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# Landslide Susceptibility Assessment Using Geographic Information System (GIS) Application of Putat Area, Gunungkidul, Yogyakarta, Indonesia

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**Abstract**. Gunungkidul is located in Central Java Province, Indonesia which is vulnerable to geological hazard such as floods and earthquake. However, it is also susceptible to landslide in some areas of Gunungkidul which contributes to damage and loss. The study area is located in Putat Area of Gunungkidul with the area covered of 25km$^2$ which aligned along latitude 7° 51' 04.35''S to 7° 51' 04.35''S and longitude 110° 30' 58.15''E to 110° 33' 41.72''E. This research aims to produce a landslide susceptibility map. The factors that triggered the landslide in Gunungkidul, Special Region of Yogyakarta such as rainfall intensity and earthquake were also analysed. The parameters that caused the occurrence of landslide were determined and the landslide susceptibility map was produced using Weightage Overlay Method (WOM) in ArcGIS software. Results showed that the susceptibility map was classified into three zones which is low, moderate and high zone. The factor that triggered the landslide were identified which is heavy rainfall intensity and earthquake. As a conclusion, the ability to detect landslide susceptibility lead to a better understanding of landslide mechanisms for the research area, thus leading to an enhanced identification of the most likely failure sites within a landslide-prone area.

## 1. Introduction

Indonesia is very complex as it is the meeting point of some tectonic plates and lies on the Ring of Fire Pacific which the Pacific plate and the continent plate of Indo-Australia pushed down below the Eurasian continental plate [1]. A complex geological setting formed as the tectonic plates in the Indonesian region move actively against each other.

Landslide is natural disaster which occurs frequently in the mountainous region of the world and causes loss and life property. It can cause a lot of damage and loss. Nearly 600 people are estimated to be killed worldwide every year due to slope failure [2]. There are two fundamental aspects that can cause the occurrence landslide which is human and environmental factor [3].Mass movements are generally harmful and fatal triggered by the high population densities [4]. Although Indonesia is one of the most vulnerable countries with experience of natural hazard such as landslide, in many regions, preparation and mitigation activities are not functioning well. These activities, however, are needed to reduce the geohazard effect.

In Yogyakarta, most of the disaster come simultaneously that may started with earthquake, then landslide with flood together, especially in 2017 where it was declared as a state of emergency. The landslide may be triggered by the earthquakes and high intensity of rainfalls especially in the southern mountains area. Most of the cases recorded worldwide, landslide is one of the most widespread natural hazards that happen after earthquake. Therefore, Java was listed as one of the most susceptibility region for landslides, especially in the southern mountainous areas.

Many approaches can be used in GIS methods in generating landslide susceptibility map. From the previous study, the spatial data were organized in GIS SPRING software [5] and calculations related to the computation of probabilistic methods performed using MATLAB software [6]. By performing both methods, it is possible to determine the slope failure by producing a study area slope inclination maps.

Shahabi & Hashim [7] used the GIS-based statistical model for generation of landslide susceptibility mapping using GIS and remote sensing data, at their study area. Their study area located at Cameron Highlands and ten factors including slope, aspect, soil, lithology, NDVI, land cover, distance to drainage, precipitation, distance to fault and distance to road were extracted from SAR data, SPOT 5 and WorldView-1 images. After calculation and determination, the maps are then constructed between factors identified using multiple models including analytical hierarchy process (AHP), weighted linear combination (WLC) and multi-criteria spatial evaluation (SMCE) models.

Rodeano et al. [8] used Weightage Overlay Method (WOM) and Landslide Susceptibility Level (LSL) map to produce a landslide hazard zoning map along Genting Sempah to Bentong area, Pahang. The study weightage the most causative factor such as land use, drainage, distance from lineament, soil lithology and geomorphology. Those parameters were retrieved from the topographic database and were classes into landslide susceptibility level from very low to high which reflects the possible occurrence of landslide in the study area. Heavy rainfall triggered the landslide by changing the land and soil intensity. From all the data, layering method by raster input was weighted.

