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SPATIAL DISTRIBUTION OF LANDSLIDE SUSCEPTIBILITY IN NEW ROAD CONSTRUCTION MENGWITANI-SINGARAJA, BALI-INDONESIA: BASED ON GEOSPATIAL DATA

I Wayan Diara*[1], R Suyarto[2], and Moh Saifulloh[3]

[1]Faculty of Agriculture, Udayana University, Denpasar, Bali-Indonesia
[2]Spatial Data Infrastructure Development Center (PPIDS), Udayana University, Denpasar, Indonesia
[3]Master Program of Geography, Gadjah Mada University, Yogyakarta-Indonesia

*Corresponding Author, Received: 01 Dec. 2021, Revised: 24 May 2022, Accepted: 12 June 2022

ABSTRACT: Landslides often occur in the Mengwitani-Singaraja new road construction area. This study aims to analyze the spatial distribution of landslide susceptibility as a basis for disaster mitigation. This study uses a quantitative and descriptive method. Data analysis through scoring technique and thematic map overlay. The parameters needed in this study include the slope, landform, geological structure, rainfall, soil type, and land cover. Spatial analysis was performed using a Geographic Information System (GIS). The study results are categorized into three landslide susceptibility maps, namely high, medium and low. Baturiti and Sukasada sub-districts are areas that have a high level of landslide susceptibility of 15.62%. The low landslide susceptibility area is the area that has the highest area, which is 30.38%, and the medium landslide susceptibility area is 26.87%. Other sites have no susceptibility for landslide susceptibility (27.1 %). High landslide susceptibility because the area is located on volcanic upper slope landforms, volcanic cones, with fractured and sloping geological structures, very steep slopes (> 45%), high rainfall (> 2,400 mm/yr.), andosol soil types, as well as land cover with low vegetation density. The occurrence of landslides in the field is spatially dominant on the road section that crosses Candikuning Village to Gitgit Village. Land management is recommended by installing coconut fiber gabions on steep slopes and terraces, plant cultivation according to conservation rules, and the addition of organic matter.

Keywords: Landslide Susceptibility Map (LSM), Mengwitani-Singaraja Road Section, Geographic Information System (GIS), Bali-Indonesia

1. INTRODUCTION

Indonesia is a country that has two great potentials, namely the potential for natural resources and the potential for disasters. Potential disasters in Indonesia are caused by geological conditions which are closely related to the tectonic setting and tropical climate conditions in Indonesia. The tropical climate is characterized by quite extreme weather changes, including temperature, rainfall, and wind direction. This condition is supported by the very heterogeneous topography of Indonesia, ranging from mountains to lowlands. In addition, as well as environmental damage is caused by land conversion, thereby increasing disaster vulnerability in the area, such as floods and landslides.

Landslides, also known as mass movements of soil, rock, or a combination of them, often occur on natural slopes or non-natural slopes and are natural phenomena, namely, nature seeking a new balance due to disturbances or factors that influence and cause a reduction in shear strength and an increase in stress, soil shear [1,2]. The landslide referred to in this study is the movement of soil mass, rock mass, and a mixture of soil and rock masses down the slope as a result of the influence of gravity or gravity. Landslides or mass movements are closely related to processes that occur scientifically in a landscape. The landscape is a natural formation on the earth's surface, such as hills, hills, mountains, mountains, plains, and basins [3,4]. Geomorphology is a part of earth science that studies the configuration of the earth's surface and the processes that shape and change it. Geomorphology can be defined as the science of landforms that form the earth's surface, both above and below sea level, their genesis, and future development, in line with the environmental context [5]. Contribution of geomorphology to the Assessment of mass movement events several factors need to be owned to assess the occurrence of mass movements or landslides, namely: slope, drainage, bedrock, soil, previous landslides, climate, and the influence of hu, man activities [6–8]. Referring to these various concepts, it can be concluded that there is a close relationship between the geomorphological conditions of an area and the characteristics of the occurrence of landslides because the factors that make up the landform will also affect the characteristics of landslides which are reflected by various types of landslides.

