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Monitoring the Soil Movement on Mount Wungkal Godean Sleman with the Analytical Hierarchy Process Method

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Abstract. The Wungkal Mountain area is a Godean hill which is probably an ancient volcano. It is an open green space area in Sleman Regency for the development of mining, housing, tile and brick industries. Because it is growing rapidly, the impact of land movement risks needs to be monitored and this is done by mapping soil movement from lithology data, soil type, land use, rainfall, and slope. The data was processed with Arc GIS software to obtain five maps from the data collected by the Analytical Hierarchy Process (AHP) method. This method is capable of calculating the weight of the landslide risk level in the Wungkal Godean mountain area. From the results of the risk mapping of ground motions, this area was found to be prone to landslides, especially in the area to the right of Mount Wungkal which is being mined for raw materials for making roof tiles and red bricks as well as for housing development. The lithology was found in the form of andesitic igneous rock which is massively altered by lithosol and grumusol soil types. Meanwhile, residential areas are safe areas for living because there has been a lot of sedimentation.

INTRODUCTION

The geology of the Godean region is composed of four rock groups: igneous mixed volcanic and fine-grained clastic deposits, pyroclastic deposits and alluvial deposits. The presence of these rocks is closely related to the potential for complex rock formations in the Godean region, which is believed to be part of the Godean-caldera volcanic system, and this requires further study. In this study, pyroclastic and sedimentary-volcanic units remain difficult to separate, and avalanche and volcanic sediments are still combined [1]. Based on topographic map analysis and field observations, the study area can be divided into two topographical units, namely the exposed hillock unit and the weak river wave unit. The denudation mound landform unit occupies the central part of the study area and covers an area of ±40% of the total study area. The hills extend in a northwest-southeast direction with steep slopes of different heights than the plains of the region, i.e., 34–60 meters, angles of ±51°, ±200 meters above sea level. The geological background of the Godean region and its surrounding rocks consists of two major groups: Tertiary rocks derived from ancient volcanic activity and Quaternary Mount Merapi deposits, which consist of avalanche and lava deposits, divided into groups. The faults in the northern Godean area and the regional geological structure in the horizontal south-east-west direction are the interpretation of this area [2]. Geological examination reveals fault zones or breccias, shear zones, and lineaments at several locations, such as South Wungkal and Juring. This consistency is also interpreted in the context of the changes that have taken place in the Godean region (see Figure 1).

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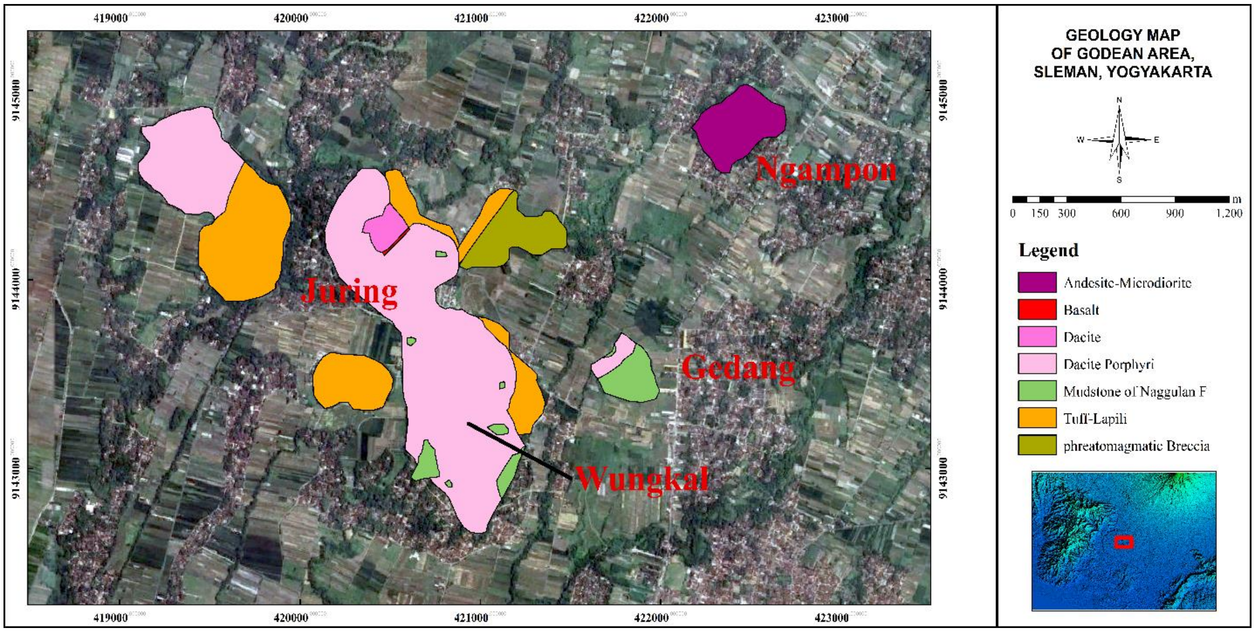

FIGURE 1. Geological map of the Godean area and its surroundings, as well as a north - south geological profile

Soil movements are caused by the presence of natural processes that change the structure of the land surface, namely disturbances in the stability of the soils and rocks that make up the slope. This disturbance of slope stability is influenced by geomorphological conditions, particularly slope factors, rock conditions or constituent soil slopes, slope hydrological conditions or water management. Ground movement is a natural physical phenomenon, but some of the consequences of uncontrolled human activity resonate with the fragility of natural conditions in natural resource exploitation, leading to slope instability that can lead to landslides which can be a causative factor [3]. These human activity factors include cultivation patterns, slope cutting, pond formation, drainage, building construction, population density, and mitigation efforts. Therefore, landslide-threatened areas need to be structured in order to create an environmental balance sheet and achieve sustainable development.

