e-ISSN 2580 - 0752

BULLETIN OF
GEOLOGY
Fakultas Ilmu dan Teknologi Kebumian (FITB)
Institut Teknologi Bandung (ITB)

IDENTIFICATION AND ANALYSIS OF LANDSLIDE SOIL VULNERABILITY AS THE BASIS OF DISASTER MITIGATION WITH GEODETIC MEASUREMENT METHODS AND QUANTITATIVE DESCRIPTION

DINDA PRATIWI DWI PUTRI[1], EDIYANTO[2] , RIYAS SYAMSUL ARIF[1], JESSICA ASTRID KARTIKA[2] , CAHYA RISKI FATHUROHMAN[1] , DESSY APRIYANTI[1]

1. Program Studi Teknik Geomatika, Fakultas Teknologi Mineral, UPN "Veteran" Yogyakarta, Jl. Babarsari No. 2, Yogyakarta, Indonesia, Email: dindap.dwip@gmail.com
2. Program Studi Teknik Geologi, Fakultas Teknologi Mineral, UPN "Veteran" Yogyakarta, Jl. SWK (Ring Road Utara) No. 104, Yogyakarta, Indonesia.

Sari – Kabupaten Karanganyar merupakan salah satu kabupaten/kota di Provinsi Jawa Tengah yang sebagian besar wilayahnya berada di sekitar Gunung Lawu dengan struktur batuan merupakan struktur sedimen atau belum mengalami litifikasi. Berdasarkan kondisi geologi tersebut, daerah sekitar Gunung Lawu rentan terhadap bencana hidrometeorologi seperti tanah longsor yang didukung oleh beberapa faktor selain kondisi tanahnya, yaitu curah hujan yang tinggi, kelerengan, tanaman yang membebani, dan atau adanya gejala struktur geologi. Salah satu dusun yang terkena bencana hidrometeorologi tersebut ialah Dusun Jambon, Desa Menjing, Kecamatan Jenawi, Kabupaten Karanganyar. Bencana alam yang menimpa Dusun Jambon 2014 silam menimbulkan keretakan tanah dan kerusakan tempat tinggal. Sebagai bentuk analisis dan mitigasi bencana, pada penelitian ini dikaji kerentanan longsor melalui parameter deformasi menggunakan alat ukur GNSS (*Global Navigation Satellite System*) untuk mengetahui besar dan arah pergerakan longsor. Hasil analisis deformasi berdasarkan alat ukur GNSS menunjukkan hasil ukuran masih memenuhi ambang batas atau tidak terjadi deformasi pada struktur tanah di 7 titik sampel yang diukur. Hal tersebut menimbulkan anomali karena kondisi longsor yang terjadi sangat parah kecuali satu area yang mencakup 1 gereja dan 13 rumah. Oleh karena itu, perlu dikaji lebih lanjut untuk membuktikan penyebab terjadinya longsor melalui parameter lain seperti gejala struktur geologi dan waktu. Hasil penelitian ini diharapkan dapat memberikan rekomendasi area aman di sekitar longsor untuk tetap dipertahankan atau tidak.

Kata kunci: Longsor, Dusun Jambon, GNSS, Geologi, Kemiringan Lereng, Kelurusan Permukaan

Abstract - Karanganyar Regency is one of the regencies/cities in Central Java Province, located around Mount Lawu. The rock structure is sedimentary or has not been lithified. Based on these geological conditions, the area around Mount Lawu is vulnerable to hydrometeorological disasters such as landslides, supported by several factors other than soil conditions, namely high rainfall, slopes, overburdening plants, or symptoms of geological structures. One of the hamlet affected by the hydrometeorological disaster was Jambon Hamlet, Menjing Village, Jenawi District, Karanganyar Regency. The natural disaster that hit Jambon Hamlet in 2014 caused soil cracks and damage to houses. As a form of disaster analysis and mitigation, this study assessed landslide susceptibility through deformation parameters using GNSS (Global Navigation Satellite System) to determine the magnitude and direction of the landslide movement. The deformation analysis results based on the GNSS measuring instrument show that the measurement results still meet the threshold, or there is no deformation of the soil structure at the 7 sample points measured. This caused an anomaly because the landslide happens conditions were very severe except for one area, including one church and 13 houses. Therefore, it is necessary to study further to prove the cause of landslides through other parameters such as geological structure symptoms and time. The results of this study are expected to provide recommendations for safe areas around landslides to be maintained or not.