Several natural factors caused the disaster, including the many volcanoes, both active and non-active, especially the western part of Sumatra Island and the southern part of Java Island. The two regions are part of the ring of fire that encircles the sunken Pacific Ocean from the Asian continent to the Americas. In addition, the territory of Indonesia is the confluence of 3 plates of Australia, Eurasia, and the Pacific, so it is often hit by tectonic earthquakes [9,10]. The earthquake shocks can cause landslides in hilly areas with steep slopes. Natural factors that affect landslides include slope, soil texture, soil permeability, rock weathering rate, effective soil depth, nick density, groundwater table depth, and rainfall, while non-natural factors include: land use and vegetation density [11–14].

The new Mengwitani-Singaraja road section of Bali Province was built on a land height of 50 meters above sea level – above 1000 meters above sea level. In areas with an altitude of > 1000 masl with a slope of > 45%, it is estimated that there is a landslide susceptibility. Thus, it is necessary to conduct this research to find out the landslide-prone locations, which will later serve as the basic material or guidelines for the government and the surrounding community in carrying out mitigation and prevention efforts so that the impact is not too large. On the other hand, disaster risk mapping for each region has also been required in the RI Law no. 24 of 2007 concerning Disaster Management in articles 35-36 and Government Regulation of the Republic of Indonesia No. 21 of 2008 concerning the Implementation of Disaster Management in Article 6, then also supported by Regulation of the Head of the National Disaster Management Agency (PERKA BNPB) No. 2 of 2012 concerning Disaster Risk Assessment. This study aims to: (1) identify the factors that most influences landslides susceptibility along the new road section (Mengwitani-Singaraja) Bali Province, (2) the spatial distribution of landslide hazards along the new road section, and (3) identify the relationship between landslide susceptibility and previous events based on field information and secondary data information.

Identification of landslide susceptibility using a Geographic Information System (GIS) can be made quickly, easily, and accurately. The Geographic Information System uses the method of overlapping or overlaying the parameters causing landslides such as slope, soil texture, soil permeability, rock weathering level, effective soil depth, nick density, groundwater level depth, and rainfall, while non-natural factors include: land use and vegetation density.

2. METHOD

2.1 Research Site

This research was conducted in villages along with the planning location of the Mengwitani-Singaraja Toll Road. 50 villages are the research areas in three regencies, namely Badung, Tabanan, and Buleleng regencies. The Research Site is located between 8°7'30" -8°3730 East Longitude and 115°00' - 115°15'00" South Latitude (Fig. 1).

Fig. 1. Research Location Map

2.2 Tools and Materials

The materials used in this research include the Indonesian Earth Map Sheet of Bali Province, Semi Detailed Soil Type Map of Bali Province, Rainfall Estimates from Rain Gauge and Satellite Observations, SPOT 6/7 the Year 2019 Image, DEM Alos Palsar, and Literature and Libraries on land suitability and conservation. The tools used in this research include Global Positioning System (GPS), Meter, Survey Form, Camera, and Personal Computer (PC) with ArcGIS 10.4 software.

2.3 Method of Data Acquisition

The types of data in this study include primary data and secondary data. Secondary data includes maps of soil types and data on landslide events in the research area. Other data is primary data which is analyzed through visual and digital interpretation. Also, Palsar DEM data acquisition is free of charge on the web page (https://search.asf.alaska.edu/). The DEM data is used for slope analysis and visual interpretation of landforms and geological structures. Land use was obtained by visual interpretation of the 2019 SPOT 7 Satellite Image recorded (Satellite Image obtained from the National Institute of Aeronautics and Space / LAPAN). Precipitation is obtained from the CHIRPS Weather Satellite, which is accessed on Google Earth Engine (GEE) cloud-based computing.

2.4 Research Method

2.4.1 Landslide Hazard Class Parameters

Land area estimation using satellite image interpretation method. Image interpretation is the act of studying aerial photographs or images to identify objects and assess their importance. Analysis of agricultural land use was carried out using 9 (nine) elements of interpretation, namely, hue and color, texture, shape, size, pattern, site, height, shadow, and association. The image used in the identification of land use is the SPOT 7 image. The map of land height and the slope was extracted through DEM Alos Palsar with a resolution of 12.5 meters, which was then reclassified according to existing provisions to obtain values according to the parameters needed in scoring landslide susceptibility.