Weathering of diorite intrusions can cause over 400 cm of weathering, depending on the physical properties of the rock and the type of minerals formed [4]. The degree of weathering of diorite intrusions is driven based on changes in physicochemical properties. From now on, we need to analyze landslides and dismantle areas for permanently safe and sustainable settlements. Based on magnetic data, Mount Wungkal is composed of clay, which is an alteration of pioneering igneous rocks [5]. This study aims to analyze soil risk by mapping ground movements using data collected by the Analytical Hierarchy Process (AHP) method through Arc GIS software.

METHODOLOGY

The research location is located in the Wungkal Mountain area, Godean District, Sleman Regency, Yogyakarta Special Region as shown in Figure 2. From the figure, there are five observation points around Mount Wungkal as indicated by a green color. Data collected at the observation location of Mount Wungkal is in the form of lithology, soil type, land use, rainfall, and slope.

The study of mapping the determination of the landslide susceptibility zone was carried out in three stages, namely data collection, calculation, and weighting of each parameter (Figure 3). The final step is mapping the landslide-prone zone in the Wungkal Mountain area using Arc GIS. In this work, landslide susceptibility level is determined by using the Analytical Hierarchy Process (AHP) method. Determining the value for each vulnerability parameter is obtained from the pairwise comparison assessment matrix method [6][7]. The results of the pairwise comparison judgment matrices produce a ranking of the most influencing parameters to determine the characteristics of the relationship between related populations and different populations with respect to other parameters [8][9].