Key words*: Landslide, Jambon Hamlet, GNSS, Geological, Slope Level, Lineament*

1. INTRODUCTION

Karanganyar Regency is one of the regencies in Central Java Province, which is located around the mountainside of Mount Lawu. The height of Mount Lawu is 3,265 meters above sea level and located in 3 regencies, which are Karanganyar Regency (Central Java), Magetan Regency (East Java), and Ngawi Regency (East Java). Of all the regencies, Karanganyar is one of the areas classified as having frequent landslide disasters in Central Java Province. This can be seen from the average frequency of disasters that occur in the Karanganyar Regency, where landslides had the highest frequency of 300 in the last five years

(Regional Disaster Management Agency of Karanganyar Regency, 2013). One of the areas that were affected by landslides and become the government's concern is Jambon Area, Menjing Village, Jenawi District. It is included in a high landslide-prone area along with several other sub-districts namely Ngargoyoso, Tawangmangu District, Jatiyoso District, Matesih District, Jenawi District, and Kerjo District. (Karanganyar Regency No.1 of 2013 concerning the RT/RW of Karanganyar Regency 2013-2032). So in this study, it is located in Menjing village and the focus of the study is in Jambon hamlet which has a severe impact on landslides.

The area has a complex geological structure due to tectonic activity around Mount Lawu. Based on the Geological Map of The Ponorogo Quadrangle Second Edition (Sampurno and Samodra, 1997), the constituent materials on the Lawu slopes, especially in the study area, are derived from Lawu Lahar units consisting of andesite, basalt, and a little pumice of various sizes mixed with volcanic sand, and a Jobolarangan Breccia unit in the form of a volcanic breccia whose distribution is surrounded by lava deposits. The landslide that occurred in Jenawi was influenced by several hydrometeorological parameters such as rainfall, temperature, wind, and humidity.

Figure 1. Landslide in Menjing Village, Jenawi, 2015.

The landslide that hit Menjing Village like presented in **Figure 1**, Jambon hamlet in 2014 and 2015 caused soil cracks and damage to houses and agriculture. In 2014 there were three landslides, 17 in 2015 there were six, and in 2017 three landslides (BPBD Karanganyar, 2017). The landslide disaster was unevenly distributed in the area, where there was one church and 13 residential houses that were still intact, while the surrounding areas were badly damaged due to landslides. Therefore, morphological and deformation studies use geodetic measurements to determine the main causes of landslides.

2. DATA AND METHODOLOGY

The research area is located in Jambon Area, Menjing Village, Jenawi District, Karanganyar Regency, Central Java Province, Indonesia. This location was chosen because of its track record of landslides that are severe enough to destroy many buildings in the village. Area of research interest presented in **Figure 2**.