2.4.2 Determination of Landslide Hazard Susceptibility Class

Determination of landslide susceptibility using a Geographic Information System through a scoring that refers to several sources. The purpose of scoring is to determine the value of the landslide susceptibility level in the research area. Then the overlay process is carried out, namely analyzing and integrating two or more different spatial data to obtain new data. In this study, 6 parameters of landslides were used to determine landslide-prone areas. The following are tables of each parameter causing landslide-prone areas that are used as a reference and reference in determining landslide-prone areas (Table 1).

The division of each class from each parameter is adjusted to the conditions of the area being observed. From each of these parameters, the data obtained is in the form of data covering the entire area of the New Road Section (Mengwitani-Singaraja, which will then be classified based on research case studies so that a parameter map will be obtained that already has each class. The classification of landslides susceptibility uses the natural break method [22, 23] so that the results show a significant difference based on each parameter. The causes of landslides are based on the smallest value to the largest value.

Table 1. Parameters for mapping landslide susceptibility

Parameter	Criteria	Score	Weight
Slope (%)	0-8 %	1	5
	8-15 %	2	
	15-25 %	3	
	25-40 %	4	
	>40 %	5	
Rainfal (mm/yr)	1500-2000	1	5
	2001-2500	2	
	2501-3000	3	
Soil Types	Mediteran, Latosol	1	2
	Andosol, Grumusol	2	
	Regosol	3	
Landuse	Sand, Forest, and Water	1	4
	Mixed Dryland Farming, Shrubs	2	
	Paddy Field, Settlement	3	
	Dryland Farming	4	
	Bare Land	5	
Geology Structure	Horizontal	1	3
	Horizontal/ Sloping	2	
	Sloping	3	
	Crack	4	
	Steep Tilt	5	
Landform	Alluvial Plains	1	6
	Limestone Hills, Caldera, Volcanic Foot Slope, Hills, Lower Slope	2	
	Volcanic Lower Slope, Hilly Lower Slope, Central Slope, Inter-Mountain Plains, Mountains Steep Slope	3	
	Volcanic Middle Slope, Hilly Upper Slope, Volcanic Slope	4	
	Volcanic Cone, Volcanic Upper Slope, *Lungur* Volcano, Caldera Valley	5	

Source: Modification by [15–21]

3. RESULT AND DISCUSSION

3.1 Factors Causing Landslide susceptibility

This study on landslide susceptibility along the Mengwitani-Singaraja road was identified based on the parameters causing landslides such as landform, geological structure, soil type, land use, rainfall, and slope derived from geospatial and remote sensing data (Fig 2)

The research area consists of volcanic landforms that generally form hills and mountains. The center of the research location, precisely in Sukasada District, is a volcanic area characterized by the presence of a lake. Through the image, it appears that the lake is surrounded by caldera cliffs. Based on the results of the analysis through visual interpretation of Hillshade Alos Palsar Imagery and Google Satellite Imagery, there are 10 landforms (Fig 2a).

An analysis of the landform digitally using the Alos Palsar DEM comparison with the vegetation index from Sentinel 2B imagery with a spatial resolution of 10 m [18]. This research is interpreted visually so that the interpretation is by the actual condition of the land cover object and topography [24]. The landform that spans the area is a volcanic downslope covering 11,578.95 ha (28.85%) of the total area of the study site.

