Geomorphological Characteristic of Landslide Hazard Zones in Sukarame Village, Cisolok Subdistric, Sukabumi Regency

Astrid Damayanti1*, Fadhil Angin1, Andhia Adib1, and Muhammad Irfan1
1Department of Geography, Faculty of Mathematics and Natural Science, Universitas Indonesia, Indonesia

*astrid.damayanti@sci.ui.ac.id

Abstract. Geomorphology is the study of landforms, the processes of its formation, and the relations between forms and processes in their spatial order. Landslide is the movement of a mass of rock or earth from a higher place to a lower level due to the interaction of the geology structures, hydrology, and geomorphology. In a geomorphological unit, various aspects actively control the occurrence of ground movements. Knowing the geomorphological characteristics is crucial to identify a large estimation of the potential for landslides in the region. The Village of Sukarame is one of the villages in the Sukabumi Regency located on the slopes of Mount Halimun, whose territory is divided into west and east, separated by the Cisukarame River. Mapping the required geomorphological units Digital Data Elevation Model Indonesia (DEMNAs) from the Geospatial Information Agency (BIG) is processed for altitude and slope data, as well as geological data and river data collected from BIG. Verification of landslide events through interviews and field surveys geomorphological unit analysis is done by overlaying and comparing the results of field observations. Also, a descriptive analysis is conducted by observing the map of landslide hazards zone from INARisk. The results show that the Village of Sukarame materialized from volcanic and fluvial origins. It has nine geomorphological units, which are the Hill Intrusion, Floodplain, Tapos Breccia Volcanic Plain, Citorek Tuff Volcanic Plain, Halimun Lava Slope, Tapos Breccia Slope, Citorek Tuff Slope, Fumaroles Plain, and Halimun Lava Field. Landslide-prone areas in Sukarame are in the geomorphological unit of Hill Intrusion, east of Halimun Lava Slope, Citorek Tuff Volcanic Plain, and along the river cliffs of the Cisukarame River and Cimaja River. The landslides occur naturally on the river cliffs of Floodplain and the cliffs of Citorek Tuff Volcanic Plain, which are dominated by sediments that cause the soil surface to become unstable. Moreover, anthropogenic activities, such as mining in the Hill Intrusion, also affect landslide occurrence in Sukarame.

1. Introduction

Geomorphology is the study of landforms, the processes of its formation, and the relations between forms and processes in their spatial order. The structure of land created by Geomorphic processes is the various chemical, and physical means by which Earth surface undergoes modification [1] by geological force inside earth called endogenic and exogenic. The endogenous energy is the force that is constructive from within the earth, such as faults, folds, and dip and strike, whereas exogenous energy, is energy originating from outside the earth such as weather, gravity, water, wind, and ice that have destructive properties. This energy creates a space between the nature of the interrelationships between the earth's surface processes and forms another surface of the planet at the heart of geomorphological discourse [1].

Geomorphology has contributed enormously to the understanding and assessment of various natural hazards (such as floods, landslides, volcanic activity, and seismicity) and a lesser extent, and geomorphologists have begun to move into the field of natural disaster mitigation [2]. One of them is a landslide, a movement of masses or rocks from higher levels of interaction with geology structures, hydrology, and geomorphology. Every year, a landslide disaster occurs because of bad planning, developer engineer, or, sadly, a practicing earth scientist has failed to recognize the warnings from an existing landslide, initial slope movement, or area of potential failure [3]. The emergence of landslide or landslide remnant does not form a threat to human activity. The relationship between the
geomorphological units to landslide is in the mass field, and the soil volume of each geomorphological unit is different, and the slope of each group also determines the level of risk of danger [4].

The landscape is a geomorphological unit which is categorized based on the characteristics of height, complexity, slope, interaction, stratification, and type of soil and rock masses [5]. In some instances, specific geomorphological units were grouped, either because the broad categories of individuals are too small and, therefore, difficult to distinguish from one another or simply because the purpose of this study does not require a level of detail [6]. Within the geomorphological unit, various aspects actively control the occurrence of ground movement. Knowing the geomorphological characteristics is very important to identify the estimated massive landslide potential in an area. Nonetheless, research on landslides and their relation to geomorphological units is a regional analysis where the events all depend on the characteristics of each region itself [7]. Knowing the geomorphological features is crucial to identify a large estimation of the potential for landslides in the area.

