International Review of Civil Engineering (I.RE.C.E.), Vol. 14, N. 2
ISSN 2036 - 9913 March 2023

Analysis of Debris Flow Hazard in Volcanic Soil by the Flood Flows Modelling (DFLOWZ) and Nakayasu Synthetic Unit Hydrograph

I. Nengah Sinarta[1], Putu Ika Wahyuni[1], Putu Aryastana[1, 2]

Abstract – *The Mount Batur Geopark area is vulnerable to debris flow triggered by heavy rainfall and weathered rocks that threaten the villages below. The estimation of the potential debris flow inundated area in this study has been determined by using the DFLOWZ model. The Digital Elevation Model (DEM) is the primary requirement data input in the model. Furthermore, the analysis of mean rainfall intensity and the hydrograph flood design have been calculated by the polygon Theissen and Nakayasu synthetic unit hydrograph method, respectively. The observation result has exhibited that basin flow occurs in the valley and river at the elevation ± 1500 m above sea level, which curves in hilly valleys and westward flow direction. The DFLOWZ analysis result depicts the area potentially inundated by a debris flow event as 49,830 m^2 with an inundation height based on the slope of 5-7 m. Furthermore, the peak of discharge debris flow, the debris flow volume, and the debris flow range are 100.15 m^3/s, 50,072.85 m^3, and 49.5 meters, respectively. This condition indicates that there is a risk of debris flow in the form of sand, silt, and boulders around the river in the range of 49.5 meters and a sediment thickness of 1-1.5 meters.*

***Keywords**: Debris Flows, DFLOWZ Model, DEM, Hydrograph Method*

Nomenclature

A	Area of the observatory
ASCII	American Standard Code for Information Interchange
α	Sediment content coefficient
B_d	Maximum width of debris flow
c	Cohesion
DEM	Digital Elevation Model
ε	Width coefficient
G_s	Specific gravity
LIDAR	Light Distance And Ranging
Q_p	Design of flood discharge in the 50 return year periods
Q_d	Peak of discharge debris flow
φ	Internal friction angle
R_0	Rainfall
SINMAP	Stability Index Mapping
SF	Safety Factor
T_p	Time log
$T_{0.3}$	Time required by the decrease in discharge
V_d	Maximum volume of debris flow
γ_d	Dry volume weight

I. Introduction

Landslide and debris flow are geological natural disasters that occur due to the gravitational movement of debris material that occurs in mountainous areas and causes property losses [1], [2]. On the other hand, based on Indonesian National Standard number 13-6982.2-2004, mass movement is defined as the movement of slope-forming material in the form of rock, embankment material, soil, or mixed material that moves down and out of the slope [3]. Two types of debris flow characteristic materials are gravel and mudflow. Gravel type flow is debris flow containing many large stones, while mudflow type is debris flow containing fewer large stones but dominated by sand and small stones [4].

Moreover in [5], the landslides have been classified into four flow characteristics, namely earth flow, mud flow, debris flow, and flow slide. Debris flow is defined as a mass movement containing grains of solid material, water, and air moving as a viscous flow [6]. Debris flow, debris avalanches, and earth flow are flow-type landslides with crushing strength and tremendous flow velocity. Debris flows are one of the crucial natural disaster events that are very destructive and threaten human life [7], [8]. The mass movement of debris has harmed humans, damaged various facilities and human wealth, and even damaged the natural environment every year in various regions of the world [9], [10]. Various research activities and studies of debris flow events have been carried out by scientists in Europe, America, and Asia, especially Japan. The classification of the threat level of ground motion based on the results of infiltration analysis on infinite slope stability is divided into 3 classes, namely low threat level (rain intensity: 48.2-49.1 mm/day, rain duration: 9-13 days, SF value: 2.65-1.82), level medium threat (rain intensity: 87.32–92.27 mm/day, rain duration: 6-7 days, SF value: 2.13–1.39), and high

