第 49 卷 第 2 期
2022 年 2 月

湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences）

Vol. 49 No. 2
February 2022

Open Access Article https://doi.org/10.55463/issn.1674-2974.49.2.23

Spatial Distribution of Landslide Potential and Soil Fertility: A Case Study in Baturiti District, Tabanan, Bali, Indonesia

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Abstract: Baturiti District is an area with history of high landslides yearly. Steep topography and steep slopes are some causes of landslides in the area. Minimal information regarding the potential for landslides can result in many victims and large losses if the disaster occurs in Baturiti District, Tabanan Regency, Bali Province-Indonesia. This study is crucial because of the urgency of the two factors that trigger land degradation. There has been no research on landslides on agricultural land and their relationship with soil fertility. Identical soil fertility is in loose soil, while loose soil is relatively easy to experience soil movement and cause landslides. This simple statement needs to be scientifically proven implemented in this research. Such conditions become a novelty in this scientific article. The purpose of this study was to identify the potential for landslides, the impact on agricultural land, and its correlation to the fertility of agricultural land. The method used is a survey method, soil analysis in the laboratory, and scoring with several landslide parameters, namely land use, slope, rainfall, landform, and geological structure. Soil fertility status analysis refers to the Soil Research Center (PPT) 1995 with 5 important parameters determining soil fertility status: CEC, Base Saturation, C-Organic, P-Total, and K-Total. Spatial data parameters were analyzed using a Geographic Information System. The results showed that the highest landslide susceptibility area was horticultural agricultural land (2,369.11 ha), applied to steep to very steep slopes. Another cause is the landform factor of the volcano's upper slopes, which has a soil-forming fraction dominated by coarse materials and high rainfall. Baturiti sub-district has low, medium, and high soil fertility status. The correlation between the vulnerability to landslides and soil fertility by (R^2= 0.526). Such conditions indicate that areas with high landslide susceptibility have low soil fertility status with moderate correlation.

Keywords: spatial, geographic information system, landslide potential, soil fertility, Baturiti district.

滑坡潜力和土壤肥力的空间分布：以印度尼西亚巴厘岛塔巴南巴图里蒂区为例

摘要：巴图里蒂 区是一个每年都有高滑坡历史的地区。陡峭的地形和陡峭的斜坡是该地区滑坡的一些原因。如果灾难发生在印度尼西亚巴厘岛省塔巴南摄政区的 巴图里蒂 区，关于山体滑坡可能性的最小信息可能会导致许多受害者和巨大损失。由于引发土地退化的两个因素的紧迫性，这项研究至关重要。没有关于农地滑坡及其与土壤肥力关系的研究。相同的土壤肥力是在松散的土壤中，而松散的土壤相对容易发生土壤运动并引起滑坡。这个简单的陈述需要在这项研究中得到科学证明。这种情况在这篇科学文章中成为了新事物。本研究的目的是确定滑坡的可能性、对农业用地的影响及其与农业用地肥力的相关性。采用的方法是调查法，在实验室进行土壤分析，用土地利用、坡度、降雨量、地形和地质结构等滑坡参数进行评分。土壤肥力状况分析是指土壤研究中心 1995 年的 5 个重要参数决定土壤肥力状况：阳离子交换容量、基础饱和度、C-有机、P-总计和 K-总计。使用地理信息系统分析空间数据参数。结果表明，滑坡敏感性最高的地区是园艺用地（2,369.11 公顷），适用于陡峭到非常陡峭的斜坡。另一个原因是火山上坡的地貌因素，其土壤形成部分以粗材料和高降雨量为主。巴图里蒂 街道具有低、中、高土壤肥力状态。滑坡脆弱性与土壤肥力的相关性为 (R2= 0.526)。这样的条件表明，滑坡敏感性高的地区土壤肥力低，相关性中等。

关键词：空间、地理信息系统、滑坡潜力、土壤肥力、巴图里蒂 区。

Received: November 24, 2021 / Revised: December 04, 2021 / Accepted: January 30, 2022 / Published: February 28, 2022

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1. Introduction

Indonesia is an archipelagic country that often occurs hydrometeorological disasters, namely disasters caused by climate change and weather. Nugroho [1] said that there had been 1,681 disasters that caused 259 fatalities, most of whom were victims of landslides. Based on disaster data obtained from the Regional Disaster Management Agency (BPBD) of Bali Province in 2013-2016, it was recorded that several villages in Baturiti District experienced landslides, namely Br. Pacung Baturiti Village, Br. Mojan Mekarsari Village, Br. Apuan Apuan Village, Perean Village, Apuan Village, Br. The Taman Tanda Service, Batunya Village, and Bangli Village and landslide disasters often occur in residential areas, agricultural land, and the Denpasar-Singaraja crossing route.

In addition to the danger of landslides, losses to agricultural land are also caused by land use that does not pay attention to aspects of land capability. Land use for agriculture often encounters various obstacles, including the low level of soil fertility caused by several chemical constraints that limit plant growth, such as acidity, nutrient availability, and low soil organic matter content. This situation is further exacerbated by the limited use of organic fertilizers in agriculture due to various reasons. Soil organic matter levels in the tropics naturally rapidly decline, reaching 30-60% within 10 years [2]. In addition, activities generally carried out in agriculture, such as fertilizers or other materials. Chemicals aimed at increasing production that is carried out excessively and not on time, dose, type, and application can cause a decrease in soil quality, including a decrease in soil fertility.

