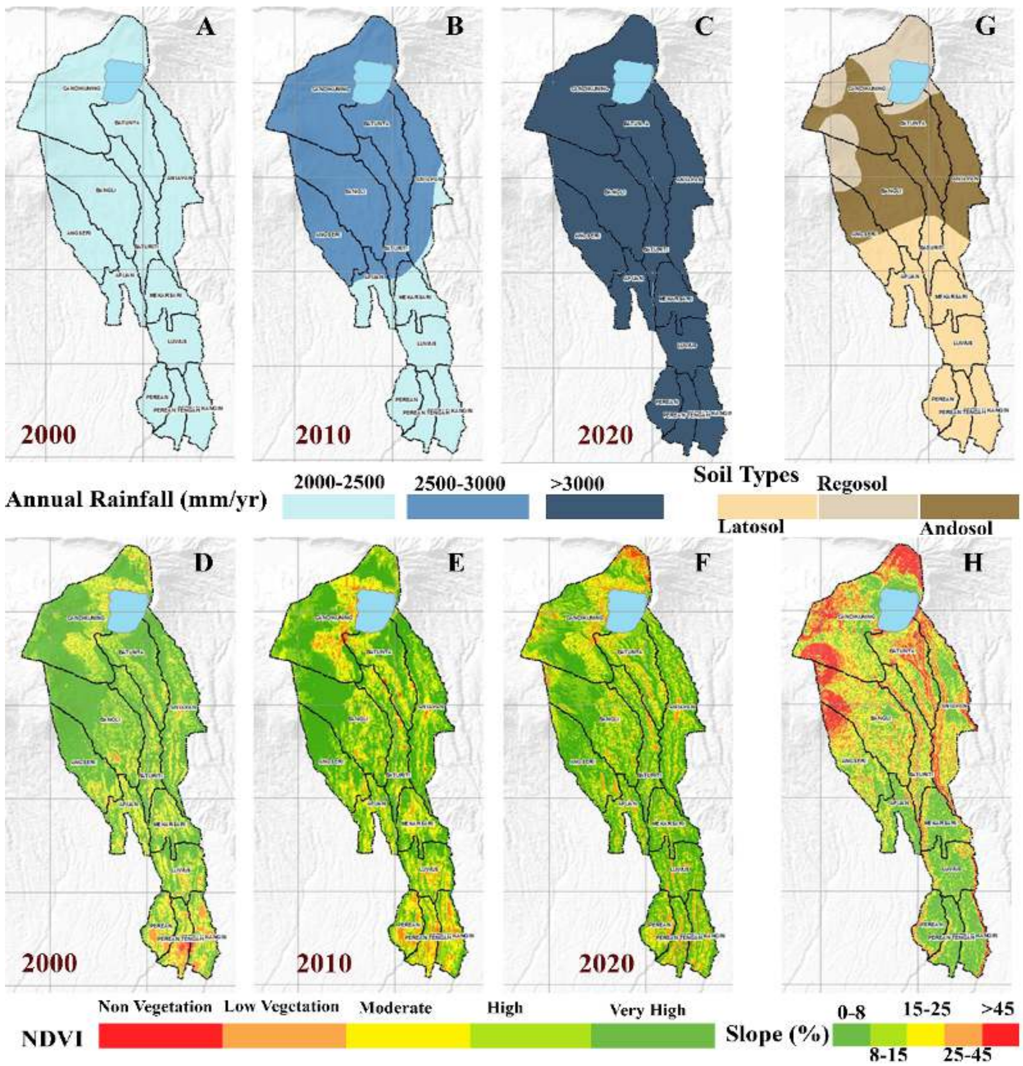

Figure 2. Thematic maps to predict landslide potential: annual rainfall in 2000 (a), 2010 (b), and 2020 (c); vegetation indices in 2000 (d), 2010 (e), and 2020 (f); soil types (g); and slope (h).

From 2000-2010 the area with no landslide potential decreased by 515.09 ha, while from 2010-2020, it increased by 2,028.29 ha. Meanwhile, areas with low landslide potential in 2000-2010 decreased by 4,027.91 ha, and in 2010-2020 increased by 4,514.19 ha. The potential for landslides in the medium category for the 2000-2010 period has increased by 4016.07 ha. From 2010-2020, it decreased by 5,984.55 ha. Areas with a high level of landslide potential in 2000-2010 increased by 526.93 ha, and in 2010-2020 decreased by 557.93 ha (Table 3 and Figure 3). Red polygons indicate spatial distribution with high landslide susceptibility. Spatially, areas with moderate to high landslide susceptibility are in the northern part of the village, namely Candikuning, Antapan, Bangli, Batunya, Baturiti, and Angseri (Figure 4). The role of each parameter on the potential for landslides in 2000, 2010, and 2020 can be seen that the parameters that change every year are rainfall and vegetation density, while the slope and soil types tend not to change.