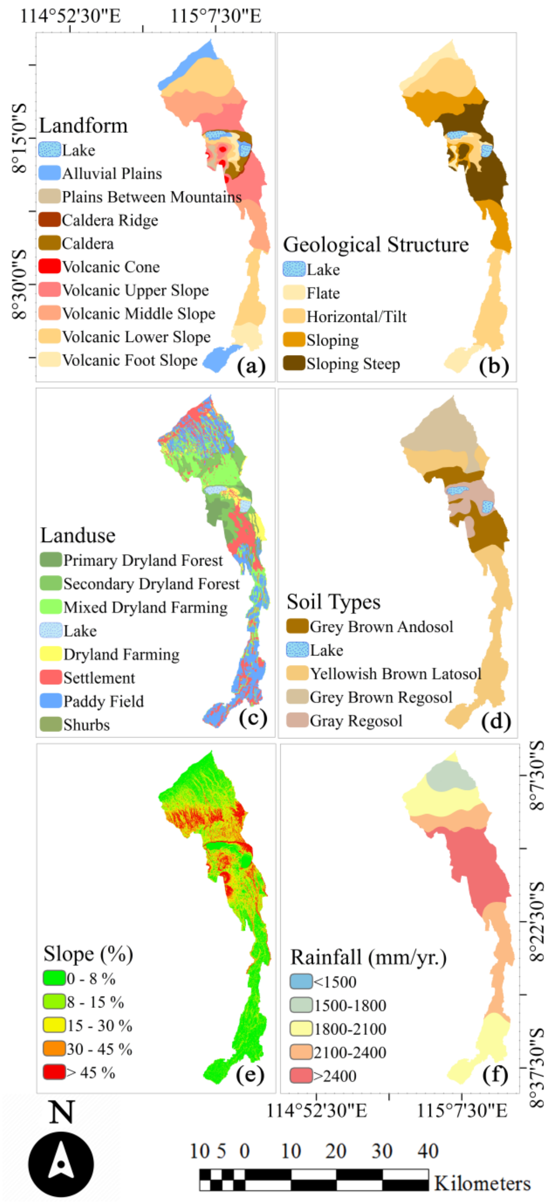

Fig 2. Spatial distribution map: Landform (a), Geological Structure (b), Landuse (c), Soil Types (d), Slope (d) derived from geospatial data, and rainfall map derived from remote sensing data

Information on the geological structure of the research area is carried out through the interpretation of Visual Hilshade Alos Palsar Imagery and Google Satellite Imagery. There are five geological structures formed, namely lakes, horizontal, horizontal/sloping, sloping, and fractures (Fig 2b). Based on the results of the analysis, it is known that the geological structure in the horizontal/sloping category dominates the research area with an area of 14,419.92 ha (35.93%).

Land use is a parameter that contributes to the occurrence of landslides. It is directly related to plant roots that function as soil binders. But on the other hand, plants that live on slopes with a certain slope act as an increase in slope loads that encourage landslides. The results of land use classification using SPOT 7 imagery show that the research location has varied land uses (Fig 2c). Based on Fig 2c, it can be seen that the use of paddy fields is widespread, namely 11,437.77 ha (28.50%).

Soil type is a very decisive factor for landslides susceptibility because the soil has the property of water permeability. This property can describe the strength or weakness of the binding (cohesion) of the soil, so that loose soil will be easy for water to pass through to enter the cross-section of the soil. This causes loose soil to be more prone to landslides than dense soil. Based on the results of the analysis, it was found that there were 5 types of soil in the research location, namely Yellowish Brown Latosol, Gray Regosol, Gray Brown Andosol, and Gray Brown Regosol. The area and percentage of soil types found in the study area are presented in Fig 2d. Based on the results of the analysis, it is known that the yellowish-brown latosol soil type has the largest area of 17,432.50 ha (43.44%).

The slope is a typographic element that affects the occurrence of landslides, the steeper the slope angle, the greater the driving force of the soil mass and soil constituent rocks. In areas that have steep slopes, weathered material or rock can easily slide due to the gravitational force that pulls the material. Based on the results of the extraction of the Digital Terrain Model of Alos Palsar Acquisition in 2011, the study area is classified into five classes of the slope, which are presented in fig 2e. Also, Palsar DEM is good for use in slope analysis because the height value in Alos Palsar DEM is the actual topographical height of the soil [24] without a canopy on it (Digital Terrain Model). The slope class with the 15-30% category dominates the research area covering an area of 9,119.38 ha (22.73%).

Rainfall is one of the parameters in determining landslide susceptibility areas. High rainfall intensity with a long duration can cause an increase in the water content in the soil. The increase in soil water content will weaken the physical-mechanical properties of the soil so that it can trigger soil movements. This study uses rainfall data from 2010 to 2020 along the

Mengwitani-Singaraja road section, which will then be averaged annually. In Fig 2f, it can be seen that the research area, which has high rainfall, is characterized by purple color on the map. Meanwhile, the decrease in rainfall in the study area is marked in blue for the area with the lowest rainfall. The highest rainfall has an average of more than 2,400 mm/year and the lowest is 1,500 mm/year.

3.2 Susceptibility Landslide

Based on the results of the weighted sum overlay from maps of landforms, geological structures, land use, soil types, slopes, and rainfall, it is known that landslide-prone areas in the research location can be categorized into four categories. The categories are low, medium, and high Susceptibility (Table 2). The high landslide hazard area is 6,256.11 ha (15.62%). Areas with a moderate landslide-prone class are spread over several areas covering an area of 10,762.08 ha (26.87%), and areas with a low landslide-prone class are the widest area of 12,168.29 ha (30.38%). Another area that is in the safe zone is 10,855.79 ha (27.1%). The spatial distribution of landslide susceptibility areas is presented in Fig 3.