## 2. Methodology

To produce the landslide susceptibility map, the secondary data collection of topographical data, Digital Elevation Model (DEM) and Digital Elevation - Shuttle Radar Topography Mission (SRTM) year 2016 downloaded from U.S Geological Survey are essential. The parameters that caused landslide were used such as slope, lithology, slope, aspect, vegetation, landuse and drainage density in order to produce the landslide susceptibility map. The selection of parameters was followed Rodeano et al. [8] and parameters were then generated from DEM data of year 2018. The average weightage score of each parameter were selected to determine the landslide susceptibility area. An overlay and raster calculation was then applied in GIS to generate expected result of landslide susceptibility map.

The study area location covers almost 25 km$^2$, which aligned at latitude 7° 51' 04.35''S to 7° 51' 04.35''S and longitude 110° 30' 58.15''E to 110° 33' 41.72'' E. Figure 1 shows the base map of the study area. Field study was conducted at several places where landslide have occurred which is at 110°32'27.6''E 7°51'37.7''S (RT 11, Dusun Kepil), 110°30'58.5''E 7°51'49.6''S (Putat II) and 110°32'34.5''E 7°52'53.0''S (Jalan Jogja – Wonosari). The actual phenomenon and field condition causing landslide were observed based on the identified parameter in order to support the result produced using weighted overlay method, thus the landslide vulnerable area can be estimated. At the 110°32'27.6''E 7°51'37.7''S (RT 11, Dusun Kepil), the slope is 13° gradient which categorized as moderate slope, the landslide that occurred started with the failure at the upper part of the cliff and the residue flowing downwards to the gravity. The lithology of the area is weathered lava, and not covered by vegetation. Due to high precipitation of continues rainfall, the porosity of soil is filled up, until it can no longer hold the water, then sliding downwards. The second area, which is at 110°30'58.5''E 7°51'49.6''S (Putat II), it is also have the lithology of weathered lava of Nglanggeran Formation, with moderately steep slope of 24°. The lava have undergoes chemical and biological weathering. The third area which is 110°32'34.5''E 7°52'53.0''S is located at KM 27 Jalan Jogja – Wonosari, occurred during heavy rain in 2017, although its slope is moderately steep with 18° gradient. The lithology is sedimentary rock of sandstone carbonate. Due to high concentration of rain, the stability of rock becoming weak, and concrete on the upper layer falls.

### 2.1. *Lithology*

Lithology map is one of the parameter used in determining the susceptibility of landslide occurrence in the study area. The differences in lithology played an important role where the area are prone or low vulnerability to landslide. The lithologic condition and formation differentiate the characteristics of rock and soil. The lithology of the study area shown in Figure 2 indicates the distribution of rocks from oldest to youngest from the northern to southern area. The Northern area was dominated by the Nglanggeran Formation consist of breccia unit which is pyroclastic and epiclastic rock. The area covered with Nglanggeran Formation of breccia unit was mostly exposed and weathered. The other unit of Nglanggeran Formation which is lava unit, consist of basaltic and andesite, was distributed on the upper layer of breccia unit and interfingering to the middle part of the study area with Sambipitu Formation. Sambipitu Formation were divided into two unit which is sandstone and claystone unit, were distributed on the center area of the study. It is also interfingering with the formation on the southern part of the study area, which is Oyo Formation of sandstone carbonate unit. To the southern south-east area, distribution of limestone unit of Ngalang member of Oyo Formation with alternation of packstone and wackstone was found.

