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The Effect of Initial Groundwater Table and Rainfall Wetting Towards Slope Stability (Case Study of Landslide in Tangkil Hamlet, Banaran Village, Pulung Subdistrict, Ponorogo Regency)

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ABSTRACT Landslide is a natural phenomenon that can be controlled by a combination of various factors, such as topography, lithological condition, geological structure, water table, etc. Landslide is stated as a natural disaster if it causes casualties, direct losses and subsequent impacts of the initial destruction, as happened in Banaran Village, Ponorogo Regency. This study is aimed to examine the effects of initial groundwater table conditions and rainfall wetting on Banaran Village landslide. This study was conducted by assuming scenarios of initial groundwater table conditions. Soil parameters were obtained by testing soil samples in the laboratory. Infiltration parameters were acquired through permeability tests using the Philip-Dunne method, while areal rainfall was calculated using the Thiessen polygon method. In addition, slope stability modeling was calculated by using SLOPE/W while rainfall wetting analysis was carried out through SEEP/W. The analysis of Banaran Village landslide through these two numerical models was conducted by considering two conditions: 1) without rainfall and 2) with rainfall and infiltration. The analysis results imply that the landslide occurred in the initial groundwater table condition in scenario 3 with a safety factor of 1.008, and in a similar scenario with a safety factor of 0.973 when taking into account rainfall and infiltration. The results from SEEP/W and SLOPE/W indicate that the initial condition of the groundwater table highly influenced the decrease of the safety factor, while the wetting process did not cause a significant decrease of the safety factor.

KEYWORDS Landslide; Safety factor; Rainfall wetting

1 INTRODUCTION

A landslide is a form of a natural disaster commonly occurs in hilly areas. Geomorphology, geology, climatology and hydrology conditions are the main controlling factors of landslides in several regions in Indonesia. Natural factors such as slope condition, rock constituents, geological structure conditions, groundwater table, rainfall, and earthquakes have a major influence on the occurrence of these landslides. Man-made factors can also trigger landslides such as slope cutting to be transformed into residential areas, highways or crop fields; adding loads to the peak of the slopes for infrastructure development, as well as rampant land conversion.

In the 1st of April 2017 at around 7:30 a.m. a landslide occurred in Tangkil Hamlet, Banaran Village, Pulung District, Ponorogo Regency. Geomorphologically, Pulung Subdistrict is a sloping to steep hill area (BNPB, 2017). According to regional geological maps made by Hartono, Baharuddin and Brata (1992), the rock lithology conditions are included in the Jeding-Patukbanteng Morphoset group (Q_j) which is composed of andesite pyroxene lava, volcanic breccias, and tuff and pumice insets.

Landslide in Banaran Village occurred when the area experienced a downpour in several days before the disaster. As a result, the slope becomes saturated rapidly due to continuous rainwater infiltration, thus increasing the load of the slope. Infiltration of rainwater into the slopes may also elevate the initial position of the groundwater table, making the soil more prone to movement. The landslide had a length of about 1 km, with an area of around 15 ha. The height of the landslide crown was at 990-1010 m above sea level (asl) (BNPB, 2017). There is a river right below the hills.

This landslide caused damages and losses especially for the residents of Tangkil Hamlet. BNPB (2017) noted that 28 residents were lost and buried in landslides, 19 residents suffered minor injuries, and 200 residents lost their homes. This incident also damaged public facilities, agricultural lands, and farms, and caused indirect damages which paralyzed development and economic activities around the area. Considering the high number of landslides events triggered by rainfall, also the high casualties as occurred in Banaran village, a comprehensive study for landslides is needed in order to formulate mitigation strategies in the future, especially in locations with similar characteristics to Banaran area.

2 LITERATURE REVIEW

The objectives of this study are (a) to estimate the safety factor during the landslide with the assumed scenario of changes in the initial conditions of groundwater table and rainfall wetting, and (b) to analyze the sensitivity of factors which affects the decrease in the safety factor.

A study of landslides in Banaran area was conducted by Suprapto, Nurmasari and Rosyida (2017). He used several overlaid data to see which areas were vulnerable to landslides, including topography/slope, soil conditions, land use, and rainfall data. The result from Suprapto, Nurmasari and Rosyida (2017) provides a spatial description and the cause of landslides viewed from hydrometeorological factors in Banaran area.

Another study of landslides related to groundwater table was conducted by Handayani, Wulandari and Wulan (2014) which analyzed the effect of groundwater table on slope stability using GEOSLOPE/W version 7.12. By entering soil testing data into GEOSLOPE/W, the factor of safety and the type of the landslide are analyzed by trial and error of slopes and its angles.

Regalado *et al.* (2005) conducted a study about the capability of Philip-Dunne method to estimate soil sorptivity (S) and Green-Ampt suction (Ψ) in the wetting zone by performing parameter sensitivity analysis. In previous studies, Philip (1993) investigated the Philip-Dunne falling head permeameter which can be used to estimate saturated hydraulic conductivity (K), although not so reliable in estimating the soil sorptivity. This follow-up study resulted in an approximate solution to enable the calculation of saturated hydraulic conductivity (K) and Green-Ampt suction (Ψ) in the wetting zone (and hence macroscopic capillary length, α^*) only from two infiltration times ti_{med} dan t_{max} without having to use costly measurements such as increasing the soil moisture as previously used in Philip (1993) in his original method.

3 RESEARCH METHOD

3.1 Mapping

Mapping data were obtained from secondary sources and analyzed by using geospatial software, which consists of geometric cross-sections of the slope, illustrating soil sampling locations and permeability tests, as well as making Thiessen polygon maps, among others.

3.2 Soil Sampling at the Research Site

Samples were taken from the undisturbed soils and landslide deposit soils as shown in Figure 1.