Soil fertility parameters were used in this study to assess soil fertility status. [3] stated that for determining the status of soil fertility, it is necessary to parameterize the chemical properties of the soil such as; Cation Exchange Capacity, Base Saturation, C-organic, Total P and K Content of Soil. When Soil nutrient levels obtained from soil analysis data are compared with the nutrient requirements of each plant, it can be seen whether the nutrient status in the soil is very low, low, medium, and high according to certain criteria. Those criteria are based on technical instructions for determining fertility status guided by the Center Soil Research, Bogor [3].

The impact of landslides and soil fertility can be minimized by identifying points prone to landslides and the spatial distribution of soils with low soil fertility. Therefore, we need an information system about landslide-prone areas to increase public awareness. A geographic Information System (GIS) is used to collect, enter, update, store, integrate, manipulate, analyze, and display information to obtain positions on the earth's surface. Utilization of GIS in the field of landslides has been carried out by [4-7]

2. Material and Methods

This study uses a quantitative descriptive method. Data analysis was also utilized through a spatial approach, with a Geographic Information System (GIS) on the ArcGIS 10.8 application. Another method is through field surveys and analysis of soil samples in the laboratory to obtain soil fertility status. This research was conducted in Baturiti District, Tabanan Regency. Tabanan is located at 08°14'30" – 08°38'07" south latitude and 114°59'00" – 115°02'57" east longitude. Baturiti sub-district is dominated by undulating to hilly land with 99.17 km2 and covers 12 villages. Baturiti District is located in the northern part of Tabanan Regency and the middle of Bali Island, as shown in Fig. 1. It also describes the Homogeneous Land Unit (SLH), which is analyzed through overlaying thematic maps such as land use maps, slopes, and soil types. The SLH map was used to sample soil fertility in the field. Topographically, Baturiti District is located at an altitude of 300 – 990 m above sea level. It includes a flat area with a slope of 2 – 15% (altitude of 300 – 400 m above sea level) and a flat to sloping area with a slope of 15 – 40% (an altitude of 500 – 990 m above sea level). The slope is an area that is quite fertile for agricultural cultivation.

2.1. Geospatial Data

The data used in this study include spatial data and tabular data. Spatial data includes landforms, geological structures, slopes extracted from the National Digital Elevation Model [8]. Soil types and rainfall are sourced from the Bali Province Development Planning, Research and Development Agency (Beppeda). Land use is sourced from visual interpretation of SPOT 6/7 imagery data acquisition in 2019. Other data comes from field surveys and laboratory analysis. This research uses a survey and scoring method. The scoring method is used to analyze the potential for landslides, while the survey method and soil analysis in the laboratory are used to determine soil fertility status. The survey method was carried out to determine the exact situation in the field. A survey was carried out to check several parameters, such as slope, soil type, landform, land use, and geological structure [9]. Scoring is carried out for parameters that affect landslides; in addition, weighting is also carried out according to the potential and contribution of each parameter in causing avalanche impacts. The greater the contribution to landslides, the higher the weight given. The scoring analysis of soil fertility refers to the determination of the Soil Research Center [3]. Spatial analysis using ArcGIS 10.6 software. The correlation uses a linear regression line by linking landslide potential with soil fertility status. The method used to obtain each objective is described in the following sub-chapters.

2.2. Homogeneous Land Unit Analysis (SLH)

Mapping of land units is done by overlaying maps which will later become maps of tentative land units; then, field checks are carried out so that the results are definitive land units. Before overlaying the map, the process is carried out first geo referencing. Georeferencing is the process of assigning a coordinate system to an image object by placing a control point at an intersection between latitude and longitude on the image in the form of the object or by placing a critical point at a location whose coordinates are known. The data obtained from several sources is then converted into a spatial form to be overlaid with other spatial data.

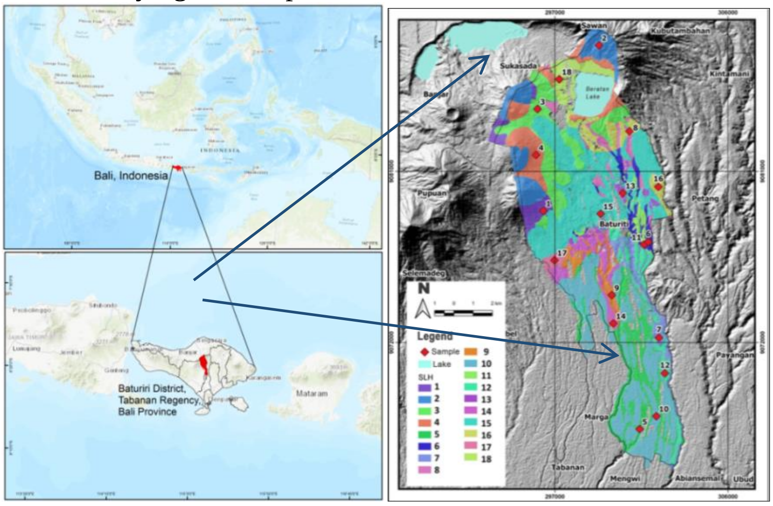

Fig. 1 The research location is viewed from a low scale (left), and the focus of the research is on Baturiti District and the location of the field sample (right)

2.3 Landslide Potential Analysis

The determination of the potential for landslides is carried out by overlaying the parameter maps that cause landslides. These parameters are scored and weighted according to their potential to cause landslides in the process overlay. The determination of the weighting uses several parameters that cause landslides, including rainfall, slope, geological structure, soil type, and land use. The parameter scores of the UGM Center for Natural Disaster Studies [9] are described in Table 1. Determination of landslide potential using natural breaks Jenks classification, in the ArcGIS 10.6 application. This classification is more representative of the potential for landslides, as has been analyzed by [10-12].

