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by Respati Hesa

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Analysis of discharge and area of the debris flow based on geological structural and rainfall levels in the slopes of Mount Abang, Kintamani

I N Sinarta^{1,*}, P I Wahyuni¹ and P Aryastana^{1,2}

¹ Department of Civil Engineering, Universitas Warmadewa, Jl. Terompong No.24 Denpasar, Bali, Indonesia

² International Ph.D. Program in Environmental Science and Technology (University System of Taiwan), National Central University, Taiwan

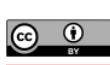
*inengahsinarta@gmail.com

Abstract. Geological structural and rainfall intensity causes the parameters of soil shear strength to decline, especially in the surface layer of soil in volcanic rocks that have not experienced weathering. Study of geological structures and rainfall intensity against the hazard of a landslide was destroyed on the slopes of Mount Abang in the Abang Batudinding Village. Soil investigations using the Geoelectric method and sampling at 6 boreholes. Geological analysis on interpretation of slope outcrops, average rainfall analysis of the Thiessen Polygon method and analysis of design flood discharge using the NHSU method. Analysis results show the morphology of the slopes of Mount Abang with a slope of more than 40% and lithology of weathered volcanic rocks consisting of volcanic breccias, and tuffs breccias in conditions rather mild to moderate weathering, if have average effective rainfall for 10-50 years at 238 mm/day. The results also show that the peak discharge of debris flow was 98.639 m³/sec with the volume of debris flow 50072.85 m³ and the width of the range was 49.5 m. This debris flow volume indicated that residents around the river with a range of 49.5 m are at risk of debris flow sediment with a thickness of 1-1.5 m.

1. Introduction

Assessment of landslide potential with deterministic modeling by combining geotechnical factors and slope hydrological models accompanied and geomorphological approaches contribute to the value of the hazard level of ground motion and validation of previous ground motion events are also needed [1,2]. The study was accomplished on the slopes of Mount Abang especially in Abang Batudinding and Terunyan Village, Kintamani District. Kintamani District is one of the districts in Bangli Regency which has an area of 366.92 km² or around 70.45% of Bangli Regency areas and also the largest district in Bali Province (6.51% of Bali Province areas). The uniqueness of the district is has a Batur caldera geopark measuring about 13.8 × 10 km, and another caldera structure is formed in the middle with a diameter of 7.5 km and a subsidiary of Mount Batur with the highest peak of +1717 m [3].

The geological structures of the research area are based on the geological map of Bali sheets [4] and based on the geological mapping of the study area formed in the Pleistocene era of 2.33-0.12 million years to 0.77-0.06 million years in the Holocene era where this volcanic rock has not been firmly compressed [5], so that the caldera slopes, especially the eastern slope of Mount Abang with minimal



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vegetation, will easily failure. The soil layers in Abang Batudinding and Terunyan village are in the form of sandy silt, sandstone, and andesite where there are cavities with fairly weathered rocks, at a depth of 2-3 m, and some parts are andesite rocks with high resistivity and some consist of weathered rocks at depth of 3-3.5 m has a risk of debris flow [6].

Level the hazard of ground motion where there are 208 landslide points based on the analysis using the SINMAP extension [7]. Based on the analysis of the Analytic Hierarchy Process (AHP) potential for ground motion Gunung Batur geopark area which is at 500 - 2000 means average sea level, with 11% of the potential of high-risk and 9 % of very high-risk [8]. This high harzard condition requires a technical analysis of the debris avalanche discharge, the extent of potential exposure and the thickness of the debris flood sediment that will occur.

2. Methods

2.1. Analysis and study literature

In general, there are two characteristics of rainfall intensity that trigger landslides in Indonesia, namely: (1) heavy rain types, usually can reach 70 mm/hour or more than 100 mm/day; (2) normal rain type in the long duration, is rain that occurs less than 20 mm/day [9]. This type of heavy rain will only be effective in triggering landslides on slopes where the soil is easy to absorb water such as in sandy silt and sand. The average rainfall intensity of 125 mm/day with a duration of 5 hours affects the amount of infiltration that causes slope collapse [10]. The higher rainfall intensity at the longer rainfall duration induce more infiltration to the slope then increasing the level of saturation and pore water pressure. Pore water pressure which initially has a negative value will increase to zero and then rise to a positive value [11].