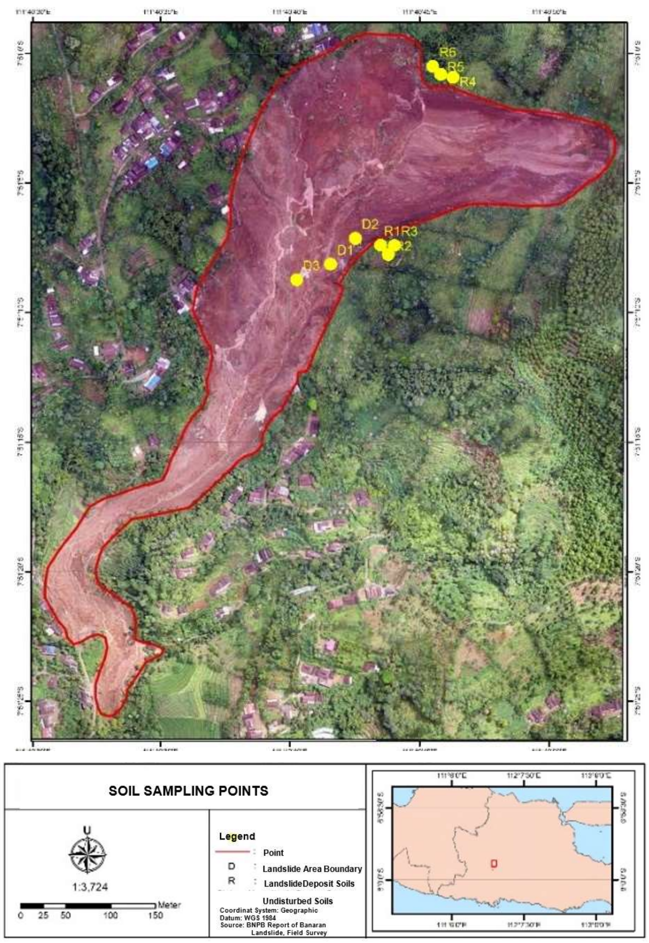

Figure 1. Soil sampling points (BNPB, 2017)

3.3 Permeability Test at the Research Site

Permeability tests by using the Philip-Dunne method were conducted in two locations as shown in Figure 2.

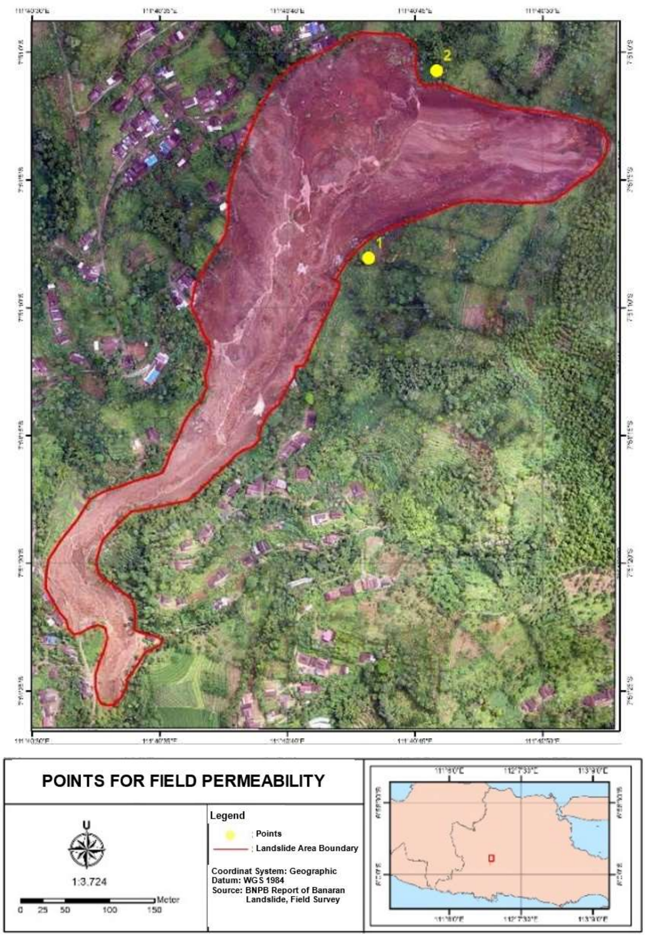

Figure 2. Points for field permeability tests (BNPB, 2017)

Muñoz-Carpena *et al.* (2002) conducted a study in which the permeability values were calculated using estimated soil permeability values. Equations conditions are only valid if $t_{max}/t_{med} < 5.4$. Boundaries of ks and ψ can be calculated using the Equation 1; 2 and 3:

$$\tau_{max} = 0.731\frac{t_{max}}{t_{med}} - 1.112; \frac{t_{max}}{t_{med}} \leq 5.4 \quad (1)$$

$$ks = \frac{\tau_{max}\pi^2 r_0}{8t_{max}} \quad (2)$$

$$log\psi = -13.503 + 19.678\sqrt{\frac{t_{med}}{t_{max}}} \quad (3)$$

where k_s is the saturated coefficient of permeability (cm/hour), $r_0 = ½\ r$ is half of the test tube radius (cm), t_{max} is the time needed for the depth of water to decrease for $H_0 = 30$ cm (second), t_{med} is the time needed for the depth of water to decrease for $H_0 = 15$ cm (second), ψ is the suction head (cm), and τ_{max} is the dimensionless time.

3.4 Soil testing in the laboratory

Soil testing consists of water content test, Atterberg limits, specific gravity (*Gs*), grain distribution, soil permeability, and direct shear test according to ASTM standard.

3.5 Landslide simulation

Landslide simulation was made using SLOPE/W to calculate the slope stability and SEEP/W for rainfall and infiltration modeling.

4 RESULTS AND DISCUSSIONS

4.1 Overall Conditions of Research Location

4.1.1 Overview of Research Location

Geographically, Banaran Village is located on the west slope of Mount Willis with coordinates of 7°51'4" of south latitude; 111°40'56" of east longitude and at an elevation of 843 m (asl). Hydrologically, the location of landslide includes 3 (three) watersheds, which are Keyang, Kali Madiun and Solo.

4.1.2 Topography

The slope levels for Pulung subdistrict range from 2% to > 140%, from flat to very steep, and the landslide area, namely Tangkil Hamlet, has a slightly steep slope which is about 15-30% (Suprapto, Nurmasari and Rosyida, 2017).

4.1.3 Geology

Based on the regional geology map of Madiun sheet made by Hartono, Baharuddin and Brata (1992), the constituent rocks in the research area fell under Jeding-Patukbanteng Morphoset group (Qj), which consisted of andesite pyroxene lava, volcanic breccias and inserts tuff, along with pumice in Figure 3. There were regional lineaments around 1.7 km northeast and 4 km northward from landslide area. Regional faults were estimated to be around 4.5 km in the northern part of the landslide location.

4.1.4 Land Use

Based on the land use planning Dinas Pekerjaan Umum dan Penataan Ruang Kabupaten Ponorogo (2012), the research area mostly consisted of farms, shrubs, rice fields, and settlements. However, over the past 4 years, land use had been changing, in which pine forests were transformed into agricultural land. In agricultural areas, residents used slopes to plant ginger and bamboo which did not have strong roots to support soil movement (Suprapto, Nurmasari and Rosyida, 2017).