https://doi.org/10.15866/irece.v14i2.20470

threat level (rain intensity: 155.38–210.14 mm/day, rain duration: 6 days, SF scores: 1.79–1.03) [11]. Indonesia has complex geological conditions, complex topography, high variability of precipitation, many active volcanoes, and a very high population density. This condition indicates Indonesia has the possibility of a high vulnerability to natural disaster events, especially debris flow [12], [13]. Natural disaster events in the form of debris flow often occur in the study area in the Mount Batur caldera around the slopes of Mount Abang which is the border of Abang Batu Dinding and Teruyan Villages around January-February when soil conditions reach saturation, resulting in environmental damage and property loss [14]. The initial approach to the flow of debris material is determined by modeling the flow using DFLOWS software with runout analysis in order to represent the estimation area of the debris flow inundation. This software has been applied to estimate the inundated area for the debris flow in the Italian Alps [15]. The output of this software is an initial forecast of the potentially inundated area of debris flow events, debris flow propagation, and planimetric debris flow. The model has been based on empirical scale relationships that avoid describing the complex dynamics of debris flow. This program's output can be significant when not using the numerical methods or if it is just wanted to get an estimate of the initial impact of the occurrence of a disaster. The user interface of DFLOWZ is very simple and user-friendly, but it can represent the results. The user can easily perform the analysis to see which parameters influence a potentially inundated area. The advantage of DFLOWZ is that it can evaluate Digital Elevation Model (DEM) modification's effect on the debris flow affected zone quickly. In addition, the DFLOWZ software does not require many input parameters.

This study has used DFLOWZ to determine the debris flow characteristic and estimate the potential of the inundated areas due to debris flow events in the Kintamani District, especially in Abang Batu Dinding and Terunyan Villages. This software has been first proposed by Berti and Simoni [16], which is a modification of the LAHARZ method developed by Schilling [17]. Modifications are made by adding the unconfined flow analysis in the DFLOWZ algorithm.

The software is available online at http://137.204.103.162/geoappl/dflowz/dflowz.htm. The main contribution of this study is the estimation of the potential inundated area, inundation height, the peak of discharge debris flow, the debris flow volume, and the debris flow range in the caldera area of Mount Batur, Kintamani District by using DFLOWZ and Nakayasu synthetic unit hydrograph.

The rest of the paper is organized as follows. Section II explains the material and the methods. The results and the discussion are presented in Section III, which focuses on the analysis result of the DFLOWZ and Nakayasu synthetic unit hydrograph. Finally, Section IV concludes the paper.

II. Material and Methods

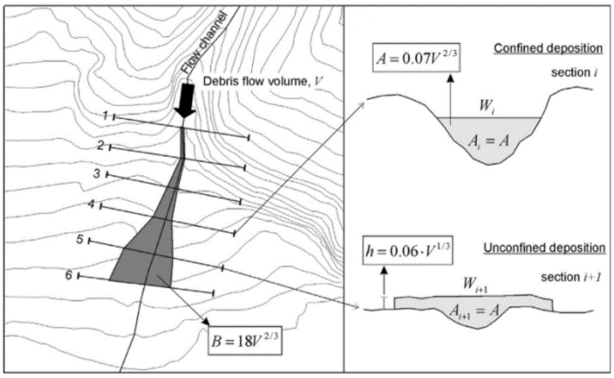
The study area has been located in the caldera area of Mount Batur, Abang Batu Dinding village, Kintamani District, Bangli Regency (Fig. 1). Bangli Regency is located in Bali province with longitude ranging from 115°13’43” E to 115°27’24” E and latitude varying between 8°8’30” S and 8°3’7” S [18]. Bangli Regency is the only regency in the Bali Province that does not have a beach area because it is located in the middle of the island of Bali. The southern part of Bangli Regency is a lowland area, while the northern part is a mountainous area with tourism objects such as Lake and Mount Batur.

The Batur caldera is one of the most beautiful calderas globally, measuring about 13.8×10 km^2, and another caldera structure formed in the center with a diameter of 7.5 km. The peak elevation of Mount Batur is +1,717 m [19]. The morphology of the Mount Batur caldera is an elliptical collapse structure measuring 13.8×10 km^2, formed about 29,300 years ago. This caldera produces a dacitic pyroclastic deposit of 84 km^3, which is called "Ignimbrit Ubud". The Batur II caldera is a circular collapse structure with a diameter of 7.5 km, which was formed about 20,150 years ago, and produced a 19 km^3 dacitic pyroclastic deposit, called "Ignimbrit Gunungkawi" [20]. Several settlements are scattered on the slopes of Mount Abang (Fig. 1) such as Buahan Village, Abang Batu Dinding Village, and Trunyan Village.