Table 1 Score and weight of criteria for determining landslide potential [9]

No	Landform Criteria	Score	Weight
1	Alluvial Plains	1	
2	Limestone hills, calderas, Foot slopes, volcanoes, hills, downslopes	2	
3	Volcanic downslope, downslope, hilly, middle slope, flat between mountains, steep slope mountains	3	6
4	Volcanic Middle Slope, hillside uphill, volcanic slope	4	
5	Volcanic cones, upper volcanic slopes, volcanic lunge complexes, valleys, caldera ridges	5	
	Structure Geology Criteria		
1	Horizontal	1	
2	Horizontal/Sloping	2	
3	Sloping	3	3
4	Crack	4	
5	Steep Sloping	5	
	Slope Criteria		
1	0 – 8 % (Flat)	1	
2	8 – 15 % (Sloping)	2	
3	15 – 30 % (Slightly Steep)	3	5
4	30 – 45 % (Steep)	4	
5	> 45 % (Very Steep)	5	
	Type of Soil Criteria		
1	Mediterranean Brown, Mediterranean Reddish	1	
2	Yellowish Brown Latosol, Brown, Reddish Latosol and Litosol, Brown Latosol and Litosol	2	
3	Gray Brown Alluvial, Hydromorphic Alluvial	3	2
4	Brown Regosol, Yellowish Brown Regosol, Gray Brown Regosol, Humus Regosol, Gray Regosol	4	
5	Andosol Gray Brown	5	
	Landuse Criteria		
1	Forests, Mangroves, swamps, irrigated rice fields, ponds, salting, sand	1	4

Continuation of Table 1

2	Rainfed Rice Fields	2	
3	Buildings, settlements	3	
4	Shrubs, gardens/plantations	4	
5	Grass, vacant land, dryland farming	5	
	Rainfall Criteria		
1	> 2,400 mm/yr	5	
2	2,100 – 2,400 mm/yr	4	
3	1,800 – 2,100 mm/yr	3	5
4	1,500 – 1,800 mm/yr	2	
5	< 1,500 mm/yr	1	

Table 2 Soil chemical properties assessment criteria

No	Soil Parameter	Very Low (VL)	Low (L)	Moderate (M)	High (H)	Very High (VH)
1	C-Organic (%)	< 1,00	1,00 -2,00	2,01-3,00	3,01 - 5,00	> 5,00
2	Base Saturation (%)	< 20	20-35	36-50	51 - 70	> 70
3	P_2O_5 HCl 25 %	< 10	10-20	21-40	41 - 60	> 60
4	K_2O HCl 25 %	< 10	10-20	21-40	41 - 60	> 60
5	CEC (me/100 g)	< 5	5-15	17-24	25 - 40	> 40

2.4. Soil Fertility Status Analysis

Soil sampling was determined purposively as many as 24 sample points. Soil samples taken in the field were then analyzed in the laboratory. The chemical properties of the soil analyzed in the laboratory were C-organic (Walkley and Black method); CEC (method NH_4OH 1N 1pH 7); Base Saturation (Cation Base/CEC*100%); total P_2O_5 (25% HCl Extraction method); K2O (25% HCl extraction method) (CPM, 2009). Evaluation of soil fertility status was carried out referring to the criteria issued by the Soil Research Center (PPT) Bogor (1995). Based on several soil chemical parameters used as benchmarks, namely Cation Exchange Capacity (CEC), Base Saturation (KB), P-total, K-total, and C-organic, which have been scored according to the concentration analysis results determined in the laboratory (Table 2). Based on the combination of the values of these chemical parameters, the soil fertility status is then determined, which will vary from very low to very high as in the study [13].

3. Results and Discussions

3.1. Spatial Distribution of Landslide Potential

3.1.1. Landslide Potential of the Entire Research Area

The potential for landslide hazard in the low potential category, which has a high percentage of area, is found in Apuan village with a value of 2.93% and 326.88 ha. In the medium potential category, which has a relatively high percentage of area, Candikuning village has a value of 12.26% and an area of 1.366.22 ha. Furthermore, the high potential category, which has a relatively high percentage of area, is found in Antapan village with a value of 4.19% and 466.34 ha. The total area of landslide potential in the low category is 1,879.48 ha, medium landslide potential is 6,736.83 ha, and high landslide potential is 2,049.61 ha.