4.1.5 Slope Geometry

The slope geometry before the landslide was obtained by overlaying the contour data of Indonesian Topographic map on a scale of 1:25.000 with a landslide map area as measured by BNPB. Slope coordinates were obtained by cutting the slope profile vertically along a predetermined path using known elevation data (Figure 4).

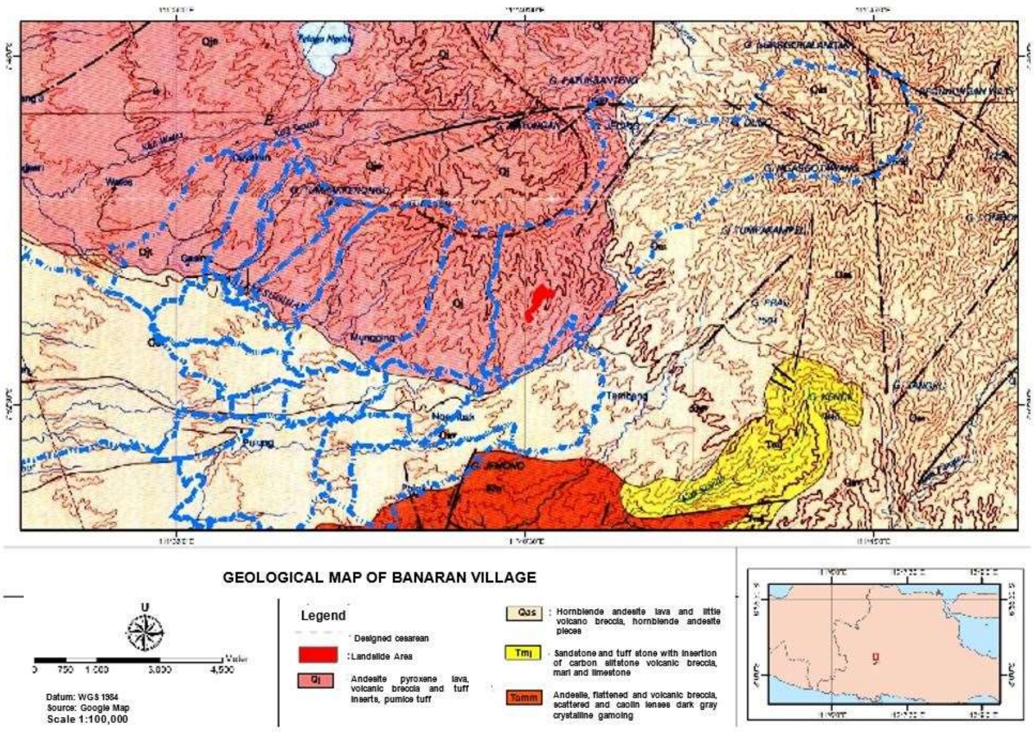

Figure 3. Geological map of Banaran Village

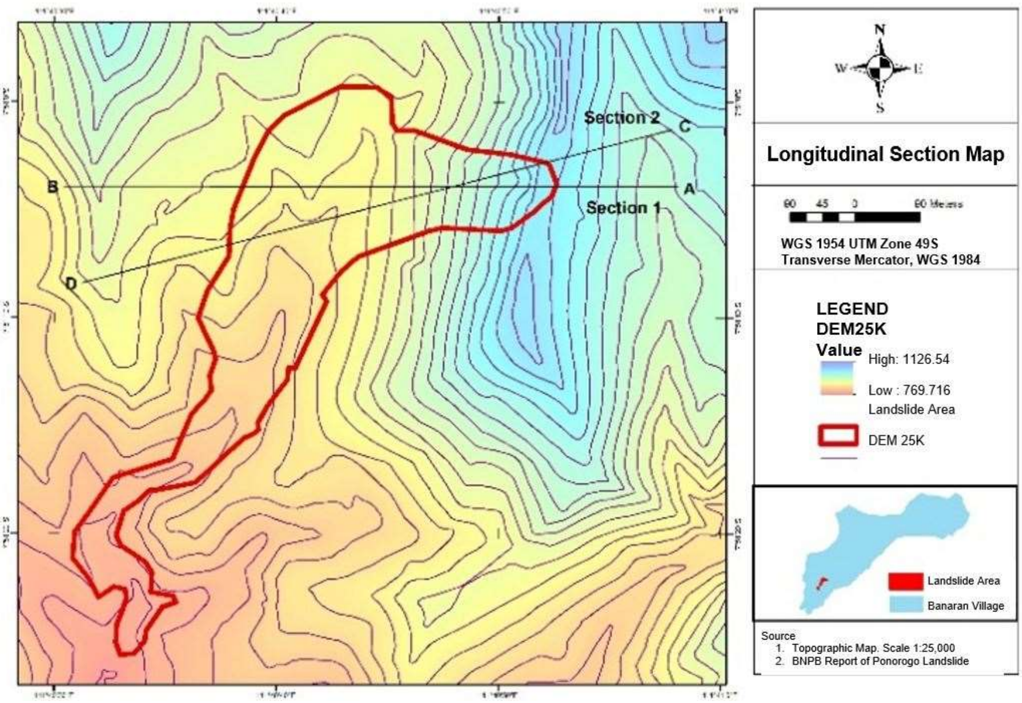

Figure 4. Longitudinal section of the slope prior to the landslide (BNPB, 2017)

The coordinates were then depicted by using the Computer Aided Design software (AutoCAD) to get the shape of the slope to be modeled Figure 5 so that they can be imported into SEEP/W or SLOPE/W.

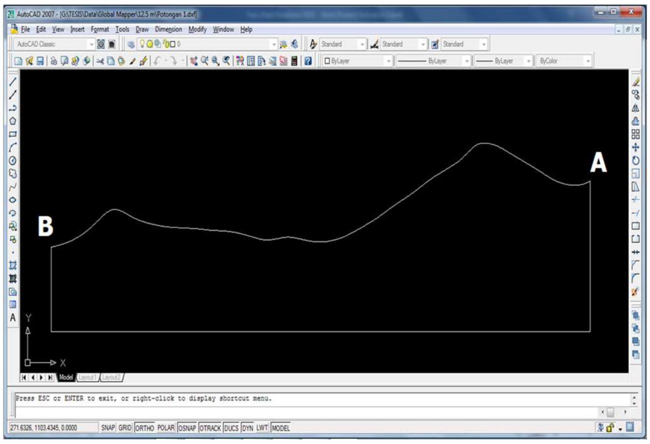

Figure 5. Longitudinal section 1 (A-B)

4.2 Hydrological Analysis

4.2.1 BMKG Data

Based on BMKG rainfall distribution data using the ten-day rainfall distribution (Dasarian) in March Dasarian I to Dasarian III, the rainfall in Pulung Subdistrict was indicated as high-very high (151-300 mm) at Dasarian I, low-medium (11-75 mm) at Dasarian II, and low (11-50 mm) at Dasarian III.