Landslide stability analysis using SINMAP has been carried out in the three villages. The results of the analysis show that the three villages are included in the upper and lower limit zones for landslides with the potential for ground movement in the form of debris flow or flash floods [21]. DEM and polyline data are the primary inputs to the DFLOWZ model. DEM data has been derived from the LIDAR data obtained online via the website http://www.earthsexplorer.usgs.gov. It is processed by Global Mapper software in order to convert it to the ASCII grid data format with a .asc extension.

The polylines have been produced by digitizing the resolution image using ArcMap software. The path that has considered a debris flow channel in the image will be digitized to form a single line, and then saved as a file with the extension .shp.

Fig. 1. Research area of Abang Batu Dinding village



(a) (b)

Figs. 2. The illustration of volume calculation on DFLOWZ [16]

The stages of the analysis in DFLOWZ are as follows:

1. Computing the expected-A and B values on a user-defined, volume basis and the EA and EB uncertainty factors;
2. Contains three DEM files, pathways, and chunks as input data;
3. Cross-sections along section grooves using DEM;
4. Move downstream i + 1, 2 ... n, and calculate the submerged width W_i + 1, 2 ... n in the same way;
5. The inundated planimetric area between two parts of B_i, while $B_i<B$ is valid, illustrates the calculation shown in Figs. 2.

The flow path identification analysis is fundamental because the debris flow material follows the flow path.

The satellite image is inputted on the ArcMap software for geo-referencing and flow path digitization to produce a polyline file with the extension .shp. The empirical method has been used in hydrology analysis in order to obtain the rainfall intensity in the study region. Rainfall intensity is the main parameter in designing flood discharge empirically due to the unavailability of observation flood discharge data. The maximum annual rainfall intensity has been used to determine the design rainfall intensity. The peak of design rainfall intensity for a different return period has been calculated by four flood frequency methods, namely Gumbel Distribution, the Log Pearson Type III, Normal Distribution, and Log-Normal Distribution, respectively [22]. This approach is commonly used in Indonesia. The design of flood discharge has been determined by using the Nakayasu synthetic unit hydrograph. This method has been widely used and assessed in several areas in Indonesia [23]. The equation of peak discharge Nakayasu synthetic unit hydrograph is [24]:

$$Q_p = \frac{AR_0}{3.6\left(0.3T_p + T_{0.3}\right)} \tag{1}$$

The peak flood time value has been multiplied by 0.75, and the peak flood discharge has been multiplied by 1.2 to adjust to conditions in Indonesia. Equation (1) is an empirical approach so that in selecting the parameter values for T_p, A, and the rainfall distribution pattern, it should be adjusted to the conditions of the study area in order to obtain a hydrograph pattern that is close to the observed flood hydrograph. The flood discharge used is a combination of water mass and sediment mass. The value of the peak flood discharge, debris volume, and maximum width of debris flow has been calculated by the following equation, respectively:

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

$$V_d = 500 \times Q_d \tag{3}$$

$$B_d = \varepsilon \times \left(Q_p\right)^{0.5} \tag{4}$$

III. Results and Discussion

Geological conditions are the values of tuff and andesite breccias that make up most of the research areas formed in the Pleistocene era with an age of 2.33 ± 0.12 million years to 0.77 ± 0.06 million years, very easily eroded due to rainfall [25]. Meanwhile, the southern part of the Batur caldera wall with constituent rocks comes from the Buyan-Bratan and Batur volcanic rocks, consisting of sandstone to silty sand, which is loose and porous. In this condition, the soil tends to escape quickly so that with moderate rain intensity with an extended frequency, it will cause ground movement in the form of flash floods [26]. The slopes of Mount Abang have relatively steep slopes with vegetation mostly in the form of shrubs. There are also forests interspersed with scrub.

Several types of plants whose roots are not strong enough to bind the planted soil around the caldera were used as agricultural land with types of crops including legumes, chilies, vegetables, cocoa, and several other crops. The Mount Batur caldera area in Kintamani District has the highest daily rainfall intensity of 125 mm in five hours so it affects the amount of infiltration that causes slope collapse. Changes in pore water pressure will be greater along with increasing infiltration so that it can cause flash floods. This area has a vulnerability to landslides, especially flash floods almost every year.