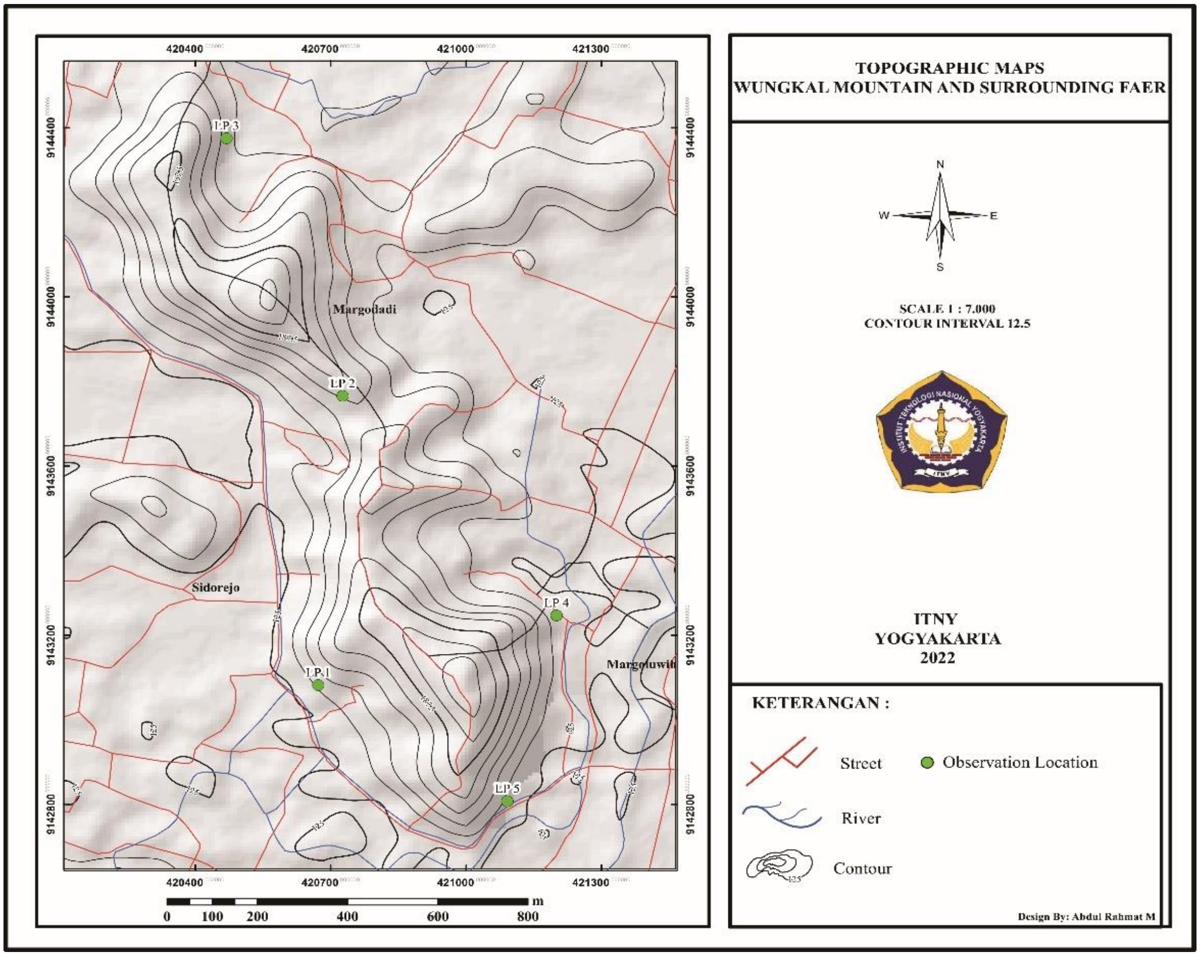

FIGURE 2. Map of research locations in the Wungkal Mountain Area

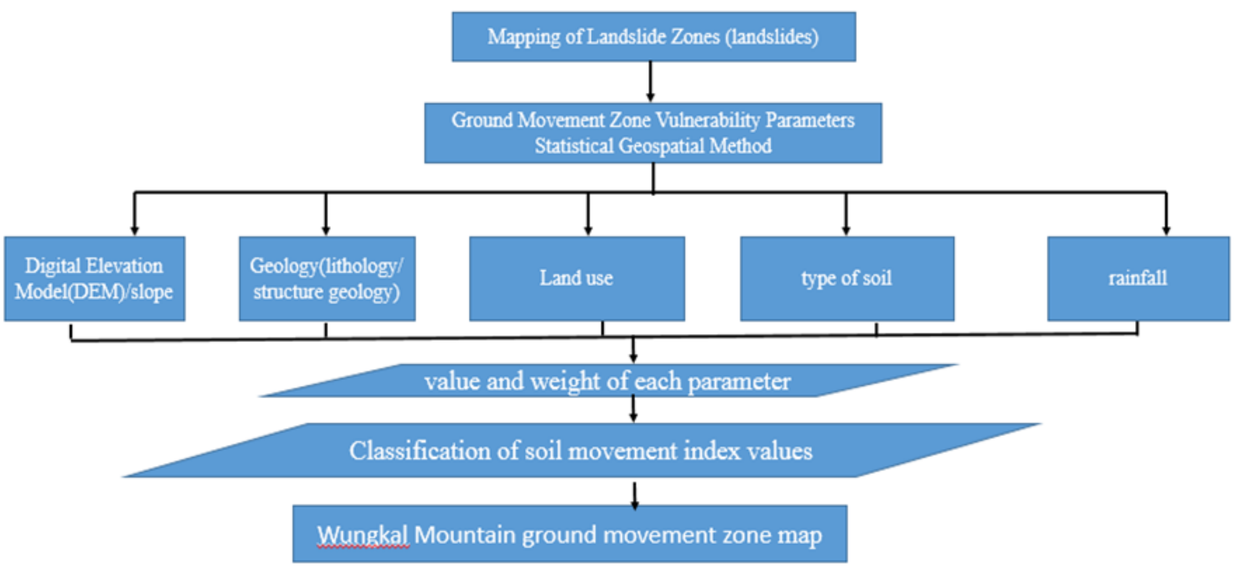

FIGURE 3. Ground movement assessment flowchart

RESULT AND DISCUSSION

Slope

There are three types of class types [10] which are based on the slope data, areas with a slope of 0-6º are given a weight of 16%, 6-20º are given a weight of 30%, and >20º are given a weight of 54% (see Table 1). The slope of the land is one of the controlling factors for the occurrence of landslides. The comparison of the sub-parameter data is obtained using the AHP method is listed in Table 1 and Table 2.

TABLE 1. Slope pair comparison matrix and normalization value

Parameter	Pair comparison matrix			Slope normalization value					
	Steep	Sloping	Flat	Class 1	Class 2	Class 3	Total	Remark	
Steep (> 20°)	1	2	3	0.55	0.57	0.50	1.62	3.0	max
Sloping (6° – 20°)	0.5	1	2	0.27	0.29	0.33	0.89	0.01	CI
Flat (< 6°)	0.3	0.5	1	0.18	0.14	0.17	0.49	0.01	CR
Total	1.8	3.5	6	1	1	1	3		

TABLE 2. Calculation of slope score and weight

Parameter	Score	Percent
Steep (> 20°)	0.54	54
Sloping (6° – 20°)	0.30	30
Flat (< 6°)	0.16	16
Total	1.00	100
Sloping (6° – 20°)	0.30	30
Flat (< 6°)	0.16	16
Total	1.00	100

From Table 2, we can see that the highest value for the slope parameter is over 20% with a score of 0.54 or a percentage of 54%. The highest of these values (see Table 1) from the paired comparisons and the calculated normalized values of the slope parameters are probably due to the greater gravitational force.

FIGURE 4. Avalanche appearance on the slope

Slopes were found to be relatively steep in the study area (see Figure 4), one of the factors determining the likelihood of landslides. The gradient factor is closely related to the gravitational force of the mass. The greater the slope of the surface, the greater the gravitational force of the mass on the slope, and ground motion can occur. In fact, as shown in Figure 5, there are few local steep points in the Wungkal Mountains due to exploitation of mining areas as raw materials for the tile and brick industries.