The spatial distribution of the potential for landslides in each village is presented in Fig. 2a. Candikuning Village has the widest potential for landslides (medium and high potential), followed by Bangli Village, Antapan Village, Angseri Village, and several other villages. The landslide potential is indicated by the red area, which is dominated by the upstream (northern) area. The potential for landslides is indicated by the orange area, which almost dominates all villages in Baturiti District. The landslide potential is low with light green areas, while there is no landslide potential in green areas (located on the southern border with Marga District). Graph of the area affected by landslide potential as shown in Fig. 2b.

3.1.2. Landslide-Prone on Agricultural Land

The level of vulnerability to landslides was analyzed through overlaying spatial data from potential landslide results with agricultural land managed by the community, such as dry fields, mixed gardens, and rice fields. Data and maps related to landslide susceptibility can be used as a basis for land management mitigation to be more alert to landslides that will occur on agricultural land, thereby minimizing losses to crop failure on agricultural land. Dryland use is the widest landslide-prone area, namely 2,369.11 ha, followed by mixed garden land (1,584.34 ha), while paddy fields have low landslide potential because they are on a flat slope (0-8%). It can be seen in the graph that the highest area is found at a moderate level of vulnerability (Fig. 3).

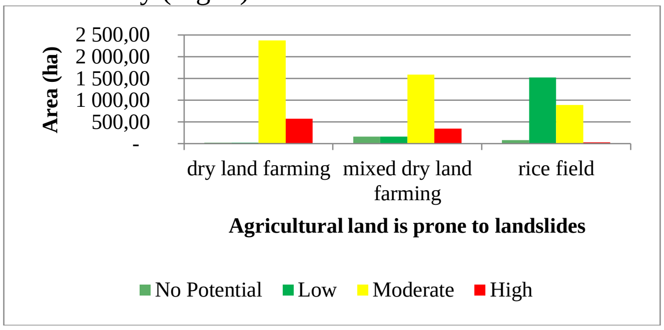

Fig. 3 Graph of potential landslide vulnerability of agricultural land

The spatial distribution of the vulnerability level of each agricultural land is presented in Fig. 4a. Vulnerability to the use of dry land is indicated by a red gradation (the redder indicates a high level of vulnerability). Vulnerability to mixed garden land use is indicated by a purple gradation (more purple indicates a high level of vulnerability). A red gradation indicates vulnerability to the use of paddy fields (the more brown indicates a high level of vulnerability). Spatially, the northern region is dominated by upland land use with moderate and high levels of vulnerability. The middle area, to the south, uses rice fields at low vulnerability. The use of mixed garden land follows a river channel with a spatial pattern extending from north to south with a moderate level of vulnerability dominance.

3.2. Spatial Distribution of Soil Fertility

Determination of soil fertility status is carried out in two stages; the first stage begins with assessing the measurement of each soil fertility parameter consisting of CEC, KB, P-total, K-total, and C-organic. Furthermore, determination of soil fertility status was carried out by combining soil chemical properties and soil fertility status, which consisted of 30 kinds of combinations based on the Bogor Soil Research Center [3]. The evaluation results between the chemical properties of the soil and the criteria for soil fertility status will get the status of soil fertility. Complete data on soil fertility status in each Homogeneous Land Unit (SLH) or village in the Baturiti sub-district are presented in Table 3.

Based on the results of the assessment of soil fertility status in the Baturiti District, Tabanan Regency, the soil fertility status is classified as low, medium, and high. Soil fertility status is low in the SLH 2 in Candikuning Village. The status of soil fertility is classified as moderate in SLH 1 (Angseri Village), SLH 3 (Candikuning Village), SLH 4 (Candikuning Village), SLH 5 (Perean Tengah Village), SLH 6 (Antapan Village) SLH 7 (Luwus Village), SLH 10 (Perean Tengah Village), SLH 11 (Antapan Village), SLH 16 (Antapan Village) and SLH 18 (Candikuning Village). While high fertility status is found in SLH 8 (Antapan Village), SLH 9 (Baturiti Village), SLH 12 (Luwus Village), SLH 13 (Batunya Village), SLH 14 (Apuan Village), SLH 15 (Bangli Village) and SLH 17 (Candikuning Village). Based on the percentage of soil fertility status in Baturiti District, which is classified as low as 5.56%, moderate soil fertility status as much as 55.56%, and high soil fertility status as much as 38.89%. The status of soil fertility is classified as moderate in SLH 1 (Angseri Village), SLH 3 (Candikuning Village), SLH 4 (Candikuning Village), SLH 5 (Perean Tengah Village), SLH 6 (Antapan Village) SLH 7 (Luwus Village), SLH 10 (Perean Tengah Village), SLH 11 (Antapan Village), SLH 16 (Antapan Village) and SLH 18 (Candikuning Village). The spatial map and soil fertility status in Baturiti District can be seen in Fig. 4b.