Table 2. Landslide Susceptibility Area Around The Mengwitani-Singaraja Road Section

No	Susceptibility Class	Area (Ha)	Area (%)
1	Safety Zone	10,855.79	27.1
2	Low	12,168.29	30.38
3	Moderate	10,762.08	26.87
4	High	6,256.11	15.62
	Total	40,044.27	100.00

Source: Data Analysis in 2021

The Buleleng sub-district is an urban area with the characteristics of the area being a flat (0-8%) to sloping (8-15%). This category of the non-susceptibility area is in the alluvial plain and volcanic downslope and has a flat horizontal geological structure, each of these parameters has a low score of 1 and 2. Soil types of gray-brown regosol are commonly found in this area, while the type of land use is dominated by settlements and rice fields. The condition of relatively low rainfall with a range of <1,500-2,100 mm/year makes this area less prone to landslides.

The area with low susceptibility for landslides in the area that has the highest area of 12,168.29 ha or 30.38% of the total area of the study area. The type of land use in this area is dominated by rice fields and mixed gardens with scores of 1 and 4. The type of soil that dominates this area is the association of yellowish-brown latosol with a score of 2. This soil type has a sandy texture and is somewhat sensitive to erosion. The topographic characteristics of this area are landforms, volcanic foot slopes, and volcanic downslopes with flat to gentle slopes (0-15%) and accompanied by a horizontal/sloping geological structure. Landslides can occur if the intensity of rainfall is high, but the rainfall conditions in this area range from 1,800-2,100 mm/year with moderate criteria.

The area of moderate susceptibility for landslides is 10,762.08 ha or 26.87% of the total area of the study area. This area is located on a moderately steep (15-30%) to very steep (<45%) slope with residential and plantation land-use types. Slope conditions are factors that influence landslides and are supported by inappropriate land use and high rainfall (> 2,400 mm/year). The lack of vegetation can cause roots as a soil binder to decrease so that in the rainy season, it will be easy to experience soil movement. The type of soil that is distributed is the same as the type of soil found in areas with low susceptibility for landslides, namely the association of yellowish-brown latosol and gray-brown regosol association. Therefore, with a high score, namely scores of 4 and 5 on the slope factor and rainfall, this area is included in the category of moderate susceptibility.

3.3 Landslide Susceptibility in New Road Construction Mengwitani-Singaraja

The Baturiti and Sukasada sub-districts are areas that have a high susceptibility for landslides of 15.62%. Based on the occurrence of landslides in the field, Sukasada District experienced landslides more often [27–29], especially in Gitgit Village and Wanagiri Village, as shown in Fig 4a. Landslide events in the area One of the Wanagiri road sections occurred on March 25, 2021 (Fig 4b) and February 21, 2020, on the Gitgit Village road section (Fig 4b). This area is an area that has steep slopes (25-40%) to very steep (>40%) with high scores ranging from 4 to 5. Land with sloping slopes has the susceptibility to experiencing soil movement, where material or rock weathered material can easily slide due to the gravitational force that pulls the material. Slope plays an active role in controlling the occurrence of soil movements and is supported by the rock layer structure. Geological structures that affect the level of landslide susceptibility do not only include rock types but also involve rock layers.

Geological structure factors in the form of folds and faults/joints/fractures can weaken the strength of rocks so that landslides have the susceptibility to occur. Cracks/joints can be a path for water seepage, which reduces the strength of rock/soil [1,30-31]. In areas with high susceptibility for landslides, the rock layer structure that dominates is horizontal, sloping, to steeply sloping, with scores of 3, 4, and 5, respectively. The Baturiti and Sukasada sub-districts are areas that have volcanic landforms. Landforms originating from volcanic processes, the land unit consists of caldera ridges, upper slopes of the volcano, and middle slopes of the volcano, each of which has a high score of 4 to 5. Landform has the characteristics of a sloping slope, as well as hilly relief. Based on these characteristics, such a landform has a higher susceptibility to landslides [16,32].