Floods, landslides, and whirlwinds are the most common disasters in Sukabumi Regency [8]. The occurrence of landslides in Kampung Adat, Sukarame Village, Cisolok District, Sukabumi Regency on December 31, 2018, resulted in the destruction of 29 houses with a population of 100 inhabitants [9]. Three factors cause landslides; tectonic processes, high rainfall, and high population. These factors shape geomorphological characteristics throughout the world to create a diversity of reliefs. Knowing the geomorphological features is very important to identify the estimated massive landslide potential in the area. Rocks that have hard lithology are relatively low against landslide hazards, while rocks that are relatively soft and not too compact are high for landslide hazards [10]. Most accumulated areas are prone to erosion by subsequent surface processes because debris is weak and easily fragmented. On the other hand, depletion areas composed of more competent bedrock tend to remain stable and quickly detected [11].

Sukarame Village located on the slopes of Mount Halimun, whose territory is divided into west and east, separated by the Cisukarame River. The village has 1256.78 Ha, including four hamlets, namely Langkob Hamlet, Lebak Lengsir Hamlet, Sukarame Hamlet, and Pamokoan Hamlet. The Langkob Hamlet in the west extending to the south, Lebak Lengsir Hamlet in the north, Sukarame Hamlet in the middle extending to the south, and Pamokoan Hamlet in the east is reaching to the south. The Sukarame Village has the lowest altitude of 150 m above sea level, and the highest is 750 m above sea level with the formation of slopes from DEM data, which reaches up to 140%. The population in the Sukarame Village is 2,583 people consist of 1,390 male residents and 1,193 female residents.

This study aims to find and determine geomorphological units in Sukarame Village that are vulnerable to landslide hazards. The benefit of this research is to inform the local government to mitigate the landslide hazard zone area. The research method used is descriptive analysis that describes the zoning area of landslides. The map used is a map of the geomorphological unit results of direct research and landslide hazard zoning maps from INARisk. Mapping the required geomorphological units Digital Data Elevation Model Indonesia (DEMNas) from the Geospatial Information Agency (BIG) is processed for altitude and slope data, as well as geological and river data collected from BIG. Verification of landslide events through interviews and field surveys. Landslide events verified through interviews and field surveys, analysis of geomorphological units with overlay methods, and comparing field observations. Furthermore, a descriptive analysis was carried out by observing the landslide hazard zoning map from INARisk.

2. Methods

Geomorphological surveys in Indonesia use the Zuidam classification to determine the slope class [12], identified by Dessauvages to determine the relationship between relief, slope classes, and height difference [13] and height classification from Verstappen [14] which is used to determine landforms. This stage identifies landforms to obtain geomorphological maps are by classifying slopes and reliefs of the earth's surface before going to the field [15]. Mapped geomorphological units, the Digital Elevation Model Indonesia (DEMNas) with a detailing scale of 30 m pixel from the Geospatial Information Agency (BIG), is processed to obtain altitude and slope data, as well as geological and river data collected from BIG. Also, medium to high-resolution satellite imagery has used that can used as an aid in identifying reliefs of the earth's surface. Satellite imagery with resolution supports an interpretation
of microscale and mesoscale landforms. The images used are Landsat 8 OLI-TIRS imagery with a resolution of 30 m or Sentinel 2A with a resolution of 15 m.

Table 1. Slope classes based on Zuidam classification

| Slopes (%) | Characteristics   |
|------------|-------------------|
| < 2        | Flat or almost flat |
| 2 – 7      | Gently Sloping    |
| 8 – 15     | Sloping           |
| 16 – 30    | Moderately Sloping|
| 31 – 70    | Steep             |
| 71 – 140   | Very Steep        |
| > 140      | Extremely Steep   |

Slopes are part of the results of landforms that can provide information on the process of formation. The valuation of the slope can be classification to complete geomorphological units by considering the length and incline. Table 1 shows the division of grade slope. The slope of 0 - 2% has the characteristics of flat or almost flat with a large denudational process and not intensive erosion in dry conditions. The gradient of 2 - 7% has low erosion characteristics — the slope of 8-15% slopes that are more prone to intense erosion. Slope 16 - 30% has slope characteristics that indicate the position before the mass movement occurs. The slope of 31 - 70% has steep features with denudational processes that occur intensively. The slope of 71 - 140% has very steep and intensive characteristics, and> 140% is very steep with a robust denudational process. There are six types of slope classes from 7 existing levels in Sukarame Village, namely classes 1,2,3,4,5 and 6.