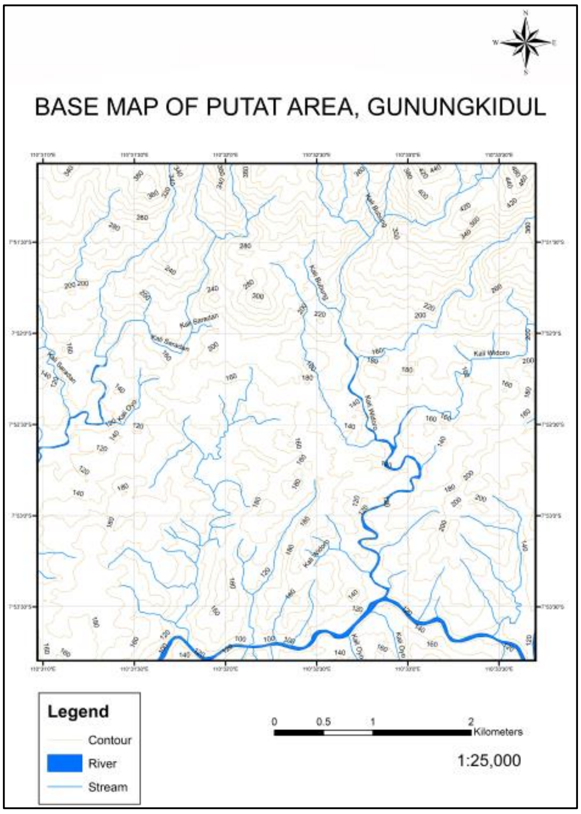


**Figure 1.** Base map of the study area

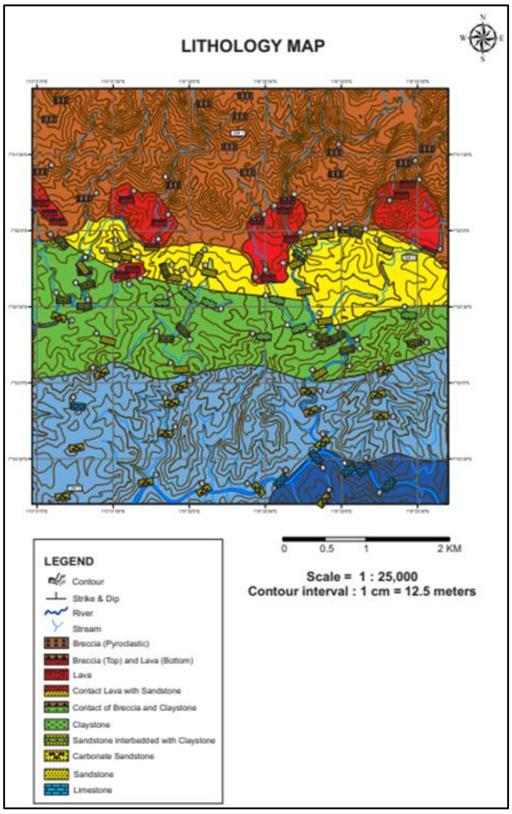


**Figure 2.** Lithology map of the study area

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### *2.2. Slope*

Slope is an important parameter in determining the landslide susceptibility in the study area. The slopes were classified into six categories according to works by Tan [8]. The study area was divided into two mountainous area on the north named Baturagung and flat area on the middle to the south of the Wonosari Plateau. The Northern side of the study area were dominated with steep to very steep slope with 25 – 35º and 35º and more, while the southern part is moderate to gentle slope. Figure 3 shows the slope map of the study area.

### *2.3. Aspect*

Aspect map were generated from DEM data. The aspect map was divided into 8 classification of slope direction that due to the North. The parameter were used to observe the direction of slope which resulting the differences in gravitational force. The instability and orientation of slope can be identified. It is measured counter clockwise in degrees from 0 (North) to 360 degree (due to North) as shown in Figure 4. The aspect direction results in several slope direction classes such as Flat, North, Northeast, East, Southeast, South, Southwest, West, Northwest and North. The direction of slope faces with respect to the sun (aspect) has influence to vegetation and construction because of exposure to wind.