Evidence of this incident is shown in Figs. 3. Fig. 3(b) depicts the sediment location due to a debris flow, while Fig. 3(a) shows a large debris flow event that occurred in 1917, which hoards the Tuluk Biyu Temple so that the temple was currently not functioning because it is almost every year when it is season the rain will be flowed by flash floods. The sediment from debris flow materials began to accumulate in the temple area starting in 2010 and continues to increase from year to year due to erosion events that keep repeating every rainy season.

These incidents can threaten villages downstream from the impact of debris flow events. The possibility of an inundated area due to debris flow events provides an estimated value for the sediment cumulative volume of debris flow. The analysis is carried out based on both satellite (Fig. 4) and DEM (Fig. 5) imagery the study region that has been downloaded to be used for the process of identifying flow paths from debris flow.

(a) (b)

Figs. 3. (a) Debris flow sediment covered Tuluk Biyu Temple.
(b) The sediment location due to a debris flow

This flow path has been usually marked with a longitudinal line on the mountain's slopes with less vegetation than its surroundings. Flow path identification has been crucial because the debris flow material follows the flow path. The terrain data that has been processed using global mapper software will produce a DEM in the form of an ASCII Grid in the form of a black and white image, as in Fig. 5. The DEM image is a black and white color, where black represents the lowest elevation, and white depicts the highest elevation. The cell size in the DEM represents the resolution of an image. The smaller cell size indicates a higher DEM resolution produced.

Fig. 4. Satellite image of debris flow
at Mount Abang, Kintamani District

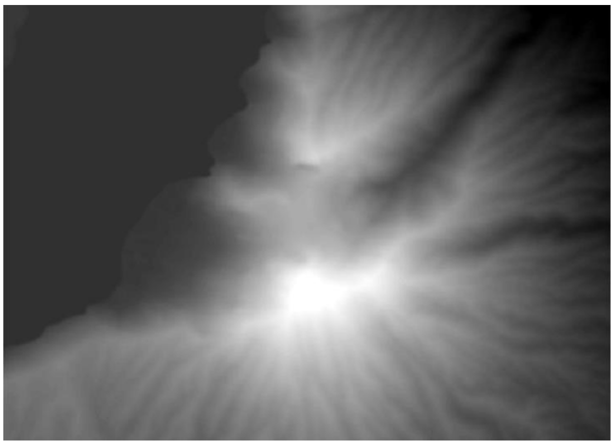


Fig. 5. DEM of Mount Abang, Kintamani District

The cell size of 5 m - 10 m, including low-resolution DEM data, has not been suitable for DFLOWZ software input. Even though in the satellite image it appears that there are several flow paths, in this study, only one flow path has been selected to be digitized. Fig. 6 shows the position of the flow path and section after being inputted into the DFLOWZ program. Debris flow on the slopes of Mount Abang occurred in 1917. The bor-log result at the Tuluk Biyu temple depicts the height of the sediment stockpile ranging from 0.5 to 1.5 meters at the highest and lowest elevations of 1500 m and 1150 m above sea level, respectively. The avalanche material mixed with flowing water as debris flowed and began to be deposited with an elevation difference of 400 meters so that it finally stopped at an altitude of 1150 meters above sea level. The estimated cumulative volume of debris flow is 144,293 m^3, however, with an average thickness of 0.50 meters (Fig. 7).

Fig. 8 shows the estimated inundation area of 288,586 m^2. The DFLOWZ analysis shows that the area of retained deposits that can cause landslides is 49,830 m^2, with inundation heights ranging from 5 to 7 meters, based on the sections made in Fig. 6. The simulation software depicts that it provides a potential hazard of debris flows due to slopes based on DEM data. The design of flood discharge has been examined by Nakayasu synthetic unit hydrograph. Daily rainfall data have been obtained from four rain gauge observations around the study region. The rain gauge station names are Kintamani, Besakih, Kubu, and Kerta, respectively.