Table 2. Identification to determine the relationship between relief, slope class, and height difference by Dessaunetes [13].

| Relief       | Slope Classes | The interval between lowest height and highest height |
|--------------|---------------|------------------------------------------------------|
| Flat         | < 2           | Below 1 m                                            |
| Undulating   | 2 – 7         | Between 1 to 10 m                                     |
| Rolling      | 8 – 15        |                                                      |
| Hummocky     | > 16          |                                                      |
| Hillocky     |               |                                                      |
| Hilly        |               |                                                      |
| Mountainous  |               |                                                      |

Relief is a form of the earth's surface based on the different heights of each region. To identify geomorphological units based on the classification of Desaunettes, first, the difference in height is used to determine relief. Sukarame Village has only two types of relief in general, hilly and mountainous. With slope classes of more than 16%, undulating reliefs have an interval height from 50 to 300 m and mountain reliefs with a height difference of more than 300 m.

Morpho arrangement is the relation between the landform and its environment, and morpho arrangement is essential to decide which geomorphological unit that forms naturally and which geomorphological unit that builds by causes of human activities. As observed at Sukarame Village, some of the areas are developed by human activities such as settlements, and paddy’s field is creating different slope percentage areas. Illegal mining activities are also creating the shape of Intrusion Hill.

For the morphogenesis and morphophonology, Sukarame’s morphological unit is shaped by time. As Halimun lava upraised on the northern part of the village that forms Intrusion Hill, and Tapos Breccia is covering some of the Halimun Lava Geological structures that creating slope of the Tapos Breccia and another geomorphological unit. As the oldest geological structure, Citorek Tuff was covering some parts of the south of the villages and didn't get covered by different quarter geological structures. Endogenic activities are now started to perish, as the result of Fumaroles Plains that comes up in the middle of this village that we can identify that lava’s activities on Sukarame Village are cooling down.
Also, the water springs of the Ci Sukarame river creating the fluvial landform on this village and resulting erosions and sedimentations alongside the river banks. After identifying morpho arrangement, morphogenesis, and morphophonology, delineation of the geomorphological unit is made and named using Van Zuidam Classifications as the main geomorphological unit classifications.

Field surveys are carried out to verify data by utilizing a 1: 25,000 scale survey work map. The map is used as a reference to determine the route of travel and the source of digital GPS reference information (Avenza) to plan sample points. Clinometer is used to get the elevation angle of the slope. At the field stage, gradients are measured and observed using clinometers and densitometers. The aim is to verify the reliefs carried out in the studio or before the field. After completing the measurement of the slope and get the elevation difference, the relief can be classified based on classification [11]. Field surveys and interviews were conducted to verify landslide events. Survey points are categorized based on a variation of the slope, height, and geology classification. As the classification, we have 22 survey points in each height with a different slope and different geology. so that representative of the morphology all around the village’s

The geomorphological unit analysis is done by overlaying and comparing field observations. To analyze and identify the application used ArcMap, Global Mapper, Surfer, and other applications that can support analysis. Besides, a descriptive study was carried out by observing the landslide hazard zone map from INARisk. INARisk uses population data, housing numbers, public facilities, critical facilities (Central Bureau of Statistics, Geospatial Information Agency, Local Government), GRDP data (Local Government), and land cover data (Ministry of Environment and Forestry of the Republic of Indonesia and Geospatial Information Agency) as parameters of landslide hazards displayed by raster data with green to red. National Disaster Management Authority (BNPB) Map's raster layer is then overlaid with the results of the identification of the geomorphological unit to make it easier to see the landslide hazard index of each geomorphological unit in Sukarame Village.

3. Result and Discussion
Sukarame Village, Cisolok Subdistrict, Sukabumi Regency, West Java, Sukarame Village has the lowest height at intervals of 0 - 200 masl and the highest at intervals of 501 - 1,500 masl. The area with the lowest elevation is exactly 150 m above sea level located in the south of Sukarame Village, which borders Cimaja Village and Karangpapak Village. The second classification for height was at intervals of 201-500 m above sea level, which is in the middle of Sukarame Village and in the southwest, which borders Karangpapak Village. Increasingly to the north, the altitude increases with the highest altitude found in the west, which borders the Cikelat Village, which is 750 m above sea level. The shape of the contour and height follows the flow of the river found in Sukarame Village.