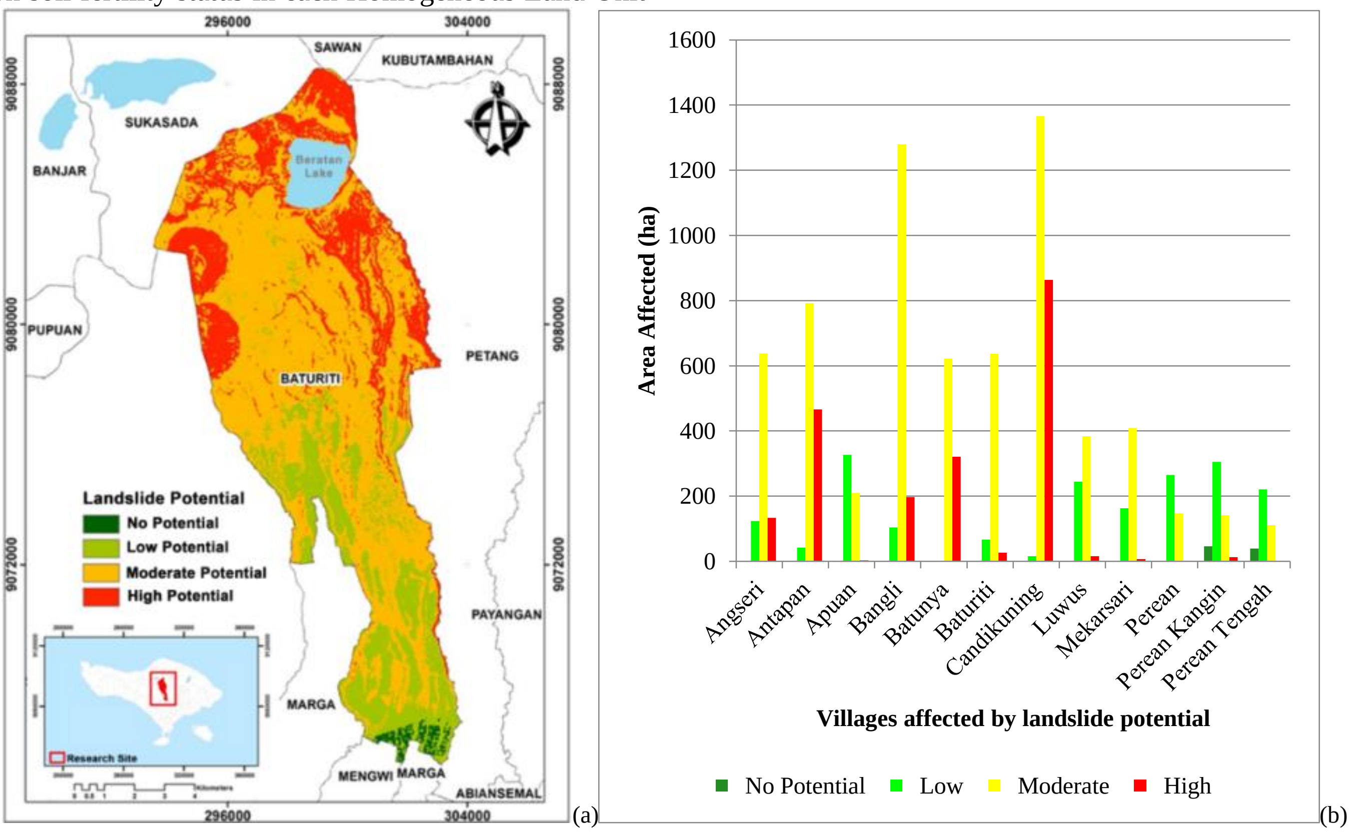

Fig 2. Map of the spatial distribution of landslide potential in Baturiti sub-district (a), a graph of the area affected by landslide potential (b)

Table 3 Laboratory analysis results and matching soil fertility status

No	Land Unit	Location (Village)	CEC	Base Saturation	C-Organic	P-Total	K-Total	Soil Fertility
1	SLH1	Angseri	35.18 (H)	67.53 (H)	8.62 (VH)	335.58 (VH)	19.01 (L)	M
2	SLH2	Candikuning	13.37 (L)	33.45 (L)	2.01 (M)	1,412.6 (VH)	25.98 (M)	L
3	SLH3	Candikuning	34.39 (H)	38.22 (M)	2.58 (M)	623.15 (VH)	23.69 (M)	M
4	SLH4	Candikuning	12.98 (L)	38.71 (M)	2.01 (M)	875.14 (VH)	24.57 (M)	M
5	SLH5	Perean Tengah	31.09 (H)	38.71 (H)	1.56 (L)	2,424.5 (VH)	29.69 (M)	M
6	SLH6	Antapan	28.88 (H)	69.17 (H)	2.54 (M)	1246.1 (VH)	27.69 (M)	M
7	SLH7	Luwus	20.68 (M)	53.06 (H)	2.07 (M)	1753.9 (VH)	25.77 (M)	M
8	SLH8	Antapan	27.83 (H)	58.01 (H)	3.72 (H)	5125.1 (VH)	48.59 (H)	H
9	SLH9	Baturiti	28.82 (H)	82.44 (VH)	2.14 (M)	991.40 (VH)	21.79 (M)	H
10	SLH10	Perean Tengah	34.54 (H)	88.01 (VH)	1.67 (L)	3075.6 (VH)	45.13(H)	M
11	SLH11	Antapan	25.49 (H)	84.75 (VH)	0.84 (ML)	865.83 (VH)	26.73 (M)	M
12	SLH12	Luwus	36.97 (H)	85.72 (VH)	3.43 (H)	812.97 (VH)	29.29 (M)	H
13	SLH13	Batunya	29.58 (H)	64.23 (H)	2.10 (M)	3,356.8 (VH)	45.03 (H)	H
14	SLH14	Apuan	34.82 (H)	68.35 (H)	2.14 (M)	9,81.72 (VH)	30.03 (M)	H
15	SLH15	Bangli	27.88 (H)	65.12 (H)	3.37 (H)	2,912.7 (VH)	43.67 (H)	H
16	SLH16	Antapan	22.23 (M)	87.62 (VH)	1.65 (L)	3,308.1 (VH)	48.04 (H)	M
17	SLH17	Angseri	27.12 (H)	47.62 (M)	3.36 (H)	1,021.1 (VH)	26.11 (M)	H
18	SLH18	Candikuning	14.98 (L)	38.71 (M)	2.96 (M)	4,857.8 (VH)	45.03 (H)	M