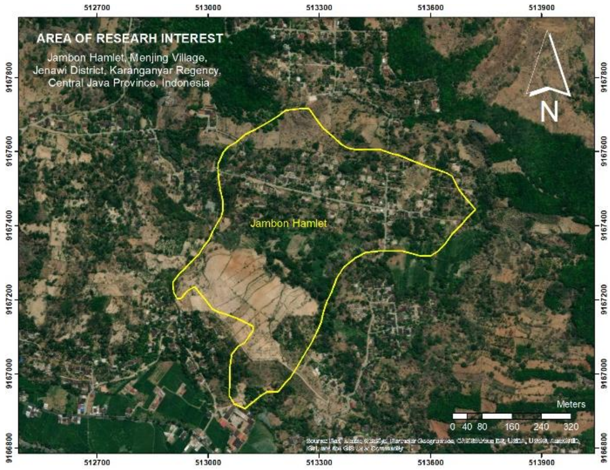

Figure 2. Area of Research Interest

There are two types of data used in this study, that is primary data and secondary data. The primary data is in the form of GNSS (*Global Navigation Satellite System)* measurement data at seven deformation monitoring points, while the secondary data used is Digital Elevation Model (DEM) to analyze the morphology of the research are The software used to process GNSS data is using the compass solution software, which is the default software for GNSS from the ComNav brand, for 3 hours of observation. The time-lapse between epoch one and epoch two is 6 months. The measurement is carried out using the static differential netting method, as for the location in the Jambon Hamlet, Menjing Village, Jenawi District, Karanganyar Regency. where the base condition is stable because it is located on the solid rock under the breccia rock arrangement. The measurement parameters include an open area around an angle of 15 degrees and easily accessible, laying points that are safe and not easily damaged, BM (Benchmark) is made of concrete, for the distribution of points is evenly distributed and the distance between points bm forms an equilateral triangle net with the distance between the base points almost the same.

The method used in this research is divided into four stages in general, that is preparation, data sampling, processing, and analysis stages.

2.1 Preparation

The data needed for conducting research, literature studies and literature review, and research theory are carried out at this stage. This stage consists of selection of data needed for conducting research including data from the results of GNSS measurements and DEM.

2.2 Data Sampling

Data collection is carried out using GNSS measurement. Positioning of GNSS is obtained from tying back through measuring the distance of several satellites whose positions are known so that the position of the observer can be determined. Observations with GNSS technology produce coordinates in the geodetic coordinate system (φ, λ, h), three-dimensional Cartesian coordinates (X, Y, Z), and time parameters. In this study, measurements were made in January and June 2020 at seven control points for monitoring the movement of deformation, the distribution of these control points presented in **Figure 3**.

Figure 3. Distribution of Benchmark.

2.3 Processing

At this stage, data processing of GNSS measurement results is carried out to be tested statistically. In addition, Digital Elevation Model (DEM) data processing is also carried out to produce slope and lineament density maps.

2.3.1 Geodetic Data Processing

After carrying out observation at each point, the next step is to process the results of the GNSS acquisition. The data that has been downloaded from the GNSS receiver is then processed for baseline smoothing and network adjustment. The coordinates generated from the baseline processing are the coordinates in the UTM system. The data in the UTM coordinates have then calculated the value of the horizontal and vertical movement of the deformation that occurs is obtained from the difference in the values of the X, Y, and Z components each time.

2.3.2 Geological Data Processing

In this study, we use a set of secondary data in the form of Digital Elevation Model (DEM) obtained from tanahair.indonesia.go.id provided by BIG (Geospatial Information Agency). DEM is processed using ArcGIS software to determine the slope level of the study area, as well as to identify lineament density which will later be interpreted to see the level of permeability and indications of geological structures.

2.4 Analysis

At this stage, analysis of the results computed from the data processing sequences is carried out.

2.4.1 Horizontal and Vertical Movement Analysis

The deformation monitoring data carried out in January and June 2020 were analyzed to evaluate horizontal and vertical movements through the significance test of different parameters. The significance test for different parameters was carried out to see the statistical significance of the difference in the coordinates of the two parameters. The test equation for the difference in parameter significance is as shown in the following equation (Widjajanti, 2010).

$$T = \frac{X_i - X_{ii}}{\sqrt{\sigma_{xi}^2 + \sigma_{xii}^2}}$$

In this case,
T : value of t count
$t_{f,\alpha/2}$: distribution of t in t-table (t-*student*) with a confidence level of α
x_i : first epoch parameters
x_{ii} : second epoch parameters
σ_{xi}^2 : the standard deviation of the first epoch parameter
σ_{xii}^2 : the standard deviation of the second epoch parameter

2.4.2 Slope Level Analysis

The slope is a value that can provide information on process conditions that affect landforms. The slope of the slope can be used to determine the level of ongoing erosion, as well as the possibility of soil movement in an area. Van Zuidam (1983) classified the slope into several classes, as can be seen in **Table 1**.