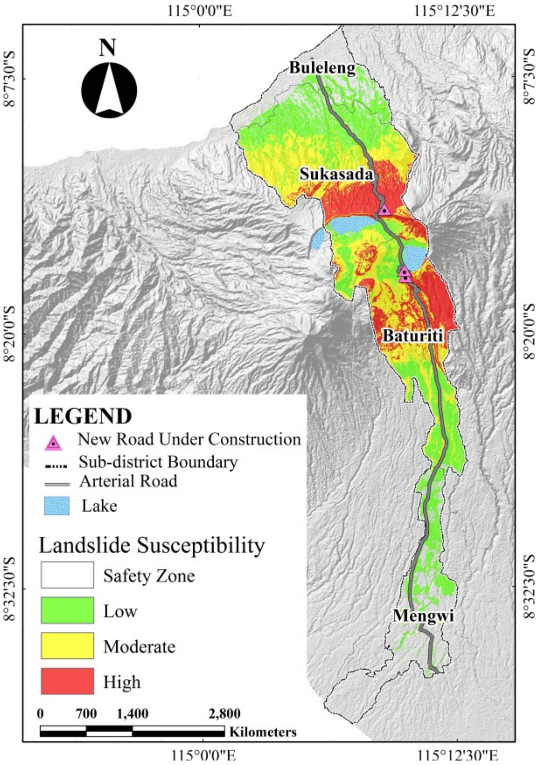

Fig 3. Landslide Susceptibility Map

The area for the construction of the new road section is in the zone of high landslide susceptibility, spatially indicated by the red zone (Fig 4a). The surrounding roads also have a high landslide hazard, as evidenced by photos of landslide events (Fig 4b). Land clearing on steep slopes in the arctic area is presented in Fig 4c. Land clearing for the construction of new roads can trigger landslides in the vicinity if there is a high supply of rainfall in the area. It is suggested that the construction of new roads should pay attention to the variability of daily rainfall (Fig 2f) to minimize landslides due to high daily rainfall.

Rainfall that occurs in this area is very high, namely > 2,400 mm / year. High rainfall intensity with a long duration can cause an increase in the water content in the soil, causing the soil mass to move. Loose soil will be more prone to landslides compared to dense soil (massive) such as clay textured soil (clay). This is because loose soil will easily pass through the water during the rainy season. Areas with high susceptibility for landslides have a distribution of soil types, namely regosol and andosol. This type of soil is very sensitive to landslides because it comes from volcanic material resulting from volcanic eruptions, which have a sand fraction and some dust fraction, so this soil is loose with a less plastic consistency and is not sticky. This makes these soils have many holes that make it easier for water to get in and out.

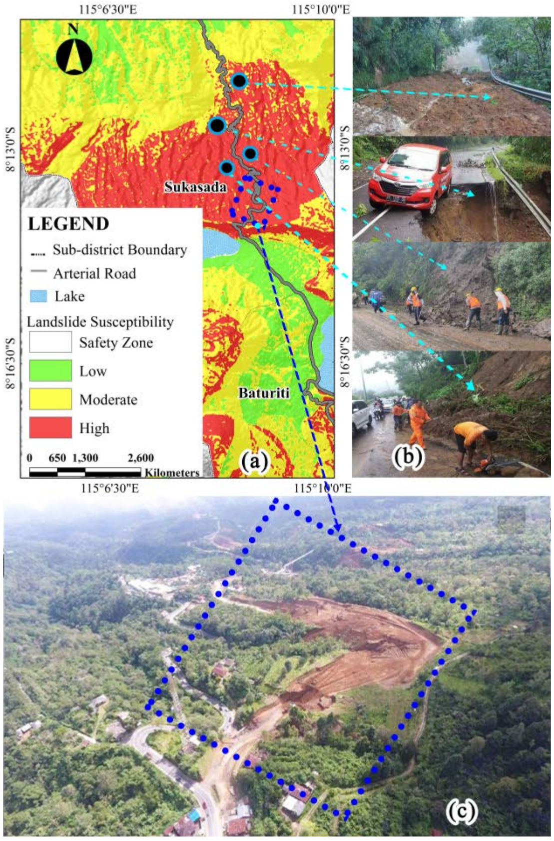

Fig 4. Landslide susceptibility map in the construction area for the development of new roads (a), Landslide events around roads based on secondary data obtained from the 2020 Regional Disaster Management Agency report (b), Land clearing conditions on very steep slopes for new road shortcuts (image source: Ministry of Public Works and Public Housing of the Republic of Indonesia, the area is in a high landslide-prone zone (c)