4.2.2 Rainfall Station

We use the rainfall data from 22 ground stations which spread in Ponorogo Regency and provided by the Office of Public Works and Spatial Planning in Figure 6.

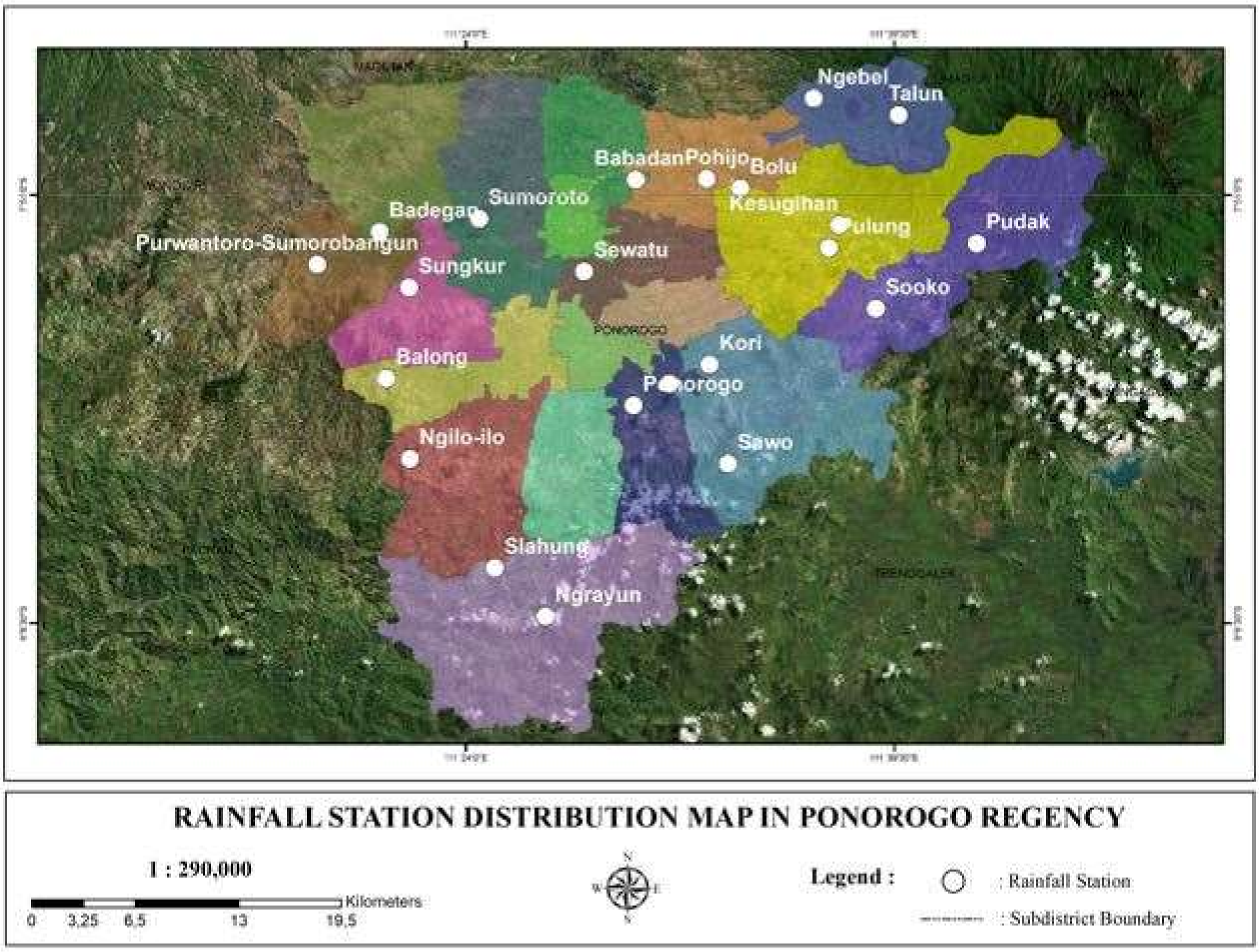

Figure 6. Rainfall stations distribution map in Ponorogo Regency

4.2.3 Areal Rainfall

Daily rainfall data from 22 rainfall stations were calculated into areal rainfall using polygon Thiessen analysis in Figure 7. The calculation was conducted based on 14 days before the landslide, during March 18 – 31, 2017.

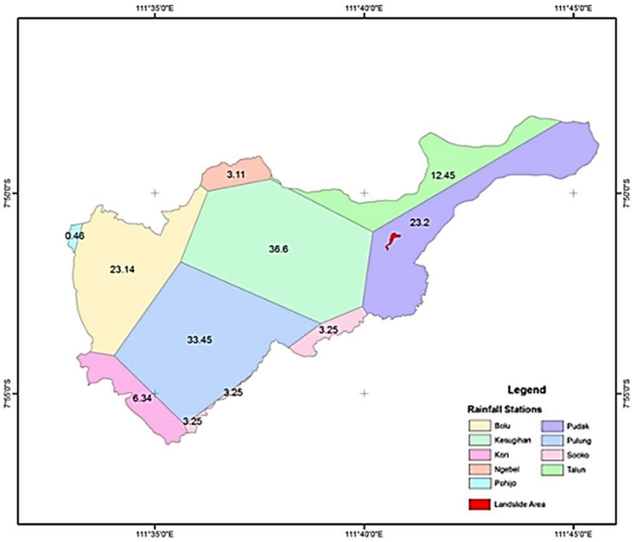

Figure 7. Polygon Thiessen Map (Dinas Pekerjaan Umum dan Penataan Ruang Kabupaten Ponorogo, 2012)

From the analysis, it was discovered that there were 9 influential rainfall stations in the Pulung Subdistrict area, namely Bolu, Kesugihan, Kori, Ngebel, Pohijo, Pudak, Pulung, Sooko, and Talun. The recapitulation of the average areal rainfall from March 18-31 2017 is presented in Table 1.

Table 1. Areal rainfall in Pulung Subdistrict March 18-31 2017.