Alluvium deposits consisting of loose rocks such as sand, gravel, and clay are soil characteristics that are easy to move due to increased pore water pressure so that the soils are prone to landslides or liquefaction events occur [12,13]. The matrix characteristics of saturated clay contribute to the speed of movement and distance of landslides in volcanic rock areas and there are two characteristics of landslides are subsidence and debris flow [5,14].

Interpreted topographic maps against hilly areas with fine to coarse rock and on sloping to steep slopes (0 - 70%) at an altitude of 0-1380 meters above sea level according to cliffs - steeply sloping river banks (> 70%) rocks consisting of sedimentary rocks (solid sand and conglomerates) and old volcanic rocks consisting of volcanic breccias, lava, tuffs, the level of surface erosion is desirable rain intensity above 100 mm/day with a long rainfall duration [15,16].

Rainfall analysis is an important factor in the hydrological analysis, especially for calculating design flood discharge both empirically and mathematical models, due to the unavailability of field discharge data at certain return periods [17]. Calculation of rainfall analysis design by using frequency analysis which commonly used in Indonesia is the Gumbel, Log Pearson Type III, Normal, Normal Log methods [18].

Nakayasu Hydrograph Synthetic Unit (NHSU) method was used to determine the unit hydrograph analysis of intermittent watershed. The general expression of NHSU can be seen in Equation 1 and correction is needed for the flood peak time value multiplied by 0.75 and the flood peak discharge multiplied by 1.2 to adjust to the conditions in Indonesia [19].

$$Q_p = \frac{1.2 \times A \times Ro}{3.6 \times (0.3TP + T_{0.3})} \quad (1)$$

Where Q_p = peak discharge; A = watershed area; Ro = unit rainfall; T_p = time lag ($T_p = T_g + 0.8T_r$, where T_g is the time of concentration and T_r is duration of effective rainfall); $T_{0.3}$ = time required to discharge reduction up to 30% peak discharge ($T_{0.3} = \alpha \times T_g$, where $\alpha = 1.5$ for quick peak discharge and $\alpha = 3$ for slow peak discharge).

Equation 1 is an empirical formula, therefore in its application to a watershed, it must be preceded by the selection of parameters that correspond to T_p , α and the rainfall distribution pattern in order to

obtain a hydrograph pattern close to the observed flood hydrograph. The design flood discharge used is a combination of water and sediment mass. Calculation of design flood discharge using the following equation:

$$Q_d = \alpha \times Q_p \tag{2}$$

$$\alpha = \frac{C^*}{C^* - C_d} \tag{3}$$

$$C_d = \frac{\tan \theta}{[(\rho_s/\rho_w) - 1](\tan \varphi - \tan \theta)} \tag{4}$$

$$V_d = 500 \times Q_d \tag{5}$$

$$B_d = \varepsilon \times Q_p^{0.5} \tag{6}$$

Where Q_p = design flood discharge; α = sediment concentration; $C^* = 0.6$ for debris flow; C_d = discharge coefficient; ρ_w = water density; ρ_s = sediment density; $\tan \theta$ = slope of river bed; $\tan \varphi$ = the coefficient of friction in the sediment; V_d = debris volume; B_d = maximum width of debris flow.

2.2. Location and investigation method

The area of study is located on the slope of Mount Abang in Abang Batudinding and Terunyan Village, Kintamani District, Bangli Regency. The surface morphology condition is almost similar and the potential for debris flow due to the intermittent river, so that debris flows analysis is focused only on Abang Batudinding Village as shown in Figure 1. The hydrological analysis is based on the maximum monthly rainfall for 10 years, from 2009 to 2018. The rainfall data were obtained from the Meteorological, Climatological and Geophysical Agency Region III. The rain gauge stations were used are Kintamani, Besakih, Kubu, Kerta. Rainfall analysis was Polygon Thiessen method as in Figure 2.