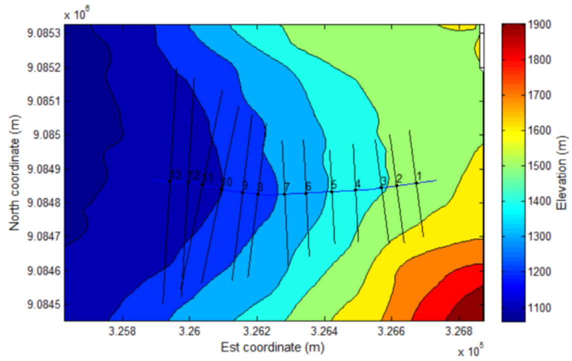


Fig. 6. Flowpath and debris flow section in the DFLOWZ program

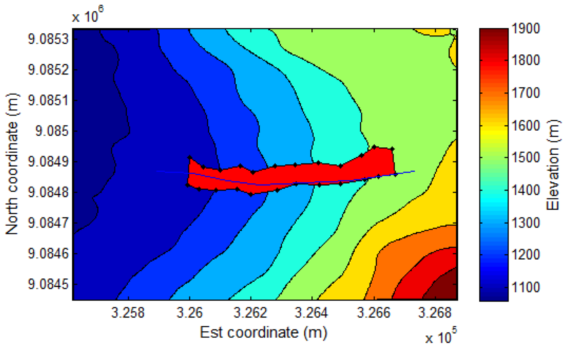


Fig. 7. Results of the DFLOWZ analysis

Fig. 8. Estimated volume of debris flows (red color)

The rainfall data used is the range of 2009 to 2018. Table I shows the effective rainfall analysis in different return years periods. The daily effective rainfall in various return years periods has been calculated based on the rational method by multiplying the daily rainfall and the surface runoff coefficient. The current study region is a forest land with hilly conditions with a 10-30% slope, so the runoff coefficient value is between 0.3 to 0.7 [27].

Daily effective rainfall has been used for calculating the hourly rainfall distribution in various return years periods using the ratio method in Table II. The hourly rainfall distribution in Table II will be used to determine the design flood discharge for different return year periods using the Nakayasu synthetic unit hydrograph method. The catchment area and the length of the intermittent river for the watershed are ± 1.39 km^2 and ± 1.802 km, respectively. The design of flood discharge is shown in Fig. 9. It clearly indicates that the discharge peak has increased with the increase of the return year periods. The design of flood discharge in the 50 return year periods (Q_{50}) is 97.89 m^3/s. These results can be used in the analysis of the potential inundation area of debris flows and to design structural or non-structural protection. The soil's physical properties used to determine the sediment flood discharge are as follows:

1. Specific gravity (G_s) = 2.65;
2. Dry volume weight (γ_d) = 1.68 gr/cm^3;
3. Cohesion (c) = 8.30 kN/m^2;
4. Internal friction angle (φ) = 30.45°.

This value has been obtained through geoelectric soil investigation and laboratory testing on samples at a depth of 2.5 meters. The investigation result has exhibited that the soil type is silty sand. The peak of discharge debris flow, debris flow volume, debris flow range, and the thickness of sediment obtained based on the combination of sediment mass and water mass have been 100.15 m^3/s, 50,072.85 m^3, 49.5 meters, and 1-1.5 meters, respectively.

However, the debris flow volume and the thickness of sediment in the DFLOWZ modeling are 49,830 m^3 and 5-7 meters, respectively. The two methods' results have a difference of 4.83%, where each approach has its advantages and disadvantages. Analysis with software can only derive the debris flow volume and thickness of sediment, while empirical analysis can be determined the debris flow volume, debris flow range, and thickness of sediment. The empirical analysis of the prediction of the slope is based on the provisions, whereas in the DLOWZ software analysis, the slope was determined by the DEM map and can be directly projected in the direction of the flow.

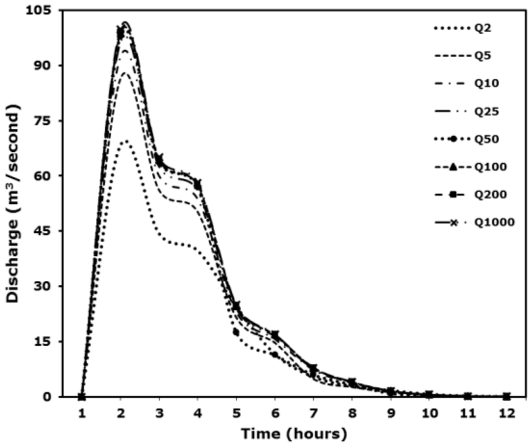


Fig. 9. Nakayasu synthetic unit hydrograph

TABLE I
EFFECTIVE RAINFALL

Return Years	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

The authors recommend combining these two analysis methods correcting again in several parameters so that the results can be closer to the existing conditions.