Date	Average rainfall (mm)	Date	Average rainfall (mm)
18	15.67	25	1.16
19	36.83	26	2.16
20	0.00	27	9.58
21	0.49	28	4.70
22	0.00	29	3.06
23	0.00	30	3.61
24	0.44	31	30.46

4.3 Soil Mechanics Analysis

4.3.1 Soil Testing Result

The parameters for the internal friction angle and cohesion from soil testing are presented in Table 2.

Table 2. Soil testing parameters

Parameter	Undisturbed soil	Disturbed soil
Internal friction angle (ϕ)	21.46°-25.16°	17.92°-26.64°
Cohesion (c)	5-13 kPa	6-11 kPa

The materials used in the simulation were assumed to be homogeneous and isotropic, with internal friction angle (ϕ) of 21.46° and cohesion (c) of 10 kPa. The Phi B value (ϕ^b) was assumed to be equal to the (ϕ) value (Muntohar and Liao, 2009). In this study, the value of ϕ^b was 21.46°. Based on the USCS (Unified Soil Classification System) classification, the tested soil sample is classified as inorganic clay with low to moderate plasticity, gravelly clay, sandy clay, silty clay, lean clay (CL).

4.3.2 The result from Soil Permeability Test

After conducting analyses using Phillip-Dunne method using equations (1), (2), (3), the obtained values of soil permeability coefficient (*ks*) and suction head value (ψ) can be seen in Table 3. The average values were ks = 1.41 x10^{-4} m/s and ψ = 4.11x10^{-4} kPa. According to Das classification (1985), the soil could be categorized into fine gravel, coarse grains mixed with medium-grain sand

Table 3. The calculation results of permeability value (*ks*) and suction head (ψ)

Point	t_{med} (s)	t_{max} (s)	k_s (m/s)	ψ (kPa)
1	59.98	265.28	2.55x10^{-4}	7.01x10^{-4}
2	635.38	3.329.33	2.60x10^{-5}	1.22x10^{-4}
		Average	1.41x10^{-4}	4.11x10^{-4}

4.4 Landslide simulation

4.4.1 Scenario

Landslide simulation began with determining the scenarios that will be used in the analysis. First, simulations were conducted by considering groundwater table which was further analyzed using SLOPE/W. The second was simulations on the initial groundwater table scenario with additional rainfall wetting process. SEEP/W and SLOPE/W were used to analyze this scenario. Analyses were conducted towards 2 (two) slopes, with the extraction method that can be seen in Figure 4.

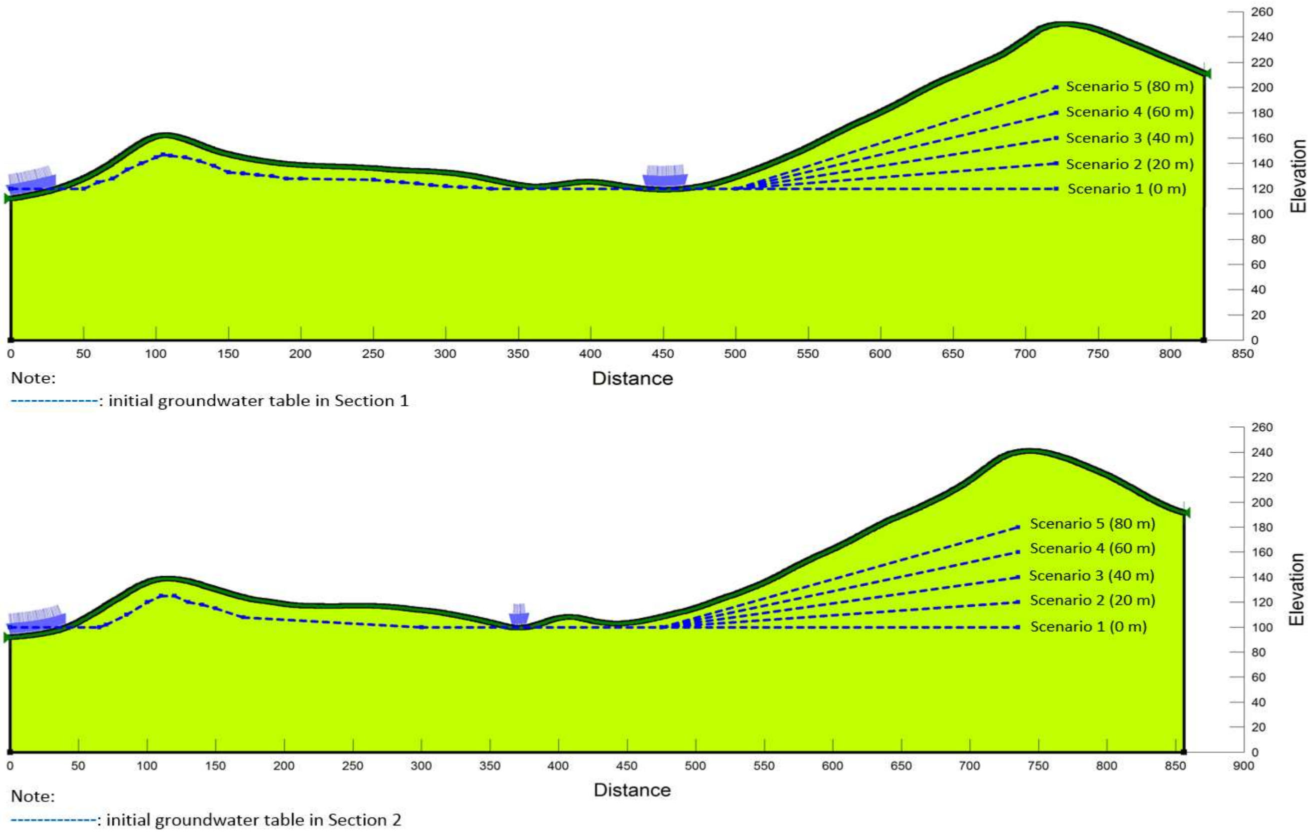

Figure 8. Scenarios of the initial groundwater table

The illustration for the groundwater table was made based on the 5 assumed scenarios in Figure 8. Each scenario is based on elevation differences. The first scenario is assumed to start from the river water level found at the foot slope. The next scenario is the addition of an elevation every 20 m. The elevation of each scenario shown in Figure 8 was the elevation on the model, not the elevation measured from the sea level. Simulations were then carried out for each scenario.

4.4.2 Analysis Method of Slope Stability

The analysis method used in this study was the Bishop Method. This method is suitable to be used on homogenous soil conditions, with circular or curvilinear slip surface (GEO-SLOPE International Ltd, 2012).