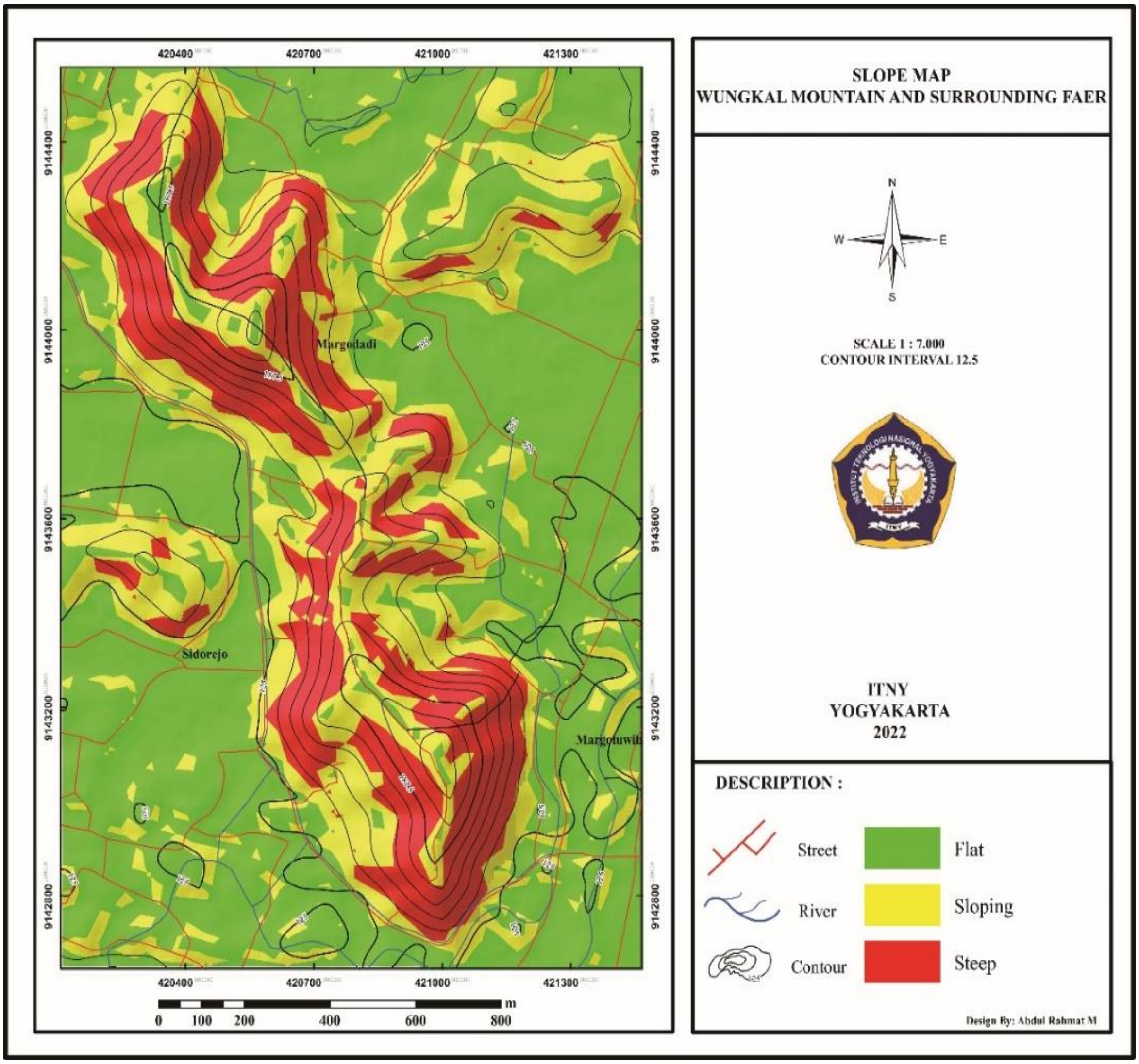

FIGURE 5. Slope inclination range in the research area

Lithology

The study area covers Wungkal Mountains with lithofacies in the form of tuff, clay and lapilli derived from andesite-intruded dacite, as shown in Figure 6. Weathered tuff is grayish-black, fresh is yellowish-gray in color, less than 1/256m in size, grains are rounded, densely packed, and well graded. Weathered reddish-brown lapili, grain structure 2 mm, grain shape rounded, package open, poorly sorted and massive structured. Between outcrops Brownish-white weathered color, bright white fresh-colored clay with a grain size less than 1/256 with a rounded grain structure. A comparison of rock subparameter data is shown in Tables 3 to 4. It can be seen from Table 4 that the highest values for lithological parameters are rough tuff with a score of 0.58 or a percentage of 58%.

TABLE 3. Lithological distribution for pair comparison matrix and calculation normalization value

Pair Comparison Matrix				**Normalization Value**			
Parameter	Tuff	Lapili	Clay	Tuff	Lapili	Clay	Total
Tuff	1	3	2	0.55	0.86	0.33	1.74
Lapili	0.3	1	2	0.18	0.29	0.33	0.80
Clay	0.5	0.5	1	0.27	0.14	0.17	0.58
Total	1.83	4.50	5.00	1	1.285	0.833	3.119