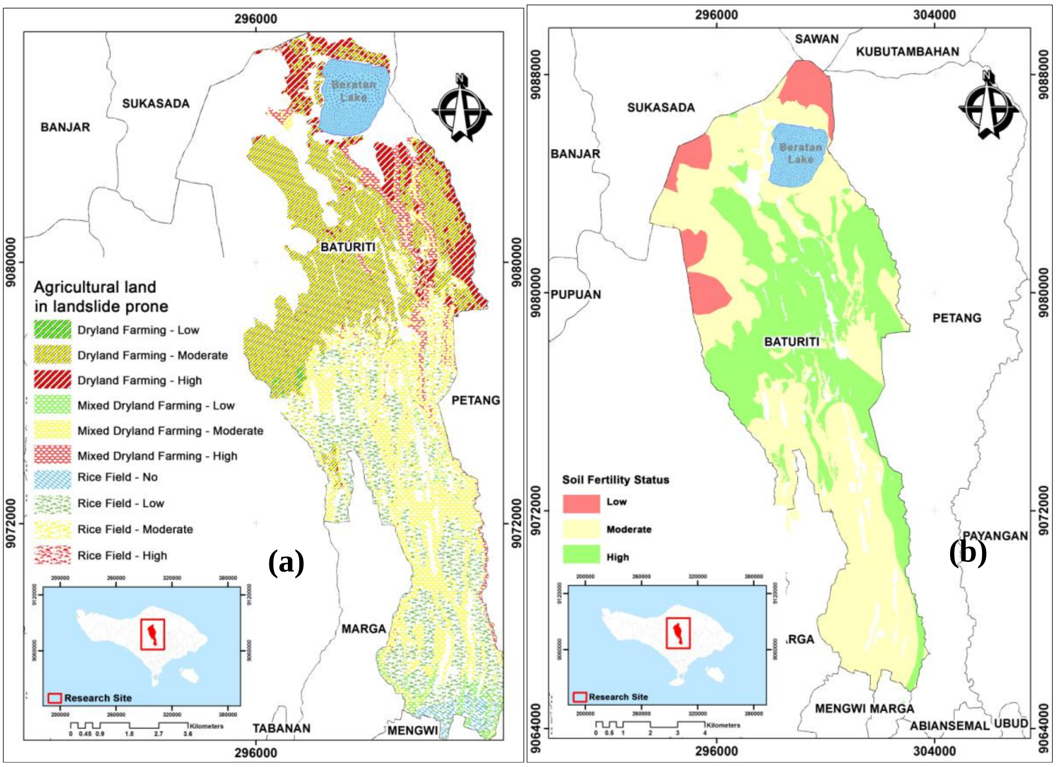

Fig 4. Landslide hazard map for agricultural land (a), spatial distribution of soil fertility status (b)

3.3. Correlation between Landslide Potential and Soil Fertility Status

Correlation regression (green correlation line) between landslide indicators and soil fertility shows a moderate category relationship with R^2= 0.526 (Fig. 5). The threshold value of the moderate correlation ranged from 0.40 – 0.599 [14, 15]. Such conditions indicate that areas with high landslide susceptibility have low soil fertility status with a moderate level of correlation. Thus, not all areas with high landslide potential have low fertility. If it has a high correlation, each area is prone to high landslides and low soil fertility status. Because in some Homogeneous Land Units (SLH), the soil fertility status is high, but the area is also in a high landslide-prone area.

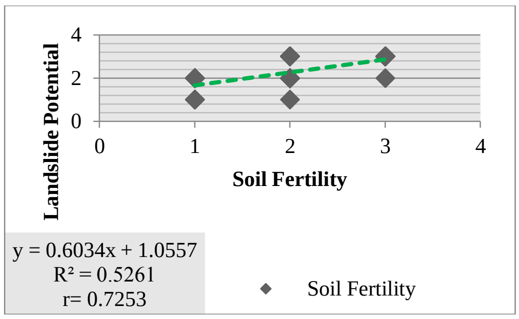

Fig. 5 Correlation between landslide vulnerability and soil fertility status (the X-axis shows the level of soil fertility (closer to 0 indicates high soil fertility; the Y-axis shows the level of vulnerability to landslides; the closer to 0 indicates low vulnerability

3.4. Discussion

Horticultural agriculture in the Baturiti sub-district is applied to the use of land or dry fields, such as potatoes [16], peppers [17], paksoy [18], strawberries [19], chili [20], and other horticultural crops. Horticultural commodities are the mainstay of farmers in the Baturiti District. Farmers cultivate dry land by planting horticultural commodities intensively and applying to steep to very steep slopes (Fig. 7). Land use that does not pay attention to environmental conservation rules can cause land degradation, one of which is landslides [21-23]. This condition occurs in Baturiti District; the highest landslide susceptibility area is found on horticultural agricultural land, applied to steep to very steep slopes. Another cause is the landform factor of the volcano's upper slopes, which has a soil-forming fraction dominated by coarse materials. Previous research stated that this area has the potential for landslides [24, 25].