The slope data can be obtained from DEM height data, which is processed using the Slope (3D Analyst) tool in the ArcMap application. The results obtained were then classified based on the slope classification, Sukarame Village included six of the seven slope classes, namely flat, gently sloping, sloping, moderately sloping, steep, and very steep. The dominance seen from Sukarame Village is the very steep class (71-140%) and steep (31-70%) in the eastern region. In the Terrain Formation Map, which was made based on the Dessaunetes relief classification [10], height differences were calculated using cross-section assistance and found that Sukarame Village, in general, has mountainous and hilly terrain formations bounded by Cisukarame River. Formation of origin Sukarame Village is dominated by volcanic and slightly fluvial, which is in Cisukarame River, which has changed its original form from volcanic to fluvial due to erosion.

The landforms of volcanic origin are landforms whose formation is controlled by the volcanic process, which is the process of magma coming out of the earth. Classical classifications of volcanic landforms are based on the types of activity, magmas, and erupted products. Improved classifications should also be found on the geomorphic scale, constructional vs. erosional origin, mono- vs. polygenesis, types of activity, and the type and volume of magma and erupted material.

Based on the Zuidam classification, Sukarame Village has a volcanic origin form consisting of volcanic slope and foot slope units with several other groups such as plains and hills with weakly sliced dendritic flow patterns, while fluvial origin forms are associated with sedimentation areas such as valleys vast river valleys and alluvial plains. This landform caused by the fluvial process due to both centralized (river) and overland flow processes. In Sukarame Village, fluvial landforms are found along the Cisukarame River.
The dominant exogenic process in the Cisukarame River is erosion due to homogeneous material against weathering so that there is no precise control over the direction of the tributary. The amount of energy of the river flow also makes the sediment particles deposited tends to have a large diameter because small particles such as clay, silt, and fine sand will continue to experience transportation until the river flow energy decreases around the downstream. Current flow makes the form of soil covered by sediment in the form of sand, gravel, crust, and bumps. In some places, the plain expanded and modified anthropogenically for agricultural purposes, thus blurring the boundary between this landscape and volcanic landscape, such as foot slopes.

3.1. Geomorphology Units
Sukarame Village has a volcanic and fluvial landscape. Volcanic landscapes divide into several types of landscapes, namely Volcanic Slopes, Volcanic Plains, Lava Fields, Fumaroles, and Hill Intrusion. Volcanic slopes dominate the area of Sukarame Village, one of them is in Pamokoan Hamlet. Based on its lithology, Sukarame Village divides into Halimun Lava Slope (Qvl), Citorek Tuff Slope (Tpv), and Tapos Breccia Slope (Qvb). The topography shows a slope to steep with an 8-70% gradient forming a straight slope to concave. River flow patterns are dendritic bent with sharp incisions. While the fluvial landscape has only a kind of view, namely the Floodplain, which is located together with the Cisukarame River, which borders the Lebak Lengsir Hamlet and the Sukarame Hamlet with the Pamokoan Hamlet. This almost flat relief flood plain extends following the Cisukarame River groove and has a very narrow width, especially in the upper reaches.

Volcanic plains found in several places at the foot of the volcano slopes located in Langkob Hamlet. This volcanic plateau is a formation that results from further erosion stages of the volcanic slope. Based on lithology, it divided into Tapos Breccia Volcanic Plain (Qvb) and Citorek Tuff Volcanic Plain (Tpv). Sloping topography with a 3-8% slope. Dendritic river flow patterns, cut media.