TABLE 4. Calculation of score and weight of lithology distribution

Parameter	Score	Percent
Tuff	0.58	58
Lapili	0.27	27
Clay	0.19	19
Total	1	100

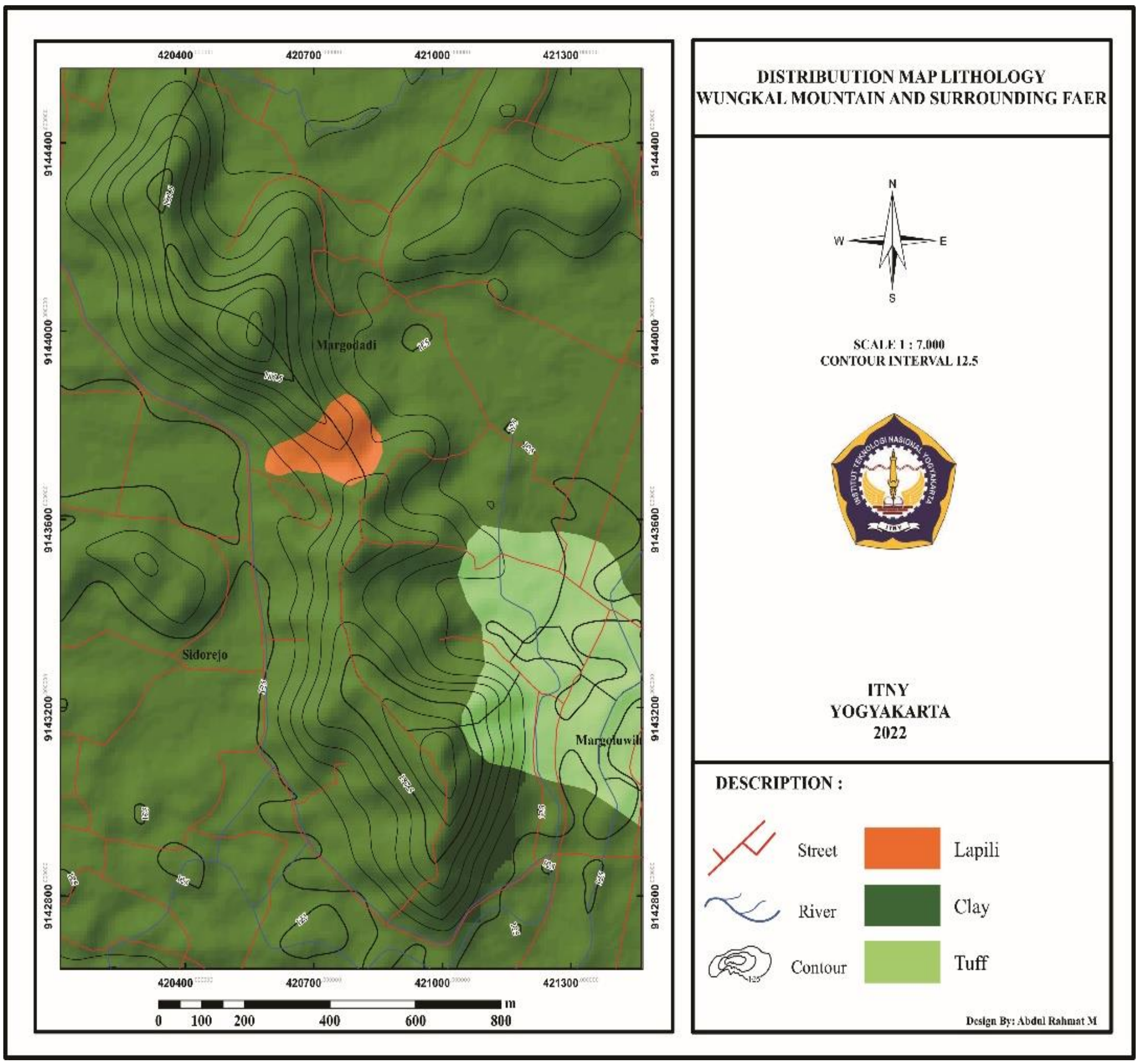

FIGURE 6. Lithology distribution map of Mount Wungkal

Type of soil

The soil types in the study area consist of Latosol, Lithosol and Grumusol (see Figure 7). The most prevalent is the Grumusol soil type. A weathered soil type of igneous rocks and yellow-brown to yellow volcanic material is characteristic of field latosols [12]. Grumusol is characterized by a dark brown soil type due to weathering of tufa rocks. The two soil types that govern landslide vulnerability are the latosol soil types. Latosol is a soil type derived from tuff host rock, volcanic material and weathered breccia, with a characteristic reddish-brown color. A comparison of soil type subparameter data is shown in Tables 5-6.

TABLE 5. Soil type pair comparison matrix and calculation normalization value

Pair Comparison Matrix				**Normalization Value**			
Parameter	Latosol	Lithosol	Grumusol	Latosol	Lithosol	Grumusol	Latosol
Latosol	1	5	2	0.69	1.43	0.67	2.78
Lithosol	0.2	1	2	0.14	0.29	0.33	0.76
Grumusol	0.5	0.5	1	0.14	0.14	0.17	0.45
Total	1.70	6.50	5.00	0.963949843	1.8571	1.1666667	3.9878

TABLE 6. Calculation of score soil types

Parameter	Score
Latosol	0.93
Litosol	0.25
Gromosol	0.15

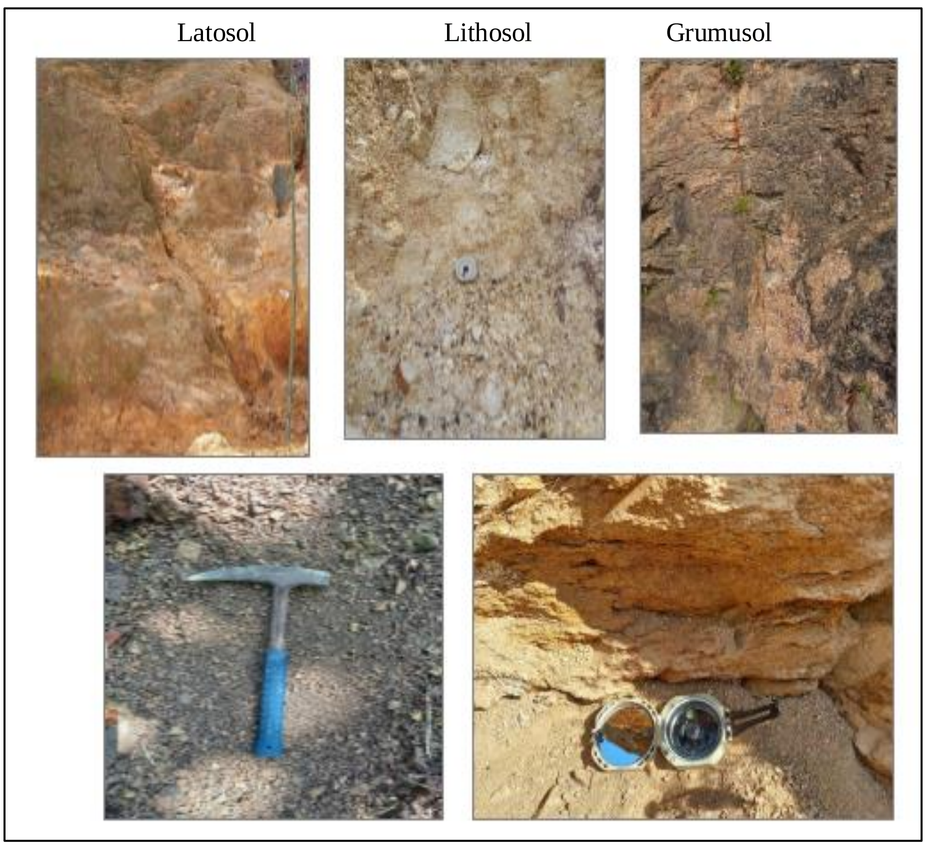

FIGURE 7. Appearance of soil types at the research site

From Table 7, the highest value for the soil type parameter is latosol with a score of 0.93 or a percentage of 93%. The distribution of soil types in the study area is dominated by Grumusol soil types, covering 50% of the study area, as a result of weathering of tuff rock from igneous rock (see Figure 7(a)). This type of soil generally develops in a sloping to hilly topography. Soil texture varies, there is a content of sand, gravel and fertility varies.

TABLE 7. Land use pair comparison matrix and calculation normalization value

Pair Comparison Matrix				**Normalization Value**			
Parameter	Habitation	Forest	Field	Habitation	Forest	Field	Total
Habitation	1	5	2	0.59	1.43	0.33	2.35
Forest	0.2	1	2	0.12	0.29	0.33	0.74
Field	0.5	0.5	1	0.27	0.14	0.17	0.58
Total	1.70	6.50	5.00	0.978	1.857	0.833	3.669

Land Use

The land use of the study area is mainly used by municipalities for settlement, extraction of raw materials for the production of tiles and bricks, fields, paddy fields and forests according to the land use classification [11]. The mine is located in a hilly area with a high landslide rate, as shown in Figure 7(b). A comparison of the land use subparameter data is shown in Tables 8 where the highest value for the land use parameter is habitation, with a score of 0.78.