Figure 1. Abang Batudinding Village.

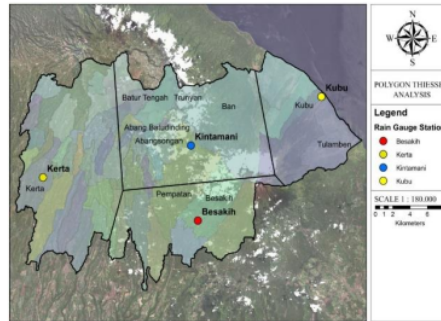


Figure 2. Area of Polygon Thiessen.

Kintamani polygon area = 201.9 km², Kubu polygon area = 100.8 km², Besakih polygon area = 130.7 km², Kerta polygon area = 208.6 km². Investigation of soil layers using the Geoelectric method with the configuration of Wenner Alfa, located in Terunyan and Abang Batudinding Village. In this study, 5 geoelectric testing sections were drawn, 3 sections were in Abang Batudinding Village, and 2 more sections were in Terunyan Village. Other secondary data are topographic maps, sedimentation, and regional administration maps.

3. Results

Soil investigation using the Geoelectric method with Wenner Alfa configuration can be concluded that the general layers of soil in Abang Batudinding and Terunyan Village in the form of sand, sandstone, and andesite. This layer of soil has the potential to cause landslides when it has a sharp slope, and also the influence of rain that can cause erosion and water infiltrate into crevices of sand and gravel, so as to encourage debris flow.

Analysis of the Bali-Nusa Tenggara Geological Map in terms of age that the geological formations of the Lower Quaternary age are around Mount Batur including Mount Abang which is spit rock from the volcanoes of Buyan - Bratan Purba and Ancient Batur. Rocks from the Lower Miocene age to the upper part are estimated to be around the Kubu Region which consists of volcanic breccias, lava, tuffs with limestone inserts which are the Ulakan Formation (the oldest Formation in Bali [20]).

On the slopes, there are weathered materials of medium size sand to lumps which are deposited mainly on the streamline of Peceburan, Nyung, and Pecalalang river. The material clogs the river channel and when heavy rainfall occurs it is transported in the form of debris flow as shown in Figure 5. Debris flow is flowing in the grooves on the slopes and surrounding areas and causing damage to agricultural areas, settlements (158 houses) and places of worship are shown in Figure 3. According to residents' information, this material movement occurs almost every year.



Figure 3. Peceburan river.



Figure 4. Debris runoff.



Figure 5. Slope outcrops in Abang Batudinding Village.



Figure 6. Weathering outcrops of rock.

Visual observations and interpretations such as Figure 4, Morphology of the slopes of Mount Abang with a slope of more than 40% and lithology of weathered volcanic rock consisting of volcanic breccias, and tuffaceous breccias in conditions rather mild to moderate weathering and sandy clay with volcanic

rocks, in the form the overflow of lava eruption of Mount Batur both has weathered and weathered to form sand. The slope outcrop is in the form of rock that is still fresh (Figure 5), but there are also features that have experienced weathering (Figure 6), where the average of the andesite breccia rocks has a volume above 60% of rock weathering or sedimentary rocks. Weathered andesite breccias produce intensive cracks in the horizontal direction.

Effective rainfall is the result of the calculation of daily rainfall with various times, multiplied by the runoff coefficient based on the rational method [17] (Table 1). The study area is a forest land in hilly condition with a slope of 10 - 30%, so the runoff coefficient value used is between 0.30 - 0.60. Effective rainfall is used for calculating the hourly rainfall distribution by the ratio method in Table 2.

Table 1. Effective rainfall.

Return Period (year)	2	5	10	25	50	100	200	1000
Daily rainfall (mm/day)	276	350	374	390	397	400	402	405
Runoff coefficient (C)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Effective rainfall (mm/day)	165.6	210	224.4	234	238.2	240	241.2	243

Table 2. Hourly rainfall distribution.