The lava field is gentle to a slight slope, which is bounded by two lower volcanic has on both sides located in the Langkob Hamlet. The lithology determined the naming to Halimun Lava Field (Qvl). The steepness is between 3-15% due to the gentle slope and well-covered land cover, and the erosion process is not as intensive as other areas. Although sloping, land use in this area is not dominated by settlements but rubber plantations because of the very high topography and limited by steep slopes.
Figure 1. Geomorphology Units and Landslide Hazard Zones in Sukarame Village, Cisolok Subdistrict, Sukabumi Regency (a &b) Documentation of landslide that occurs on February 2019

Fumaroles Plains is a plain where water vapor emits as an embodiment of volcanism underneath. This landscape has a very narrow area and located in the middle of the floodplain of the Cisukarame River. Cisukarame River water and shallow groundwater boiled by hot rocks below. The heat at the bottom makes water smoke envelop the area.
Hill Intrusion, located in the study area, is an isolated hill that protrudes amid the volcanic slope in the Lebak Lengsir Hamlet. The steepness ranges from 71-140%, much higher than the steepness of the surrounding volcanic slopes. Based on observations in the field, lithology consists of intrusive rocks, namely granite, and this is different from the Leuwidamar Geological Map sheet 1: 100,000 PPPL Geological results which state that the lithology conditions in the study area only consist of extruded rocks such as lava, breccias, and tuffs. Intrusion hills formed by granite, which has characteristics that tend to be harder and erosion resistant, making the steep hill formations isolated in the middle of a flatter topography. Convex hill shape, different from most slopes in the sinking study area. The weak centrifugal radial flow pattern is thin. Granite rocks here contain quartz veins, which often gold found, and it makes residents open illegal gold mines in the hills and cut down their vegetation, creating a tendency for higher erosion.

3.2. Zoning of Landslide
Evaluation of landslide volumes based on the type of failure, the morphology, and geometry of the study area [13]. Implementation of research area modeling produces landslide maps and factors of landslide conditions. In this research, explain the vulnerability of landslides, so that trigger factors such as rainfall and seismic acceleration are not taken into account [11]. Overlay analysis of landform maps with landslide hazard zoning maps from INARisk shows that the Sukarame Village area has a high hazard index in the north and east shown in red in Figure 1. This map is used in indirect vulnerability assessment as an evidence map [16]. Landslide hazard zones determined by rock lithology, slope, and relief of areas that make hazard zones obtained from INARisk, parts of the map that do not have pixel values are water bodies (Fluvial and Alluvial) and places with 0 - 2% slope, so they do not have a landslide hazard value. Volcanic rocks and sediments which have a dominant slope value of 2 - 25%, have non-sedimentary lithology, and have relief shapes with height differences below 150 m, are categorized as having landslide hazard values between low to moderate. Meanwhile, the dominant slope <25%, has a sedimentary lithology and forms of assistance with a height difference above 150 m, can be categorized as having moderate to high landslide hazard values. Analysis of landform map overlay with landslide hazard zoning map from INARisk shows that the Sukarame Village area has a high hazard index in the north and east, which is indicated by a tight grater in Figure 1 (a). This map used in indirect vulnerability assessment as a map of evidence. The highest risk index dominates the north and east of Sukarame Village. Geomorphological units located on those are Halimun Lava Slope and Hill Intrusion, which are dominated by mountains and steep hills while the lowest risk index is in Halimun Lava Field, which is a large flat surface whereas the rest of the study area is classified as medium risk index that dominated by slightly sloping landforms. The landslide that happened in February 2019 is shown in Figure 1 (b) occurs on a very steep concave slope. Unfortunately, this zoning of landslide hazard area still can be improved its accuracy because of the data source of the landslide-prone area that used only taken from INARisk and available in mesoscale level not in micro-scale level.

4. Conclusion
The results showed that the Sukarame Village originated from volcanic and fluvial origin formation, and had nine geomorphological units namely Intrusi Hill, Flood Plain, Tapos Breccia Volcanic Plain, Volcano Tuff Citorek, Halimun Lava Slope, Tapos Breccia Slope, Citorek Slope Plateau, Fumarol Plains Volcanic Plain, Padang Lava Halimun. Landslide-prone areas in Sukarame Village occur in the geomorphological intrusion unit and the Halimun Lava Slope to the east, and on the Tuff Citorek Plain and along the riverbank of the Cisukarame River Floodplain and the Cimaja River. Landslides in Sukarame Village occur naturally in the geomorphological unit of the riverbank of the Floodplain and the Citorek Tuff Volcanic Plain, which are dominated by sediment, which causes the ground surface to become less stable. Besides, landslides in Sukarame Village occurred because of anthropogenic activities, namely in the intrusion hill geomorphological unit as a result of mining activities.
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