IV. Conclusion

DFLOWZ modeling provides simulation results of potential debris flow hazards using DEM as primary data. The modeling result is equipped with an uncertainty factor value to accommodate the landslide characteristics.

TABLE II
HOURLY RAINFALL DISTRIBUTION

Return Years		2	5	10	25	50	100	200	1000
T (hour)	Ratio	Hourly Rainfall (mm)							
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

The simulation results provide information on the potential inundation area and depth of inundation due to debris flow events. The DFLOWZ analysis result depicts the area potentially inundated by a debris flow event as 49,830 m^2 with an inundation height based on the slope of 5-7 m.

The empirical approach analysis contributes to results that are more convincing because of the input of hydrological analysis results and the results of soil investigations. The empirical approach analysis depicts that the peak of discharge debris flow, debris flow volume, debris flow range, and the thickness of sediment have been 100.15 m^3/s, 50,072.85 m^3, 49.5 meters, and 1-1.5 meters, respectively. The two approach results have a difference of 4.83% in the debris flow volume. The advantage of the empirical approach is that there is information on the width of the range of debris from the valley line, in addition to information about the volume of debris and thickness of sediment. Detailed field observations are required to detect the path and direction of the debris flow out of the valley. Field observation becomes a requirement and a limitation of assessing the debris flow hazards. It is crucial to select model parameters and interpret the correct results by considering the complex nature of the landslide causes of erosion. Alternative design for retaining walls using suitable vegetation or combination soil and bioengineering technology on volcanic rocks also needs to be considered to reduce the impact of surface erosion and debris flows [28].

Acknowledgements

We would like to thank the Ministry of Research, Technology, and Higher Education of the Republic of Indonesia for the financial support in a research grant. We also acknowledge the Soil Mechanics Laboratory of the Civil Engineering Department, Faculty of Engineering and Planning, Warmadewa University for granting permission to use the equipment. Our gratitude also goes to the Disaster Management Agency (BPBD) of the Bangli district which provided access to research in the region.

References

[1] J. Dou, T. Oguchi, Y. S. Hayakawa, S. Uchiyama, H. Saito, and U. Paudel, GIS-Based Landslide Susceptibility Mapping Using a Certainty Factor Model and Its Validation in the Chuetsu Area, Central Japan, in *Landslide Science for a Safer Geoenvironment*, Cham: Springer International Publishing, 2014, pp. 419–424.

[2] C.-W. Chen, H. Saito, and T. Oguchi, Rainfall intensity–duration conditions for mass movements in Taiwan, *Progress in Earth and Planetary Science*, vol. 2, no. 1, p. 14, Dec. 2015. doi: 10.1186/s40645-015-0049-2

[3] National Standardization Agency of Indonesia, *Indonesian National Standard number 13-6982.2-2004 concerning inspection of landslide disaster locations*. Jakarta: National Standardization Agency of Indonesia, 2004.

[4] O. Hungr, S. G. Evans, M. J. Bovis, and J. N. Hutchinson, A review of the classification of landslides of the flow type, *Environmental and Engineering Geoscience*, vol. 7, no. 3, pp. 221–238, Aug. 2001. doi: 10.2113/gseegeosci.7.3.221

[5] B. B. Broms, Landslides, in *Founadtion Engineering Handbook*, H. F. Winterkorn and H. Y. Fang, Eds. New York: Van Nostrand Reinhold Company, 1975.

[6] D. M. Cruden and D. J. Vernes, Landslide Types and Processes, in *Landslides: Investigatioan and mitigation*, T. R. Board, Ed. 1996.