Table 1. Slope measure (Van Zuidam, 1983).

Slope	Slope Class
0^0 - 2^0 (0% - 2%)	Flat or almost flat
2^0 - 4^0 (2% - 7%)	Sloping
4^0 - 8^0 (7% - 15%)	Ramps - steep
8^0 - 16^0 (15% - 30%)	Steep
16^0 - 35^0 (30% - 70%)	Steep - sheer
35^0 - 55^0 (70% - 140%)	Sheer
> 55^0 (> 140%)	Very sheer

2.4.3 Lineament Analysis

Lineament is one of the geomorphological elements that represent geological structures. The appearance of the straightness on the surface is reflected by the morphological straightness caused by the relief, such as the straightness of valleys, ridges, and rivers.

All stages of the research methodology in full are presented in the following flow chart in **Figure 4**.

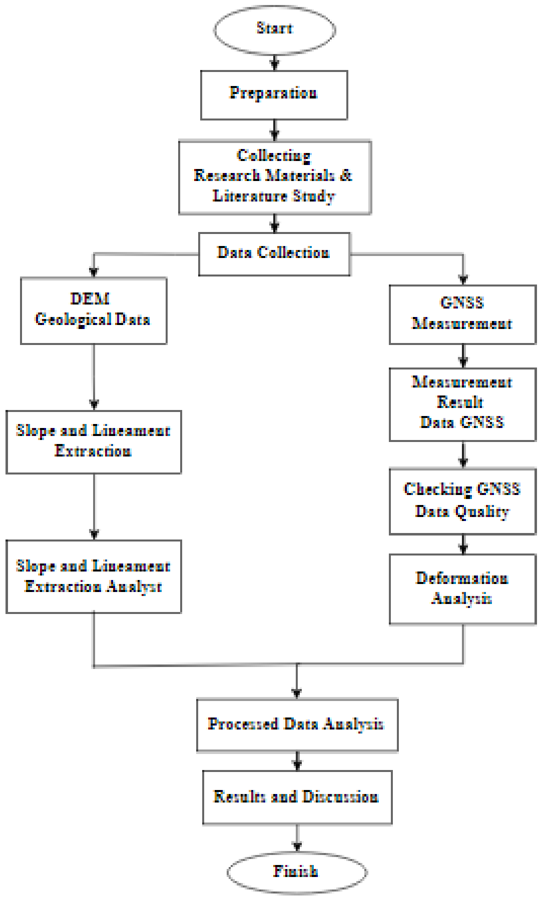

Figure 4. Research Flowchart.

3. RESULTS

The results in this study are divided into horizontal and vertical movements, slopes, and linement density.

3.1 Horizontal and Vertical Movement

The horizontal and vertical movement statistical result against are present in **Table 2** for X, **Table 3** for Y, and **Table 4** for Z.

Table 2. Statistical Result Against X Difference.

No	Test Against X Difference	Test results
BM 1	Base Station	
BM 2	0,050	Not Significant
BM 3	-0,102	
BM 4	0,079	
BM 5	-0,042	
BM 6	-0,016	
BM 7	0,068	

Table 3. Statistical Result Against X Difference.

No	Test Against Y Difference	Test results
BM 1	Base Station	
BM 2	-0,128	Not Significant
BM 3	0,011	
BM 4	0,996	
BM 5	-0,176	
BM 6	1,170	
BM 7	-0,194	

Table 4. Statistical Result Against Z Difference.