Land use conditions as a factor causing landslides are related to land stability, control of water saturation, and the strength of soil particle bonding [30]. Land that is used for forests and plantations is relatively more able to maintain land stability because of its deep root system so that it can maintain cohesiveness between soil particles and soil particles with bedrock and can regulate runoff and water infiltration when it rains. Unlike the case with land use in the form of fields and shrubs, which are vegetation that cannot maintain land stability because it has a shallow root system so that it does not maintain the compactness of soil particles. Sukasada District has the greatest landslides susceptibility when compared to other districts. The high susceptibility for landslides in Sukasada District is caused by high rainfall and steep slopes, so it will pose a great risk to road users. Areas that have a high landslide susceptibility are recommended to the surrounding community to be resilient to disasters.

The location of the new road construction is spatially located in the landform unit of volcanic origin. The bedrock has undergone much weathering in this landform unit to form a deep weathered zone with thick soil solum. The weathered zone with thick soil solum causes the ability to hold water relatively high, so slope stability is disturbed. Research by Trigunasih & Saifulloh [31] states that some areas have low to high soil fertility. The coefficient of determination (R^2=0.526) shows a moderate correlation between landslide susceptibility and soil fertility status. In general, areas with high landslides have good soil fertility status. Soil fertility is related to land management efforts in agricultural areas. Land management that is often carried out in this area is the provision of gabions from coconut fibers in areas prone to high landslides and the application of organic fertilizer to agricultural land [32-36].

Soil organic matter is one of the ingredients for forming soil aggregates, which has a role as an adhesive between soil particles to unite into soil aggregates, so organic matter is essential in forming soil structure. The effect of organic matter application on soil structure is closely related to the texture of the treated soil. In heavy clay soils, there is a change in the coarse and robust lump structure to a more refined structure, not coarse, with a moderate to a substantial degree of structure, making it easier to cultivate. Organic components such as humic acid and fulvic acid, in this case, act as a cementation of clay particles by forming a clay-metal-humus complex [37]. In sandy soils, organic matter can be expected to change the soil structure from single grain to lumpy form, thereby increasing the degree of structure and aggregate size or increasing the structure class from fine to medium or coarse [38]. Even organic matter can change the initially unstructured (solid) soil to form a good structure or crumbs with a moderate to a solid structure. Such conditions affect the stability of soil aggregates so that soil resistance to rainwater increases. The increased infiltration capacity of water in the soil reduces runoff and landslides [35,36]

4. CONCLUSION

Geospatial data plays a role in the findings of this study in the form of landslide distribution. With geospatial data, it is easier for the community residents, government, and readers of these scientific articles to understand the location of high landslide susceptibility and the parameters that cause it. Geospatial data is geographically referenced so that the condition of the information on the map describes the actual conditions for phenomena on the actual surface of the earth. Landslide susceptibility along the Mengwitani-Singaraja road section was obtained into three susceptibility classes: low, medium, and high potential hazard areas. Baturiti and Sukasada sub-districts are areas with a high level of vulnerability to landslides, with 6,256.11 ha (15.62%). Areas with low vulnerability to landslides have the highest area, namely 12,168.29 ha (30.38%), a moderate landslide susceptibility area of 10,762.08 ha (26.87%). The other area is in the safe zone, covering an area of 10,855.79 ha (27.1%).

The high landslide susceptibility because the area is located on volcanic upper slope landforms, volcanic cones, with fractured and sloping geological structures, very steep slopes (> 45%), high rainfall (> 2,400 mm/yr.), andosol soil types, as well as land cover with low vegetation density. The area for the construction of the new road is susceptible to landslides. So that every rainy season, there will be landslides in the field. Based on this research, it is recommended that further research be carried out in the form of landslide risk to predict losses caused by landslides. Furthermore, it is necessary to carry out mitigation efforts against the level of landslide risk to minimize the impact that occurs due to landslides. One form of mitigation from the field of land conservation is the installation of coconut fiber gabions, terracing, construction of drainage channels, annual plants that strengthen soil aggregates, and applying organic matter.

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