[7] S. Lee, H. An, M. Kim, H. Lim, and Y. Kim, A Simple Deposition Model for Debris Flow Simulation Considering the Erosion–Entrainment–Deposition Process, *Remote Sensing*, vol. 14, no. 8, p. 1904, Apr. 2022. doi: 10.3390/rs14081904

[8] M. F. Qodri, N. Noviardi, A. H. F. Rizqi, and L. Z. Mase, Numerical Modelling Based on Digital Elevation Model (DEM) Analysis of Debris Flow at Rinjani Volcano, West Nusa Tenggara, Indonesia, *Journal of the Civil Engineering Forum*, vol. 7, no. 3, p. 279, Aug. 2021. doi: 10.22146/jcef.63417

[9] L. Wei, K. Hu, and J. Liu, Quantitative Analysis of the Debris Flow Societal Risk to People Inside Buildings at Different Times: A Case Study of Luomo Village, Sichuan, Southwest China, *Frontiers in Earth Science*, vol. 8, Jan. 2021. doi: 10.3389/feart.2020.627070.

[10] M. Mikoš and N. Bezak, Debris Flow Modelling Using RAMMS Model in the Alpine Environment With Focus on the Model Parameters and Main Characteristics, *Frontiers in Earth Science*, vol. 8, Jan. 2021. doi: 10.3389/feart.2020.605061

[11] Sinarta, I., Rifa'i, A., Fathani, T., Wilopo, W., Spatial Analysis of Safety Factors due to Rain Infiltration in the Buyan-Beratan Ancient Mountains, (2020) *International Review of Civil Engineering (IRECE)*, 11 (2), pp. 90-97. doi: https://doi.org/10.15866/irece.v11i2.17668

[12] I. N. Sinarta and I. W. A. Basoka, Safety factor analysis of landslides hazard as a result of rain condition infiltration on Buyan-Beratan Ancient Mountain, *Journal of Physics: Conference Series*, vol. 1402, no. 2, p. 022002, Dec. 2019. doi: 10.1088/1742-6596/1402/2/022002

[13] I. N. Sinarta, P. Ika Wahyuni, and P. Aryastana, Debris Flow Hazard Assessment Based on Resistivity Value and Geological Analysis In Abang Mountain, Geopark Batur, Bali, *International Journal of Civil Engineering and Technology*, vol. 10, no. 11, pp. 11–18, 2019.

[14] BPBD, Summay report of mass movement disaster in Kintamani district, Bangli regency, Bali province, Bali, 2017.

[15] M. Berti and A. Simoni, DFLOWZ: A free program to evaluate the area potentially inundated by a debris flow, *Computers & Geosciences*, vol. 67, pp. 14–23, Jun. 2014. doi: 10.1016/j.cageo.2014.02.002

[16] M. Berti and A. Simoni, Prediction of debris flow inundation areas using empirical mobility relationships, *Geomorphology*, vol. 90, no. 1–2, pp. 144–161, Oct. 2007. doi: 10.1016/j.geomorph.2007.01.014

[17] S. Schilling, *LAHARZ; GIS programs for automated mapping of lahar-inundation hazard zones*, Washington, 1998.

[18] P. Aryastana, M. I. G. Mosa, W. Widiana, I. M. E. E. Putra, and G. Rustiawan, Application of normalized difference vegetation index in classifying land cover change over Bangli regency by using Landsat 8 imagery, *Journal of Infrastructure Planning and Engineering (JIPE)*, vol. 1, no. 1, pp. 8–14, 2022. doi: https://doi.org/10.22225/jipe.1.1.2022.8-14

[19] R. W. V. Bemmelen, *The Geology of Indonesia. General Geology of Indonesia and Adjacent Archipelagoes*. Batavia: Government Printing Office, The Hague 1949, 1949.

[20] I. S. Sutawidjaja, Ignimbrite Analyses of Batur Caldera , Bali , based on 14 C Dating, *Indonesian Journal on Geoscience*, vol. 4, no. 3, pp. 189–202, 2009.

[21] I. N. Sinarta, A. Rifa'i, T. F. Fathani, and W. Wilopo, Pemetaan Ancaman Gerakan Tanah berdasarkan Indeks Stabilitas pada ekstensi SINMAP di Kabupaten Bangli, Bali (Land Movement Hazard Mapping based on the Stability Index of the SINMAP extension in Bangli Regency, Bali), in *National Conference on Geotechnical 2016, HATTI Yogyakarta*, 2016, vol. 1.

[22] V. Te Chow, D. R. Maidment, and L. W. Mays, *Applied Hydrology*. New York: McGraw-Hill, Inc., 1987.