No	Test Against Z Difference	Test results
BM 1	Base Station	
BM 2	0,109	Not Significant
BM 3	-0,118	
BM 4	-0,707	
BM 5	-0,022	
BM 6	-0,461	
BM 7	0,056	

The t-table value with 95% confidence level (α = 5%) and at (df,α/2) is 1.96. If the t-count is smaller than the t-table value (t df value, α/2) indicates that the parameter has an insignificant difference. The table above shows that all the test results are not significant for all movement values.

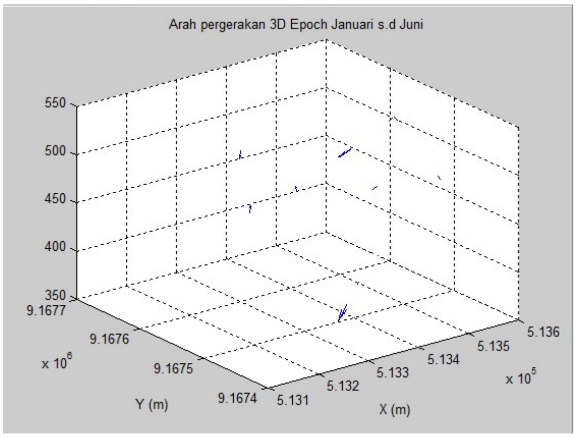

Figure 5. Vectors Deformation.

Figure 5 is a deformation vector resulting from the measurement of GNNS in Jambon hamlet for 2 epochs where it can be seen that the largest deformation vectors are located in BM 4 and BM 6, with the largest shifting point for X values occurring in BM 6 and the largest shifting points for Y and Z values being located in BM 4, but the shift is not so large as to cause landslides and is still in the tolerance stage.

Therefore, the results of the significance test of the different parameters carried out can be stated that there is little movement both vertically and horizontally. So it can be concluded that there is no vertical or horizontal movement in the geometry that is so significant.

3.2 Slopes

Jambon which is located in the middle of Menjing Village has various slopes from 0% – 70% (marked in green – orange) like presented in following **Figure 6**, which is classified as flat – sheer with a slope angle of $0^0 – 35^0$ (Van Zuidam, 1983). It can be seen that the center of Menjing Village has a relatively flat slope and is surrounded by a slope that is ramps – sheer. That ramps - sheer slope is identified as a ridge and classified as prone to erosion and soil movement at a slow speed. The area is indicated on a volcanic slope composed of fine volcanic materials or an erosion field, where the material originates from the activities of Mount Lawu in the southeast of this research area.

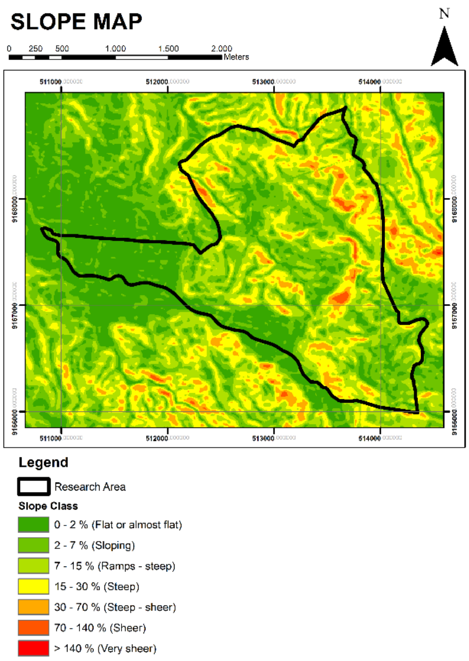

Figure 6. Slope map in Menjing Village.