Table 3. Changes in l for 2000-2010, 2010-2020.

No	Landslide Category	Area (ha)	
		2000-2010	2010-2020
1	No Potential	-515,09	2,028.29
2	Low	-4,027,91	4,514.19
3	Moderate	4,016,07	-5,984.55
4	High	526,93	-557.93

The slope is one of the triggering factors for landslides in hilly/mountainous areas. The steeper the slope, the greater the chance of landslides. This is due to the volume and velocity of surface water flow increasing along with the steepness of the slopes (Wang K et al., 2020; Ramesh, 2021). As a result, this condition has the potential to cause landslides.

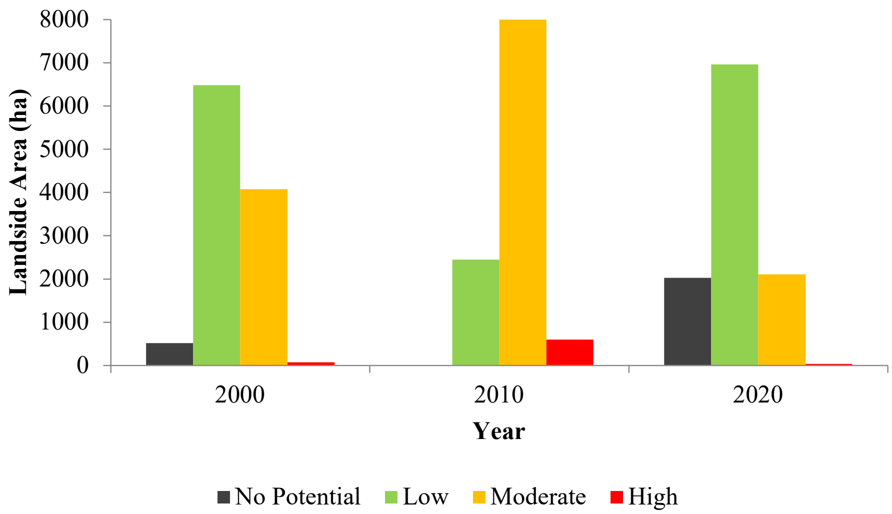

Figure 3. Graph of comparison landslide potential during 2000, 2010, and 2020.