TABLE 8. Calculation of score and land use weight

Parameter	Score	Percent
Habitation	0.78	78
Forest	0.25	25
Field	0.19	19
Total	1	100

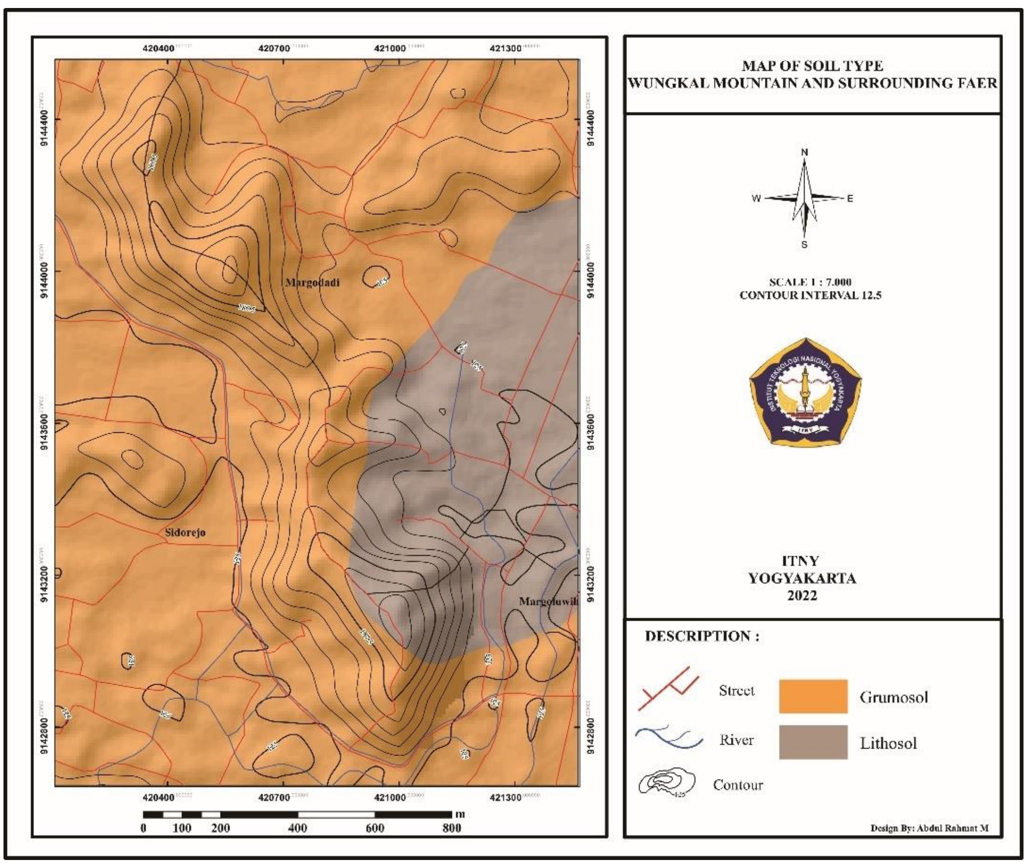

FIGURE 8. Map of soil types in Wungkal Mountain area

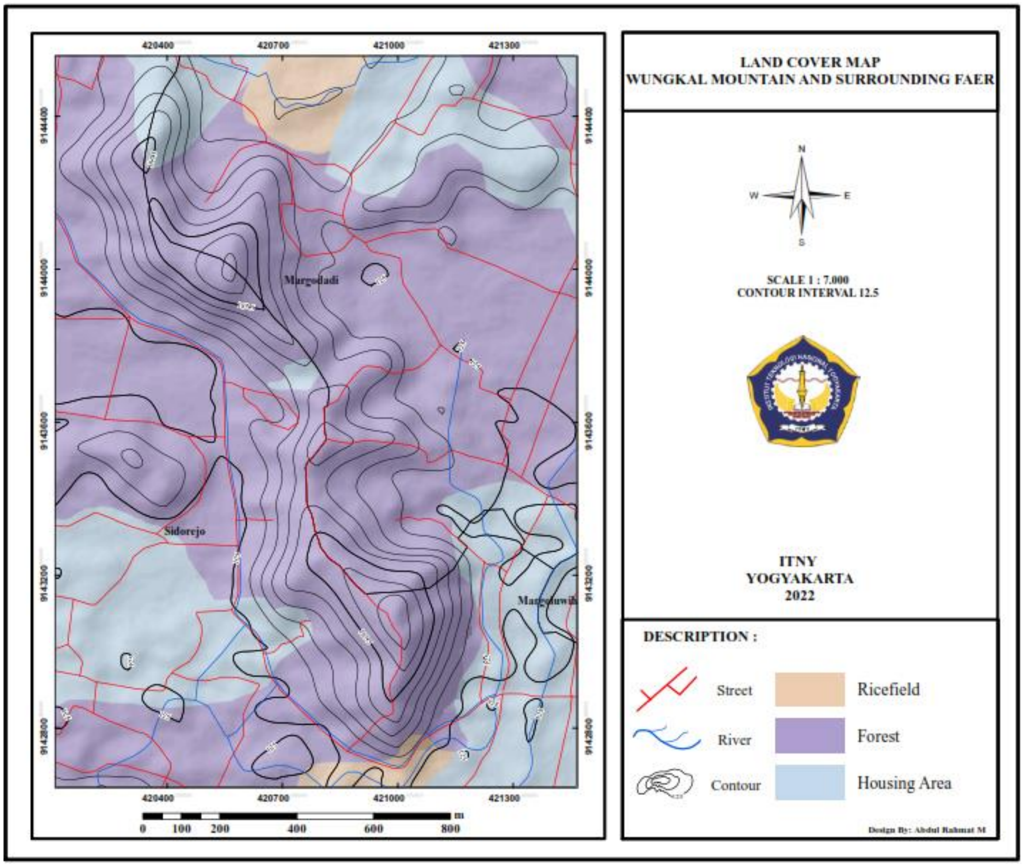

FIGURE 9. Map of land use in the area of Mount Wungkal

Rainfall

Figure 10 shows the rainfall data in the study area which were obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) at Godean District, Sleman Regency, Yogyakarta Special Region. The intensity of rainfall in the research area is divided into 3 levels, namely High (201 – 300 mm) with a percentage of 54%, Medium (151 – 200 mm) with a percentage of 30%, Low (51 – 100 mm) with a percentage of 16% (see Tables 9-10). The highest value rainfall parameter is with a score of 0.54 or a percentage of 54%.