4.4.3 Numerical Simulation of Pore Water Pressure

The software being used is a 2-dimensional (2D) software. The rainfall was calculated per m unit the analysis selected for this study was transient with initial head/pore water pressure from parent analysis so that the analysis results from SEEP/W could be used on SLOPE/W software. Table 4 groups the parameters entered into the software.

Table 4. Entered parameters in numerical analysis

SEEP/W	SLOPE/W
Material ▪ Soil permeability value ▪ Value of negative pore water pressure ▪ Index properties of soil	Material ▪ Shear strength parameter (Mohr-Coloumb) ▪ Value of negative pore water pressure ▪ Index properties of soil
Analysis ▪ Transient analysis method ▪ Time	Analysis ▪ Analysis method: Bishop ▪ Infiltration result from SEEP/W
Boundary conditions ▪ Rainfall data ▪ Zero pressure ▪ Head	

4.4.4 Applied Boundary Conditions

Boundary conditions applied in this modeling consisted of rainfall data, zero pressure, and head.

a) Rainfall data entered into the application was the average rainfall calculated using the Thiessen polygon method which was obtained over a period of 14 days prior to the landslide.

b) Zero pressure was used in conditions where rivers exist.

c) Upstream is used for conditions in the upstream area in transient analysis method in the form of head function which was made as high as the groundwater table in the scenario. This was done to lock the position of the groundwater table's position to prevent it from falling.

4.4.5 Slip Surface

Slip surface was illustrated using entry and exit range. With the entry in form of points on the right side (upstream area) namely the point indicated as the landslide crown, while the exit range was made using certain distance range that was suspected as the foot of the landslide.

4.5 Analysis Result

4.5.1 Analysis Result of Changes in Initial Groundwater Table Condition

The simulation results using SLOPE/W for variations of changes in the initial groundwater scenario in the cross-section 2 shows the safety factor values as shown in Figure 9.

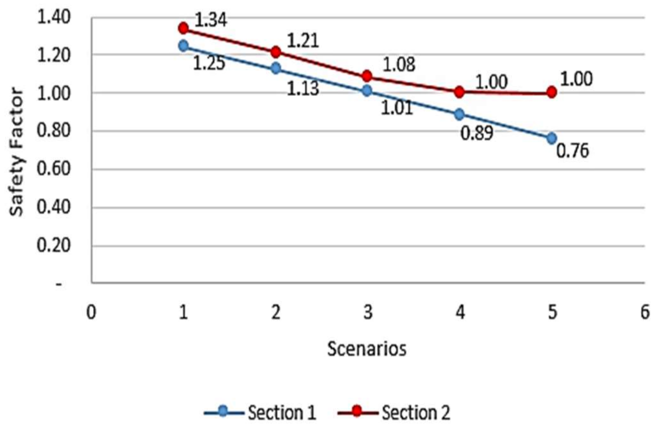

Figure 9. Relationship between the scenarios of initial groundwater table to the safety factor value

Figure 9 shows the safety factor for each of the groundwater table scenario. From the overall safety factor values obtained from 2 analyzed cross-sections, cross-section 1 produced smaller values, which implied that the modeled slope was more critical in cross-section 1 and had the potential to experience landslide first. Henceforth, the analysis was conducted only towards cross-section 1. From the analysis, it can be concluded that the landslide in Banaran Village occurred in scenario 3, where the slope safety factor = 1.008. The safety factor value and the shape of slip surface generated from the analysis using SLOPE/W for scenario 3 in cross-section 1 can be seen in Figure 10.

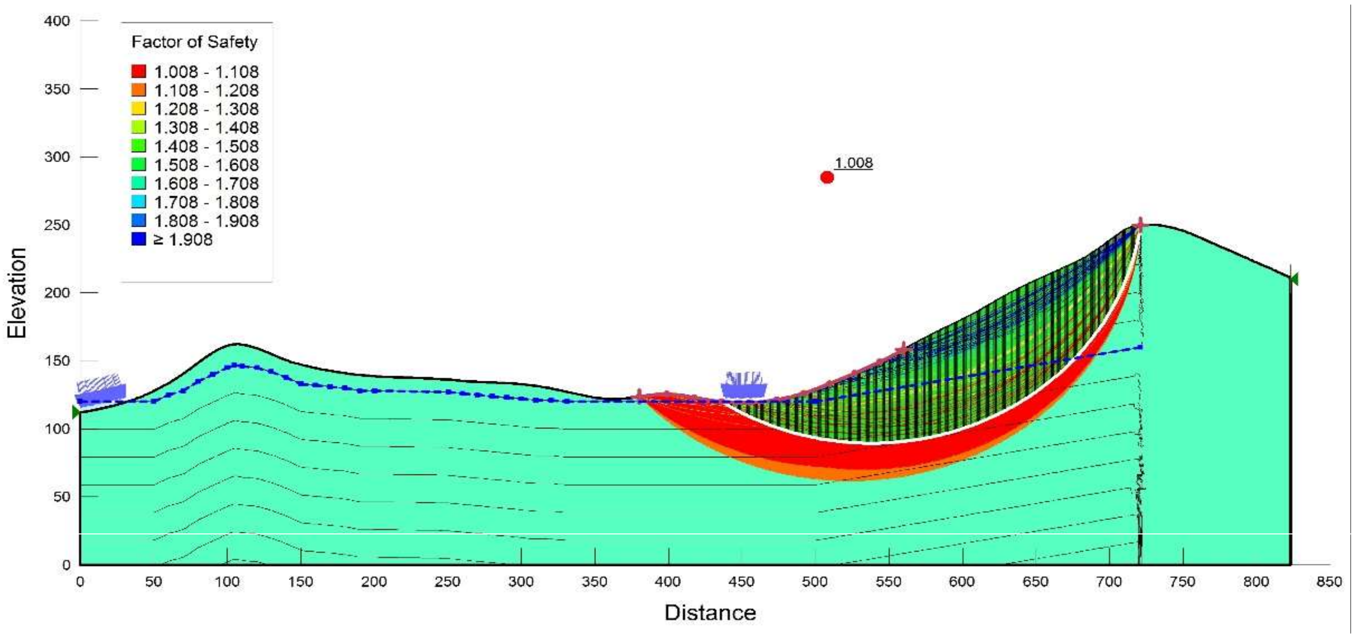

Figure 10. Safety factor value and shape of slip surface in scenario 3

4.5.2 Analysis Result of Changes in Initial Groundwater Table Condition and Rainfall Wetting

Simulations were subsequently conducted towards the changes of scenario in initial groundwater table combined with rainfall in the landslide location. Simulations were carried out by comparing the rainfall wetting process that occurred for 14 days before the landslide with the wetting process that took place throughout March 2017, with a total of 31 days. Based on SLOPE/W analysis in each scenario's simulations for both conditions mentioned above, the safety factor variations were obtained, as shown in Figure 11 and Figure 12. From the results, it can be seen in Figure 13 that the safety factor from both the 14th and 31st day were almost identical.