Return Period (year)	2	5	10	25	50	100	200	1000	
T (hour)	Ratio	Hourly rainfall							
1	0.693	114.82	145.61	155.59	162.25	165.16	166.41	167.24	168.49
2	0.180	29.84	37.85	40.44	42.17	42.93	43.25	43.47	43.79
3	0.126	20.94	26.55	28.37	29.58	30.11	30.34	30.49	30.72

Hourly rainfall distribution by using the ratio method was used to determine design flood discharge in different return year period by using the NHSU method conducted on the intermittent river in Karangasem Regency with the watershed area is ± 1.39 km² and length ± 1.802 km. The analysis result of the design flood hydrograph using the NHSU method can be seen in Figure 9.

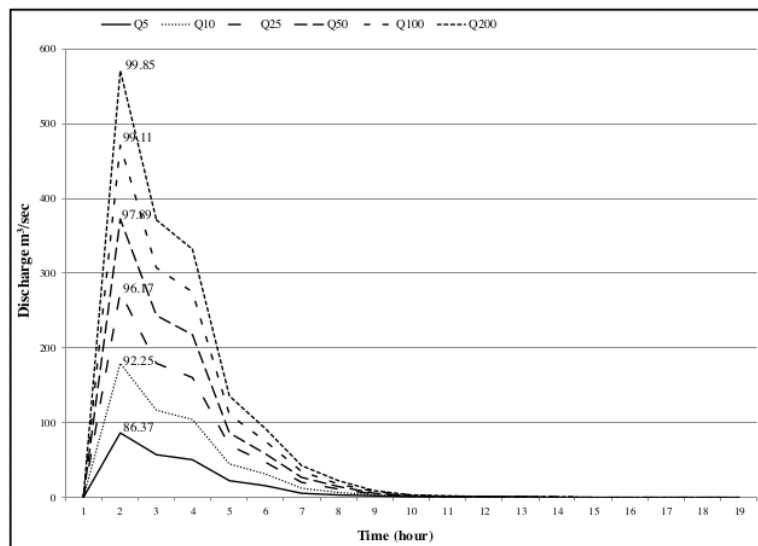


Figure 7. The design flood hydrograph on intermittent river.

Based on Figure 7, the design flood discharge using the NHSU method for the possible flood volume using a 50-year return period is 97.890 m³/s, this analysis can also be used for planning a flash flood protection structure. Sediment analysis to calculate sediment flood discharge based on geoelectric soil investigation data and laboratories testing at 2.5 m depth and the soil type is silty sand, with physical soil properties: specific gravity (G_s) = 2.65, the weight of dry content (γ_d) = 1.68 gr / cm³, cohesion (c) = 8.30 kN/m², and deep friction angle = 30.45°. Flood discharge used is a combination of water and sediment mass, which obtained debris peak flow rate is 98.639 m³/sec, the debris-flow volume is 50072.85 m³, and the width of the range is 49.5 m.

4. Conclusion

Morphology of the slopes of Mount Abang with a slope of more than 40% and lithology of weathered volcanic rocks consisting of volcanic breccias, and tuffs breccias in conditions rather mild to moderate weathering and sandy clays with volcanic rocks, where the average chunk of Breccia rocks Andesite experiencing weathering has a volume above 60% of weathering rocks or sedimentary soils so that the effective rainfall averagely at 10-50 years at 238 mm/day will cause the dissolution of the surface layer of the soil which triggers debris flow. The analysis results show that the peak discharge of debris flow was 98.639 m³/sec with the volume of debris flow 50072.85 m³ and the width of the range was 49.5 m. This debris flow volume indicated that residents around the river with a range of 49.5 m are at risk of debris flow sediment with a thickness of 1-1.5 m. For the purposes of waterworks planning such as check dams or sabo dams, the NHSU method was used to determine the design flood discharge in the 50 year return period [21]. The design flood discharge in the 50 year return period is 97.89 m³/sec. The fixed sediment capacity or static sediment volume is 7829.86 m³, while the dynamic sediment volume is 10335.417 m³.

7. Acknowledgment

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