3.3 Lineament Analysis

The ridges and valleys are the two morphologies observed as the basis for lineament withdrawal. The existing ridge pattern is divided into two, namely parallel and turned ridge patterns. This ridge pattern can be interpreted as a result of endogenous forces in the form of tectonic activity. The sharp V valley is associated with ramps-sheer slopes, so vertical erosion (towards the riverbed) can occur very strongly because it is influenced by tectonic. Lineaments are drawn manually and generate major lineaments for general analysis. The dominant lineament direction is Northwest - Southeast. The existence of this Northwest - Southeast lineament same as the relative direction of the Lawu Fault which is regionally in the southeast of the study area. The visualization of lineament analysis can be seen in **Figure 7**.

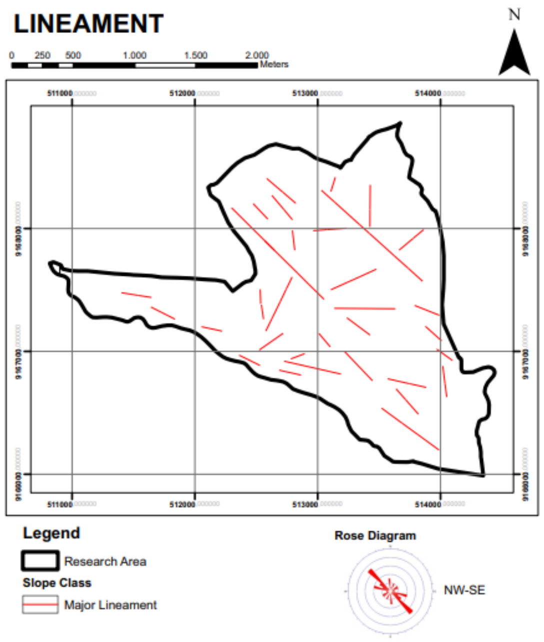

Figure 7. Major lineament in Menjing Village.

4. DISCUSSION

Based on the results of GNSS processing and the analysis of horizontal and vertical movements that have been carried out, it shows that there is no geometric horizontal or vertical movement from January to June 2020. This is shown by the t-count result which is smaller than the t-table value (t-value df, a /2), so that the results of the significance test for different parameters are not significant for all points. In addition, the immobile point is also caused by the standard deviation value of each point which is greater than the difference in point values between the two epochs.

Slope analysis shows that the study area has various slopes with a flat – sheer slope, which indicates that the area is composed of fine volcanic materials originating from Mount Lawu. This is in line with regional geological maps which show that this area is composed of volcanic breccias surrounded by lava deposits. Landslides that occur are not only triggered by slopes that are classified as prone to erosion and soil movement but also indications of the constituent material in the form of unlithified sediments. The pattern of parallel and curved ridge lineaments and sharp V valleys is interpreted as the result of endogenous forces in the form of tectonic activity. The existing valley morphology is associated with one of them with steep slopes, so that vertical erosion can occur. The presence of a line with a Southwest-Northeast direction is the same as the relative direction of the Lawu Fault, which may affect endogenous activity in the study area. In addition, the Northwest - Southeast lineament direction are possible interpreted as a minor faults whose presence needs to be further identified.

Landslides occur due to deformation and geological phenomena that affect them. However, the landslides that occur are not evenly distributed in the area. There is 1 church and 13 residential houses that are still intact, while the surrounding area was badly damaged due to landslides. This anomaly is in line with the anomaly resulting from the analysis of geodetic measurements and surface morphology analysis. If seen from the lineament analysis, the Jambon Area in the middle of Menjing Village, can be interpreted that in this area there is an uneven distribution of lineaments, which these lineaments can indicate a geological structure. The area that did not experience landslides was interpreted as not a deformation zone and built above the Jobolarangan Breccia Unit, while the landslide area was interpreted as being in a deformation zone with a strong stress effect and built above the Lawu Lahar Unit.