It indicates the difference in the 14 days and 31 days of wetting process does not have a significant effect on the safety factor's calculation, thus further discussion of the analysis will only towards the wetting process 14 days before the landslide. The analysis result of the initial condition of groundwater table with wetting from 14 days of rain showed that the modeled landslide in Banaran Village slope occurred in scenario 3 when the safety factor (SF) = 0.973. Based on Figure 13, the safety factor values for each of the scenario of initial groundwater table with rainfall wetting tended to increase and produced the smallest value in the 14th day. Scenario 3 had the most critical value of safety factor.

The simulation using SEEP/W to analyze the initial condition of the groundwater table with rainfall wetting resulted in changes in the pore water pressure values as shown in Figure 14. Changes in the value of pore water pressure occurred due to the infiltration of rainwater into the soil. These changes are shown by colors as seen in Figure 15. From the analysis, it was known that the value of pore water pressure will decrease when it approached the groundwater table. Pore water pressure below the groundwater table is positive in value and the greater the distance from the groundwater table, the higher the value will be. Above the groundwater table, or in a relatively dry area, the pore water pressure is negative. Water that seeps into the soil fills the cavities that were previously filled with air, then the air will be pushed out and replaced by water. Pore pressure that was formerly negative (dry) will be positive over time, proportional to the degree of soil saturation. If the soil is infiltrated to form groundwater table, then the value of the pore pressure on the surface of the groundwater table is equal to 0 (zero). Safety factor value and the shape of slip surface obtained from the analysis using SLOPE/W for scenario 3 can be seen in Figure 15.

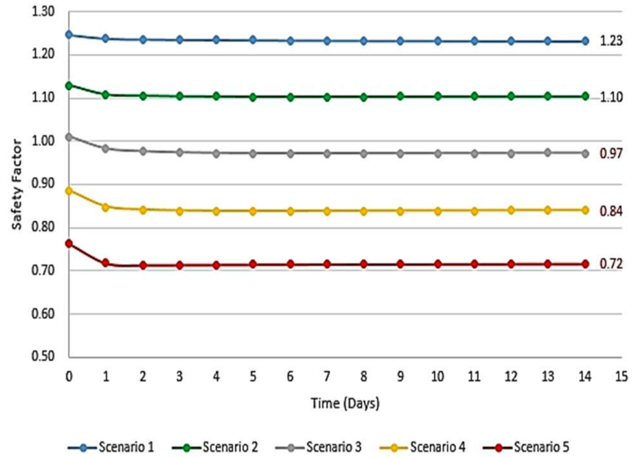

Figure 11. Graph of safety factor changes caused by wetting for 14 days

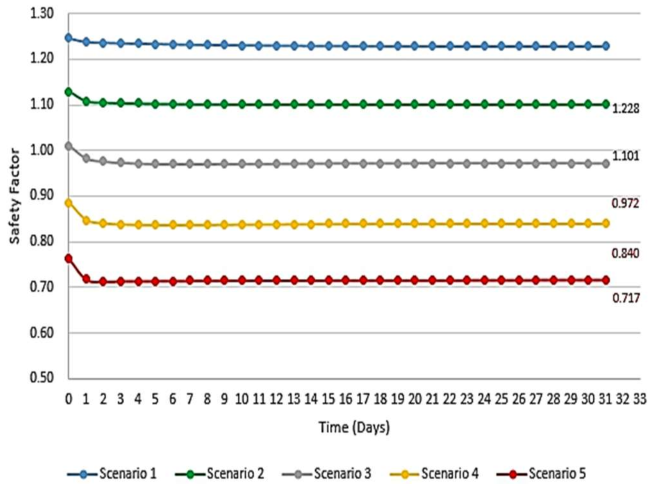

Figure 12. Graph of safety factor changes caused by wetting for 31 days

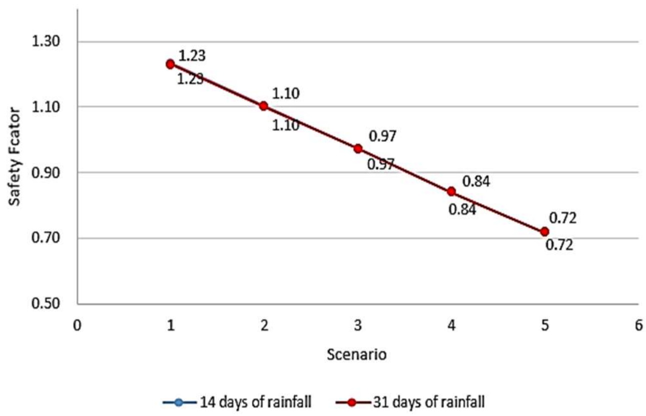

Figure 13. Graph of safety factor comparison between 14 days and 31 days of rainfall