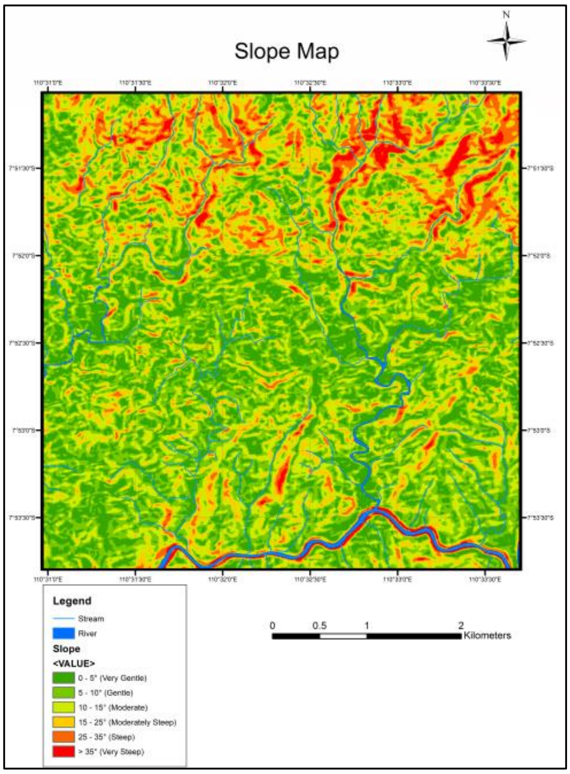


**Figure 3.** Slope map of the study area

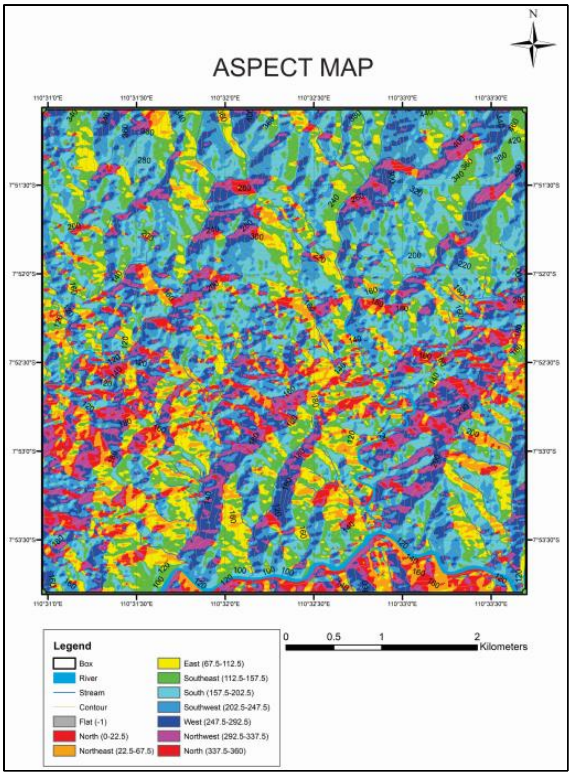


**Figure 4.** The aspect map

### *2.4. Vegetation and Landuse*

Land use map were produced from the secondary data collected from Kementerian Agraria & Tataruang or Badan Pertahanan Nasional year 2017. Most of the lands were used for plantation such as paddy field, eucalyptus oil tree (pokok kayu putih), grassland, garden and some of them were covered by forest. Besides, settlement areas which have medium population density are allocated in the Desa Putat area. Land cover indicates the stability of the slopes. Human activities can accelerate and have strong influence in the occurrence of landslides. The interference of human in natural land cover such as slope deforestation, removal of slope support in road cuts, alteration of surface runoff paths have become factor triggers for the manifestation of landslides and create damage to the environment. Human activities made can change the flow of groundwater through destruction of vegetation by logging, fires or droughts, and increased the risk for landslides. Figure 5 shows the landuse and vegetation maps of the study area.

### *2.5. Drainage Density*

Drainage density refers to total length of the streams and river in a drainage basin divided by the total area of the drainage basin. The vulnerable area of landslide to occur can be determined in extent of debris flow and seepage due to rainfall infiltration. Drainage density map were extracted from DEM data in ArcGIS.The drainage density was classified into three categories which are low, moderate and high as shown in Figure 6. High drainage density indicates the high possibilities of the landslide occurrence. This is because, the surface runoff is high.