As seen in Fig. 6, high vulnerability is indicated by the red area, which is spatially more dominant in the northern part of the Baturiti District. The vulnerability level map can then be used as a basis for landslide disaster mitigation. Carrying out disaster management is one step that needs to be taken, namely disaster mitigation. Mitigation is a series of efforts to reduce disaster risk through physical development and awareness and capacity building to face disaster threats [26]. The series of disaster mitigation efforts, in general, is an interrelated cycle of main activities, which include hazard analysis (hazard), disaster mitigation, early warning system development, emergency response/response, and rehabilitation and reconstruction [27]. This mitigation effort is an act of introducing disaster risk to the community. The introduction is carried out in the form of various threats/vulnerabilities that exist in the area, how to reduce threats their vulnerabilities, and increase the community's ability to deal with existing vulnerabilities and vulnerabilities. Mitigation is also a preventive action or preparedness in a disaster. In this case, the mitigation carried out is structural and non-structural [28, 29].

Efforts to mitigate the structure will be directed through artificial protection methods and natural protection methods. Meanwhile, non-structural mitigation efforts are carried out by providing maps of disaster-prone and vulnerable areas, spatial planning/land use, public information/extension, and law enforcement [30]. In addition, it is a form of structural mitigation by strengthening buildings and infrastructure that can be affected by disasters, such as building codes, engineering designs, and constructions to withstand and strengthen structures and build landslide-resistant structures, river retaining walls, and others. Meanwhile, non-structural mitigation efforts, such as avoiding disaster areas by building away from disaster locations, can be identified through spatial and regional planning and by empowering the community and local government [30-32].

Technically, mitigation can be done by forming slopes of the land to be gentler in areas with the potential for landslides (Slope Reshaping). That can be done by stripping loose (unstable) material on the slope; stripping the material can reduce the load on the slope, which minimizes the magnitude of the driving force on the slope and is effectively applied to slopes steeper than 40%. Reinforcement of steep slopes with landslide retains structures at the foot of the slope. An appropriate drainage system is applied to the slopes. The drainage system regulation aims to prevent rainwater from seeping into and collecting on slopes prone to landslides. Thus, it is necessary to make surface drainage that drains runoff rainwater away from slopes prone to landslides and subsurface drainage that functions to drain or drain rainwater that seeps into the slopes. Mitigation is vegetatively carried out by reforestation on vacant land, with plant species such as bamboo, pine, and others that bind strongly to river slopes. Plant species should have deep roots (reaching rocks), tight roots, and binding soil aggregates, and it is recommended not to choose plant species that are not too heavy (light biomass weight) and taproot. Baturiti District has a low to very high soil fertility status in terms of soil fertility. The low fertility status of the soil is due to the low CEC and KB values, moderate C-Organic, very high P-Total, and moderate K-Total. That is due to the type of soil at the research site in Candikuning Village, including Gray-brown Regosol, whose texture is dominated by sandy clay loam. As a result, there is little exchange of alkaline cations because the soil texture is sandy clay loam. According to [33], areas with low CEC and KB can exchange cations such as Ca, Mg, Na, and K, whose availability is low to moderate, so that the nutrients needed by plants range from low to low. Currently, Moderate soil fertility status because one of the parameters determining soil fertility status is low/very low. Locations in District Baturiti have high soil fertility status due to the high cation exchange capacity (CEC), Base saturation (KB), organic C, P2O5, and K2O. High CEC at the research location (SLH 8 (Antapan Village), SLH9 (Baturiti Village), SLH12 (Luwus Village), SLH 13 (Batunya Village), SLH 14 (Apuan Village), SLH 15 (Bangli Village), and SLH 17 (Candikuning Village). The location of this research has a high ability to exchange cations so that a high CEC causes the availability of nutrients needed by plants to be more available.

Based on the results of determining soil fertility status, soil fertility status is low in SLH2 in Candikuning Village, with limiting factors for CEC and KB content. Applying organic fertilizer corrected this limiting factor to increasing the soil's CEC and KB in the research area. Low C-Organic content was found in SLH 5 (Central Perean Village), SLH 10 (Central Perean Village), SLH 11 (Antapan Village), and SLH 16 (Antapan Village). For low soil C-Organic content, organic matter is added to the soil and returned plant debris to the soil. Meanwhile, the research location with low total K content was found in SLH 1 (Candikuning Village) with fertilizers containing potassium such as KCl fertilizer. The correlation between landslide potential and soil fertility is moderate. Such conditions indicate that not all areas have the potential for landslides, which has implications for the declining status of soil fertility. However, these two indicators challenge researchers to conduct further research by taking more samples and doing it in multiple locations, considering that this research was first conducted in Indonesia.