The results of GNSS measurements which

DOI: 10.5614/bull.geol.2022.6.2.4

show no horizontal and vertical movements even though the area is prone to landslides can be caused by several reasons, one of which is when the GNSS measurements were carried out on epoch one to epoch two the soil condition at the measurement location was stable from landslides. This is supported by news on the Karanganyar BPBD website in 2015 which states that the last landslide in the research area occurred on March 23, 2015. After that year there have been no more landslides so it is very possible in the measurement range from January to June 2020, there is no 3D movement. geometrically. In addition, the absence of movement in the results of GNSS observations can also be caused by the time difference between the two is too close. From this discussion, based on geological analysis, Jambon Hamlet is prone to landslides, although the results of geodetic measurements from the 2 epochs measured do not show any shifts as a form of disaster mitigation, periodic deformation monitoring, or in-depth research through geological structure analysis and subsurface measurements as preventive measures can be carried out.

5. CONCLUSION

Based on the results of data analysis and discussion, it can be concluded that:

1. There is no vertical or horizontal movement of soil from January - June 2020 from the results of the GNSS measurement, which is shown by the results of statistical analysis that reflect that the area is stable in the observation period.
2. The area that did not experience landslides was interpreted as not a deformation zone and built above the Jobolarangan Breccia Unit, while the landslide area was interpreted as being in a deformation zone with a strong stress effect and built above the Lawu Lahar Unit.
3. Areas that have experienced landslides can be maintained and safe buildings built if the buildings built are on a solid layer of soil such as the Jobolarangan Breccia Unit. Construction of buildings need to pay attention to layers of rock to avoid landslides.
4. The combination of spatial and geological analysis can analyze soil vulnerability and assist in making policies for landslide disaster mitigation, one of which is through periodic deformation monitoring as a preventive measure for disasters in Jambon Hamlet, Menjing Village, Jenawi, Karanganyar Regency.

ACKNOWLEDGMENT

The authors thank to Geomatics Engineer UPN “Veteran” Yogyakarta for support and funding this research. Also thank to all Jambon hamlet residents who have been willing to help in this research.

REFERENCE

Naryanto, H. S. (2011): Analisis Risiko Bencana Tanah Longsor di Kabupaten Karanganyar, Provinsi Jawa Tengah, Jurnal Dialog dan Penanggulangan Bencana, 2(1), 21-32.

Prawiradisastra, S. (2012): Analisis Morfologi dan Geologi Bencana Tanah Longsor di Desa Ledoksari Kabupaten Karanganyar, Jurnal Sains dan Teknologi Indonesia, 10(2).

Ramadhani, N. I., & Idajati, H. (2017): Identifikasi Tingkat Bahaya Bencana Longsor, Studi Kasus: Kawasan Lereng Gunung Lawu, Kabupaten Karanganyar, Jawa Tengah, Jurnal Teknik ITS, 6(1), C87-C90.

Sampurno, Samodra, H. (1997): Geological Map of The Ponorogo Quadrangle Second Edition.

Toyib, T., Sukiyah, E., Haryanto, A.D. (2020): Analisis Kerapatan Kelurusan (Liniament Density) Untuk Pendugaan Zona Permeabilitas di Daerah Gunung Patuha, Padjadjaran Geoscience Journal, Vol. 4, No. 5, Oktober 2020: 393-400.

Widjajanti, N., 2010, “Deformation Analysis of Offshore Platform using GPS Technique and its Application in Structural Integrity Assessment”, *Ph.D Disertasi*, Universiti Teknologi PETRONAS, Malaysia.

Zuidam, R. A. V. (1983): Aerial Photo-Interpretation Terrain Analysis and

Geomorphology Mapping, ITC: Smith Publisher The Hague.
Laporan Singkat Pemeriksaan Gerakan Tanah Di Kecamatan Jenawi, Kabupaten Karanganyar, Provinsi Jawa Tengah, retrieved from web site : https://vsi.esdm.go.id/index.php/gerakan-tanah/kejadian-gerakan-tanah/1742-laporan-singkat-pemeriksaan-gerakan-tanah-di-kecamatan-jenawi-kabupaten-karanganyar-provinsi-jawa-tengah. Accessed 22 December 2021.