[23] A. Hidayat, L. M. Limantara, W. Soetopo, and D. Sisinggih, Alpha Parameter Modeling of Nakayasu Synthetic Unit Hydrograph Based on the Watershed Shape Factor, *Journal of Hunan University Natural Sciences*, vol. 49, no. 1, pp. 31–37, Jan. 2022.
doi: 10.55463/issn.1674-2974.49.1.5

[24] D. S. Krisnayanti, M. E. Bolla, J. K. Nasjono, and M. J. M. Wangge, The analysis of alpha parameter on Nakayasu Synthetic Unit Hydrograph in Timor Island watersheds, *IOP Conference Series: Materials Science and Engineering*, vol. 669, no. 1, p. 012015, Nov. 2019.
doi: 10.1088/1757-899X/669/1/012015

[25] I. N. Sinarta, A. Rifa'i, T. F. Fathani, and W. Wilopo, Geotechnical Properties and Geologi Age on Characteristics of Landslides Hazards of Volcanic Soils in Bali, Indonesia, *International Journal of GEOMATE*, vol. 11, no. 26, pp. 2595–2599, 2016.
doi: 10.21660/2016.26.67987

[26] I. N. Sinarta, A. Rifa'i, T. F. Fathani, and W. Wilopo, Landslide Hazards due to Rainfall Intensity in the Caldera of Mount, Bali, in *The 1st Warmadewa University International Conference on Architecture and Civil Engineering (WUICACE)*, 2017, vol. 1, pp. 160–167.

[27] M. K. Goel, Runoff Coefficient, in *Encyclopedia of Snow, Ice and Glaciers*, V. P. Singh, P. Singh, and U. K. Haritashya, Eds. Dordrecht: Springer, 2011, pp. 952–953.

[28] F. Rey et al., Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration, *Science of The Total Environment*, vol. 648, pp. 1210–1218, Jan. 2019.
doi: 10.1016/j.scitotenv.2018.08.217

[29] Bagwari, S., Gehlot, A., Singh, R., Thakur, A., Rainfall Induced Landslide Monitoring System, (2021) *International Journal on Engineering Applications (IREA)*, 9 (1), pp. 19-30.
doi:https://doi.org/10.15866/irea.v9i1.19543

Authors' information

[1]Department of Civil Engineering, Faculty of Engineering and Planning, Warmadewa University, Bali, Indonesia.

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

I. Nengah Sinarta was born in Denpasar, July 2, 1970. In 1996, he received a Bachelor's degree Civil Engineering in from Udayana University. Then he received a Master's degree in 2003 and a Doctoral degree in 2018 at the Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia. In 1998, he joined Warmadewa University. His experiences include research, design, and education. He also published many papers in National Conferences and National/International Journal, which focus on the field of Civil Engineering, Geotechnical Engineering, landslide hazards, and geological disasters. Mr. I Nengah Sinarta joined the Indonesia Society for Geotechnical Engineering (ISGE/HATTI)-ID. No.: 15.2223.OR
E-mail: inengahsinarta@gmail.com

Putu Ika Wahyuni was born in Denpasar, September 9, 1971. In 1996, he received a Bachelor's degree Civil Engineering in from Udayana University. Then he received a Master's Environmental degree in 2007, a Master's in Civil Engineering in 2016, and a Doctoral degree in 2020 at the Department of Civil Engineering, Tarumanagara University, Indonesia. In 1998, she joined Warmadewa University in 1996. Her experiences include research, design, and education. He also published many papers in National Conferences and National/International Journal, which focus on the field of Civil Engineering, Construction Management, and Risk Management
E-mail: ikawahyuni9971@gmail.com

Putu Aryastana was born in Buleleng Regency on February 2, 1982. He graduated with a Bachelor's degree in the Department of Civil Engineering at Udayana University on 2004. Then he received a Master's of Sains and Master's of Engineering from a double degree program in 2012, at the Department of Environmental Science, Udayana University, Bali & Yamaguchi University, Japan. He has been a lecturer at Warmadewa University since 2013. His experiences include research, design, and education. He also published many papers in national/international conferences and journals, which focus on the field of civil engineering, remote sensing, environmental science, and water resources management.
E-mail: aryastanaputu@yahoo.com