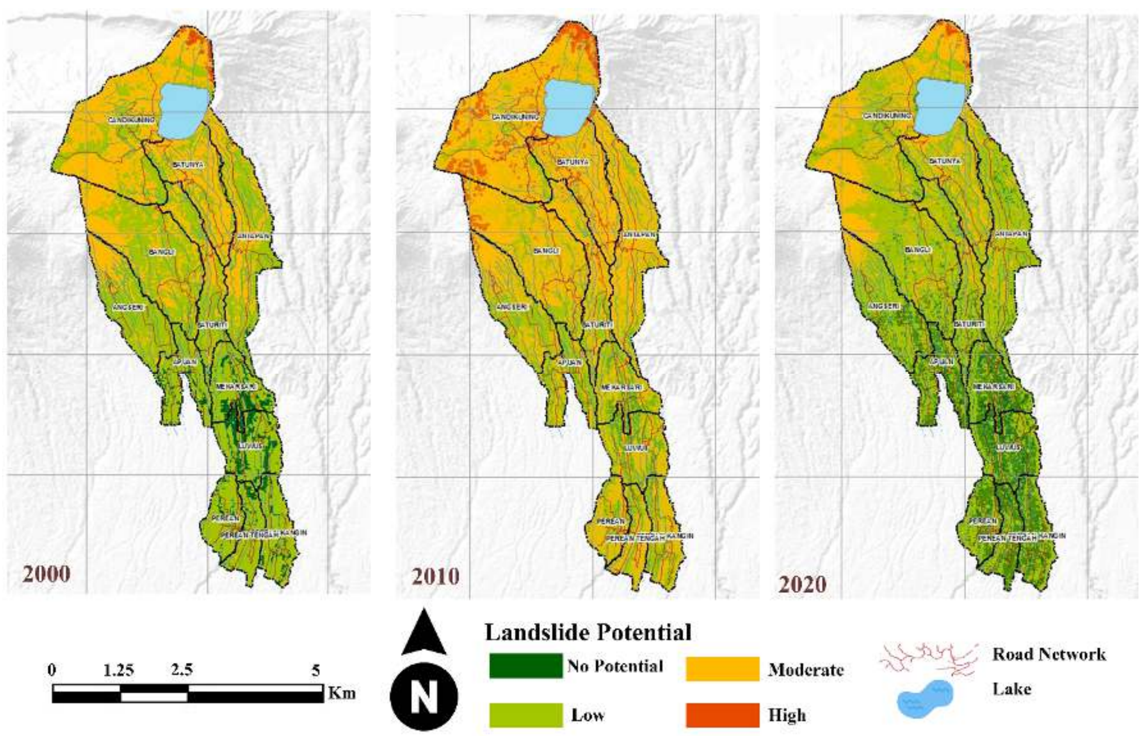

Figure 4. Spatio-temporal of landslides potential map during 2000, 2010, and 2020.

Another parameter that affects the occurrence of landslides is the type of soil. In the research area, it is known that the dominant soil type is yellowish-brown Latosol, while the other soil types are gray-brown Andosol and gray Regosol. Each type of soil has a different sensitivity to landslides. Soil types of gray Regosol and gray-brown Andosol are soils susceptible to landslides because they come from volcanic materials resulting from volcanic eruptions. These soil types have a fraction of sand and some dust, so these soils are loose with less plastic and non-sticky consistency, and these soils have many cavities that facilitate the entry and exit of water (Fan et al., 2016; Liu et al., 2021). High-intensity rainfall triggers soil movement so that the soil becomes saturated. This saturation occurs when the absorption of rainwater by the soil decreases. Landslides often occur in hilly and mountainous areas, especially on sandy soils such as

Regosol or Andosol in wavy areas where landslides are likely to occur, so land management accompanied by conservation actions is very necessary. Sand and silt-textured soils are very susceptible to landslides compared to clay textures which have better water holding capacity (Wang K et al., 2020; Liu et al., 2021).

Vegetation density affects the potential for landslides, namely medium and high potentials with lower vegetation density than those with no and low potential (Gonzalez-Ollauri and Mickovski, 2017; Zhong et al., 2021; Saito et al., 2022). The occurrence of landslides is not only caused by topography and the abundance or absence of vegetation at that location. Vegetation is one of the essential factors in maintaining slope stability because the presence of plants or trees in the area will significantly affect the landslide process (Fiorucci et al., 2019; Qu et al., 2021). The effect of ground cover vegetation is to protect the soil surface from rainwater collisions, reduce the speed and volume of runoff water, hold soil particles in place through the root system and the resulting litter, and maintain the stability of the soil's capacity to absorb water (Liu et al., 2021). Good cover vegetation, such as thick grass or dense forest, can eliminate the influence of topography on landslides.

Land use change from vegetation to non-vegetation affects landslide susceptibility (Senanayake et al., 2020; Bourenane and Bouhadad, 2021; Rabby et al., 2022). The more dense vegetation in an area, the smaller the potential for landslides and vice versa. The rarer the vegetation, the greater the potential for landslides, so vegetation management is needed to cope with losses caused by landslides (Qu et al., 2021). One example of losses that landslides can cause is damage to facilities and infrastructure such as housing, roads, and agricultural land (Soma and Kubota, 2018; Priyono et al., 2020). Conservation efforts and vegetation management are in areas with high potential and moderate potential for landslides. They were needed to anticipate the occurrence of more extensive landslides. The government is expected to strengthen the community's early warning system through education so that people are aware of the threat of disasters that can come at any time and anticipate landslides.

Conclusion

Baturiti Subdistrict has low to high potential for landslides, which are administratively scattered in Candikuning, Baturiti, Antapan, Batunya, and Bangli villages. The landslide potential in the high category in 2000, 2010, and 2020 respectively, is 70.12 ha (1%), 597.05 ha (5%), and 39.12 ha (1%). Based on the findings of this study, the leading cause of landslides is high rainfall, followed by reduced vegetation density. Other factors include steep slopes (>45%) and soil types of Andosol and Regosol. Weaknesses and uncertainties of this study are found in the type of spatial data used in building the landslide potential model. Soil type and rainfall data with low spatial resolution do not match with DEMNAS data and Landsat image data, resulting in a relatively general landslide distribution. Future researchers need to build a landslide hazard model with more complex parameters and include inventory data in building the model so that the results are close to field conditions. The advice to local governments and communities is that areas with medium and high potential need to be conserved and maintained to anticipate more significant landslides. The government is expected to strengthen the community's early warning system through education so that community are aware of the threat of disasters that can come anytime so that landslides can be anticipated.

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