TABLE 9. Rainfall pair comparison matrix and normalized value

Pair Comparison Matrix (mm)				**Normalization Value (mm)**			
Parameter	High (201-300)	Medium (151-200)	Low (51-100)	High (201-300)	Medium (151-200)	Low (51-100)	Total
High (201 – 300)	1	5	2	0.59	1.43	0.33	2.35
Medium (151 – 200)	0.2	1	2	0.12	0.29	0.33	0.74
Low (51 – 100)	0.5	0.5	1	0.27	0.14	0.17	0.58
Total	1.70	6.50	5.00	0.978	1.857	0.833	3.669

TABLE 10. Calculation of score and rainfall weight

Parameter	Score	Percent
High (201 – 300 mm)	0.54	54
Medium (151 – 200 mm)	0.30	30
Low (51 – 100 mm)	0.16	16
Total	1	100

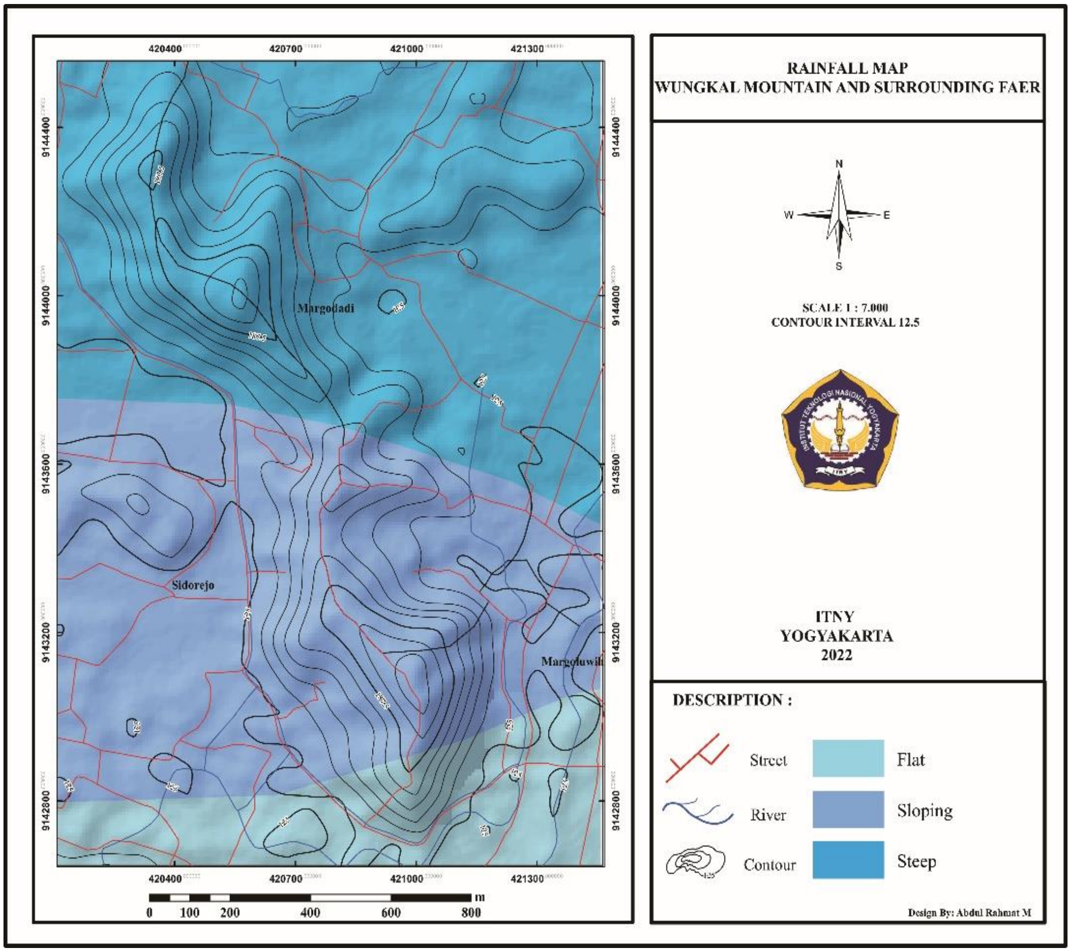

FIGURE 10. Rainfall map of Wungkal Mountain area and

Determination of Weights for Ground Movement Threat Level Parameters

Weights for each parameter are determined using the AHP method. Each parameter is compared to get the parameter precedence relative to other parameters. Parameters with the highest priority scale have the highest weight. As a result of field observation and analysis, it was shown that the sediment movement in the survey area is affected by the rocky depressions that compose the depressions. This is evidenced by the high probability of landslides occurring in the slope conditions and the lithology that composes the slope. The rock quality of the weathered slope is quite high and the angle of the slope is large, which affects the strength of the slope. A comparison of the data for each parameter is shown in Tables 10 and 11.