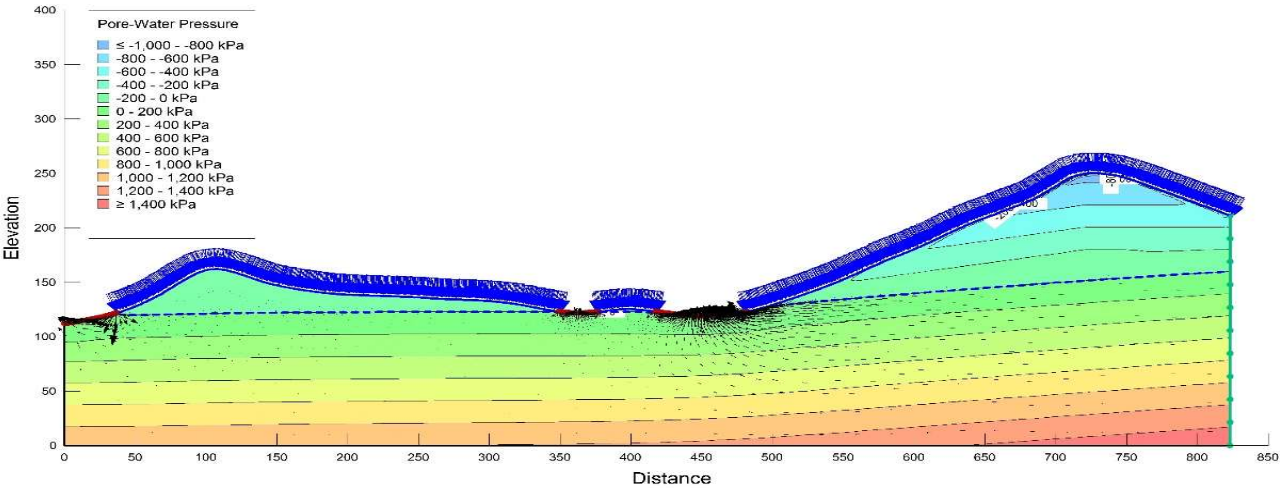

Figure 14. Changes in the value of pore water pressure in scenario 3

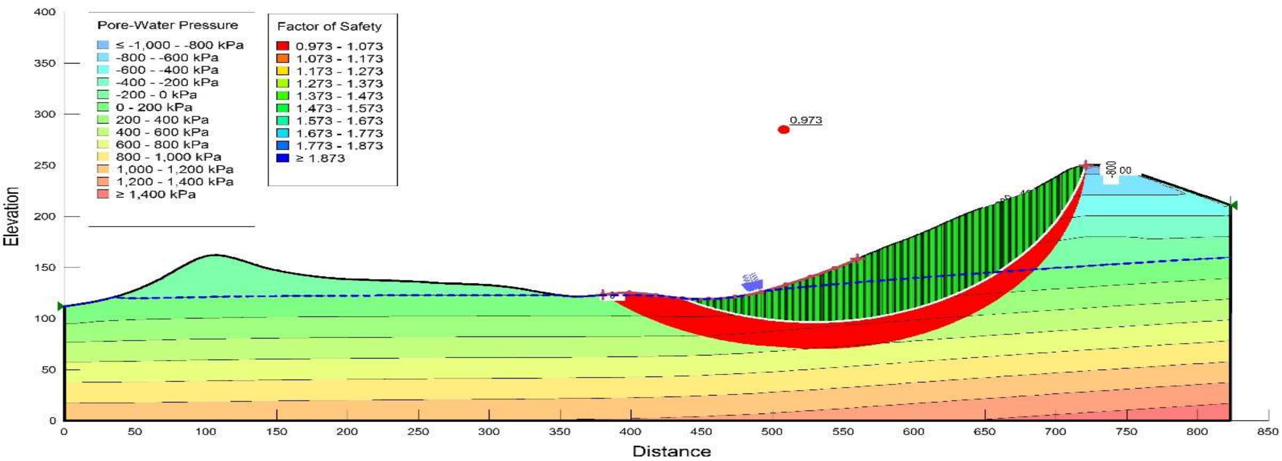

Figure 15. Safety factor values and shape of slip surface in scenario 3

The infiltration of rainwater into the slopes resulted in an increase in soil density (increasing soil mass load), reduction even loss of suction in unsaturated water zone, and an increase the pore water pressure in the soil. Meanwhile, negative pore water pressure and cohesion will decrease.

Changes in pore water pressure affected the parameters of soil shear strength, the higher the pore water pressure, the lower the cohesion will be, while the internal friction angle relative to matric suction will increase.

4.5.3 Sensitivity Analysis on Factors Influencing the Decrease of Safety Factor Values

Safety factors obtained from the analysis of the initial condition of the groundwater table tended to have slightly larger values compared to the result of the analysis that took rainfall into account. However, the difference was not too significant compared with the change in safety factor values in each scenario for both analyses. From the overall results, it can be concluded that the initial condition of the groundwater table was a factor that was more sensitive to the decrease in safety factor value. The results from both of the analyses using SLOPE/W can be seen in Figure 16. The infiltration effect was smaller because the shape of the original slope in the field (3D) could not be represented in 2D models.

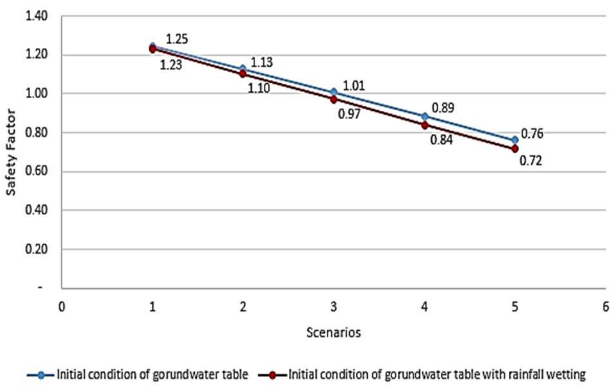

Figure 16. Graph of safety factory from analysis of the initial condition of groundwater table and initial condition of groundwater table with rainfall wetting

5 CONCLUSIONS

The result of soil testing in the laboratory indicated that the undisturbed soil parameter's value of internal friction angle (ϕ) was 21.46°-25.16° and its cohesion value (c) was 5-13 kPa. Whereas the landslide soil deposits (disturbed soil) had the value of 17.92°-26.64° (ϕ) and 6-11 kPa (c).

The soil permeability test in accordance with the Philip-Dunne method obtained the permeability coefficient (ks) of = 1.41×10^{-4} m/s and suction head (ψ) of = 4.11×10^{-4} kPa, which fell into soil category of fine gravel, coarse grain mixed with medium sand (Das, 1985). Based on slope stability analysis using SLOPE/W, safety factor value of 1.008 was calculated from the analysis of changes in initial groundwater table condition in scenario 3. As for the assumed scenario for changes in initial groundwater table conditions with rainfall wetting for 14 days prior to landslide, a safety factor of 0.973 was obtained and occurred in scenario 3.

The results of the analyses using SEEP/W and SLOPE/W showed that the initial groundwater table condition had a profound effect towards the decrease in safety factor while wetting process did not cause a significant decrease of the safety factor.

For the future research in the same location, it is recommended to make the amount of sampling to be more evenly distributed to acquire better data and provide contour maps before and after landslides with the same scale and datum. More detailed data such as the data of groundwater table monitoring and soil layers would be needed. The Automatic Rainfall Recorder (ARR) needs to be installed in landslide-prone locations so that the generated rainfall data would correspond with the actual conditions on the site. For studies related to landslides, in particular, rainfall data should be recorded hour-by-hour. Since 2-dimensional modeling is still insufficient to analyze landslides because it could not represent the shape of the original slope in the field, it is necessary to do a 3-dimensional analysis to incorporate concave topography in increasing the groundwater table. These recommendations are also intended for research in other locations with similar issues.

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