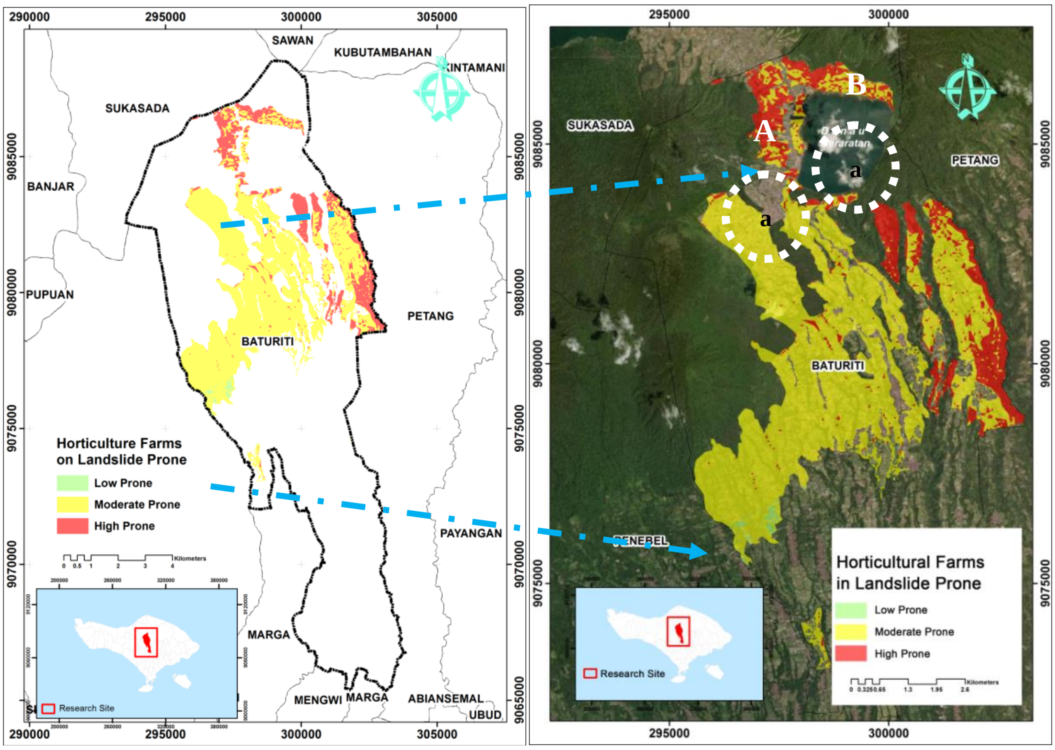

Fig. 6 Landslide hazard map for horticultural agricultural land, Baturiti district

Fig. 7 Land management for horticultural crops on steep slopes, intercropped with perennials (annual); seen on the map (Fig. 6) in the western part of lake Beratan (A) at coordinates X: 297597.62, Y: 9084680.01 (a), seasonal agricultural land use with shallow roots on a steep slope in the northern part of lake Beratan (B) at coordinate X: 298590.73, Y: 9086343.15 (b)

4. Conclusion

Baturiti District has a low to high landslide potential. Candikuning Village has the widest potential for landslides (medium and high potential), followed by Bangli Village, Antapan Village, Angseri Village, and several other villages. The highest landslide susceptibility area is found on horticultural agricultural land (2,369.11 ha), which is applied to steep to very steep slopes. Another cause is the landform factor of the volcano's upper slopes, which has a soil-forming fraction dominated by coarse materials and high rainfall. The land of the research location in Baturiti District has a low, medium, and high soil fertility status. The soil fertility status is classified as low in

Candikuning Village and moderate in Angseri Village.

Meanwhile, high fertility status is found in Baturiti Village. Parameters of soil fertility that became the limiting factor in the research area were low CEC content, low Base Saturation, low to very low C-Organic content. Directions for managing soil fertility in the study area in Baturiti District by adding organic fertilizer as a soil enhancer, returning plant litter to the soil, and adding potassium fertilizer in the form of KCl into the soil. The correlation between landslide susceptibility and soil fertility shows a moderate category relationship with R^2= 0.526. Such conditions indicate that areas with high landslide susceptibility have low soil fertility status with a moderate level of correlation. The novelty of this research is the relationship between the potential for landslides and the condition of soil fertility on agricultural land. The correlation shows a moderate level, land that has the potential for landslides tends to have low soil fertility. Fertile soil is not only seen from loose soil, but there are other factors, namely the chemical nature of the soil (pH, CEC, base saturation, organic matter, N and K). These factors, the content in the soil depends on the management of agricultural land carried out by farmers. Well-managed land (e.g., terracing on sloping land and planting parallel to contour lines) can reduce the impact of landslides and reduce soil nutrient leaching due to high rainfall. The weakness of this research is the limited number of field samples (i.e., 1 sample per land unit) and the time the research is carried out for a year, so the results have not been optimal and consistent. They have not represented clear conditions in the field. Further research needs to be carried out with a larger sample in various locations and at different time intervals so a high level of consistency is obtained and detailed results that describe the real conditions in the field.

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