TABLE 11. Soil susceptibility parameter comparison matrix

Parameter	Slope	Lithology	Land use	Type of Soil	Water Absorption
Slope	1	2	5	4	5
Lithology	0.5	1	0.2	2	2
Land use	0.2	2.0	1	0.5	3
Type of Soil	0.3	0.5	2.0	1	2
Water Absorption	0.2	0.5	0.3	0.5	1
Total	2.2	6.0	8.5	8.0	13.0

TABLE 12. Calculation of eigen values normalization of parameter comparison

Normalization	Slope	Lithology	Land Use	Type of Soil	Water Absorption	Total	Weight	Percentage
Slope	0.47	0.33	0.59	0.50	0.38	2.27	**0.45**	**45**
Lithology	0.23	0.17	0.02	0.25	0.15	0.83	**0.17**	**17**
Land Use	0.09	0.33	0.12	0.06	0.23	0.84	**0.17**	**17**
Type Of Soil	0.12	0.08	0.23	0.13	0.15	0.71	**0.14**	**14**
Water Absorption	0.09	0.08	0.04	0.06	0.08	0.35	**0.07**	**7**
Total	1.00	0.92	0.96	0.94	0.92	5.00	**1**	**100**

Based on the results of AHP processing of landslide control parameters such as slope, soil quality, land cover, rock quality, and precipitation, a map such as Figure 11 shows the likelihood of a potential landslide. This map shows three classes of landslide vulnerability levels, including safe, medium, and vulnerable. The resulting map shows how much potential the area has for landslides. As shown, 50% of research areas are safely classified. Areas classified as "moderate" are located on slopes and have a lithosol soil type, mainly forest use areas, residential areas and industrial mining areas. On the other hand, 15% of the study area is potentially hazard and the location points are distributed from north to south of the study area. The study area has latosol and grumusol soil types and lies in land use areas in the form of forests, settlements and industrial mines, which is a dry field.

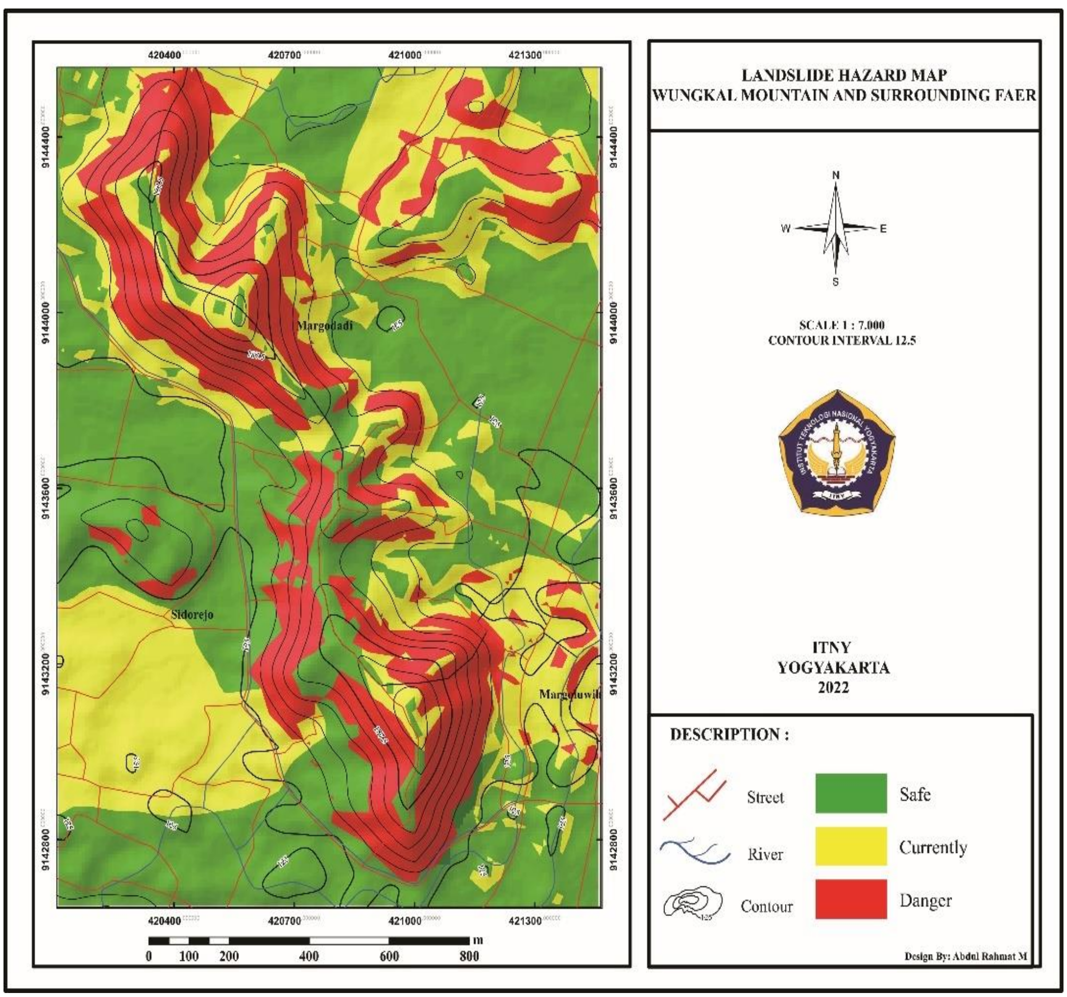

FIGURE 11. Landslide hazard map for the area of Mount Wungkal

CONCLUSION

Soil movements at the study site are driven in some places by large angled slopes and high weathering effects on the lithology. Rainfall data show a preponderance of heavy rainfall over the northern regions last year. The land cover data is dominated by forest, which means that the impact on the surroundings is safety. However, it turns out that there is actually mining activity in the tile and brick raw material industry that can cause flooding during heavy rains. This is supported by water absorption capacity. On the ground, each site with five location points showed an absorption predominance of more than 2 minutes. In conclusion, the results of landslide analysis using the AHP method show that the research area still being safe in landslide-prone conditions because only a few points are forest and mining areas, but have the potential for flooding due to the lack of water absorption in the area's soil. For further research, the accuracy of land movement risk detection can be compared with other methods and measurements.

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