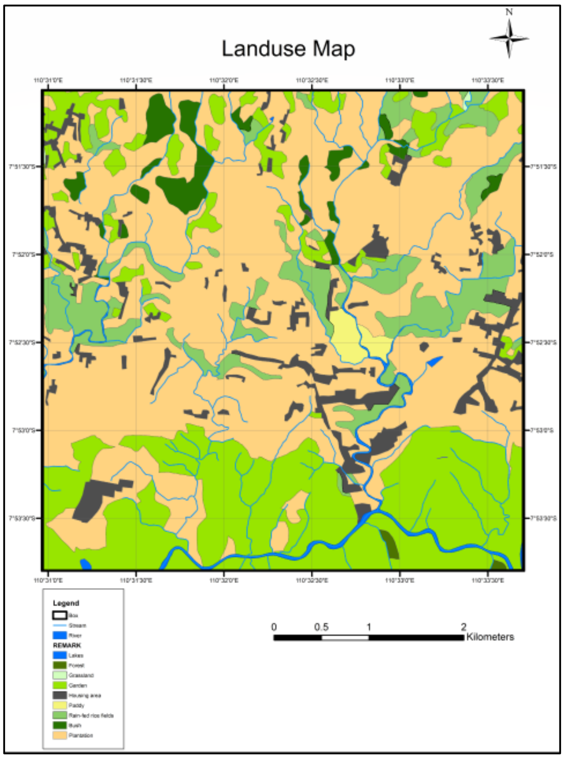


**Figure 5.** Landuse and vegetation map

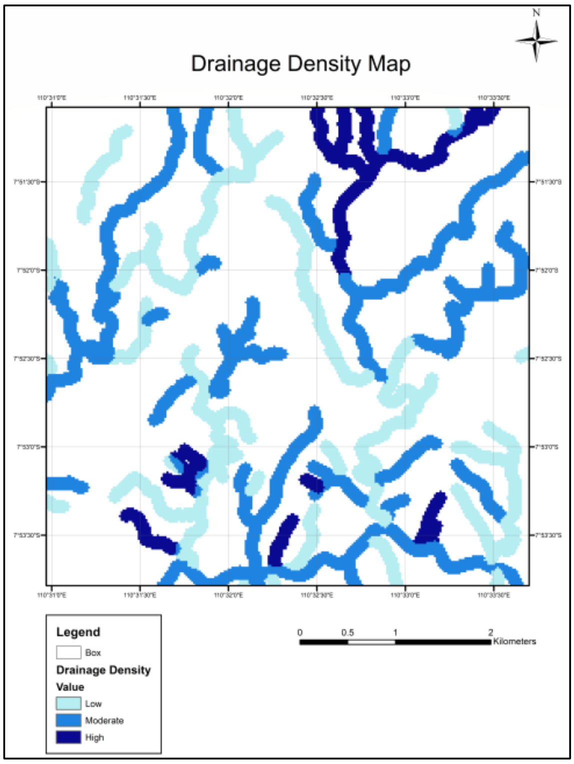


**Figure 6.** Drainage density map

### *2.6. Landslide Susceptibility Analysis*

All selected parameters were converted into raster data set before the landslide susceptibility map can be produced. These raster data then were reclassified its weightage. These different methods apply different rating system as well as the weights, which are highly dependent on study area, and the controlling factors. Therefore, these weights and ratings play a vital role in the preparation of susceptibility maps using any method. Many of the works for LSZ mapping in Himalayan regions employ rating system based on the expertise experience, which tend to be dependent on the knowledge of expert or mapping geomorphologists and less on the learning capabilities from the data provided [10].

The landslide susceptibility map was prepared using weightage overlay method using GIS application. The parameters of landslide causative factor that were chosen are lithology, slope, aspect, vegetation & landuse and drainage density. The parameters were assigned with weightage respectively and the sum of all factor were equal to 100% and using the formula:

$$S = \frac{\Sigma\, wisij}{\Sigma\, wi} \quad \text{(Equation 1)}$$

It is important to reclassify the data in order to generate the landslide susceptibility map using the weightage overlay method as shown in Table 1.

**Table 1.** Raster datasets and value of influence

| No | Raster Datasets | Influence |
|---|---|---|
| 1 | Lithology :<br>Lava<br>Volcanic Breccia<br>Claystone<br>Sandstone<br>Sandstone Carbonate<br>Limestone | 25 |
| 2 | Slope :<br>0 - 5 º<br>5 - 10 º<br>10 - 15 º<br>15 - 25 º<br>25 - 35 º<br>> 35 º | 25 |
| 3 | Aspect :<br>North-Facing (337.5 – 22.5)<br>North-East (22.5 – 67.5)<br>East-facing (67.5 – 112.5)<br>South-East (112.5 – 157.5)<br>South-facing (157.5 – 202.5)<br>Southwest-facing (202.5 – 247.5)<br>West-facing (247.5 – 292.5)<br>North-West (292.5 – 337.5) | 10 |
| 4 | Vegetation & Land use :<br>Lakes<br>Forest<br>Grassland<br>Garden<br>Housing area<br>Paddy<br>Rain-fed rice fields<br>Bush<br>Plantation | 15 |
| 5 | Drainage density :<br>Low (0 – 455)<br>Moderate (455 – 911)<br>High (911 – 1367) | 25 |
| | TOTAL | 100 |

## 3. Results

Figure 7 shows the landslide susceptibility maps of Putat area and its surrounding. From the maps, the majority of the study area has a moderate susceptibility to landslide with 75% of the study area. 15% of the study area consists of low susceptibility towards landslide while 10% is high susceptibility to landslide hazard.

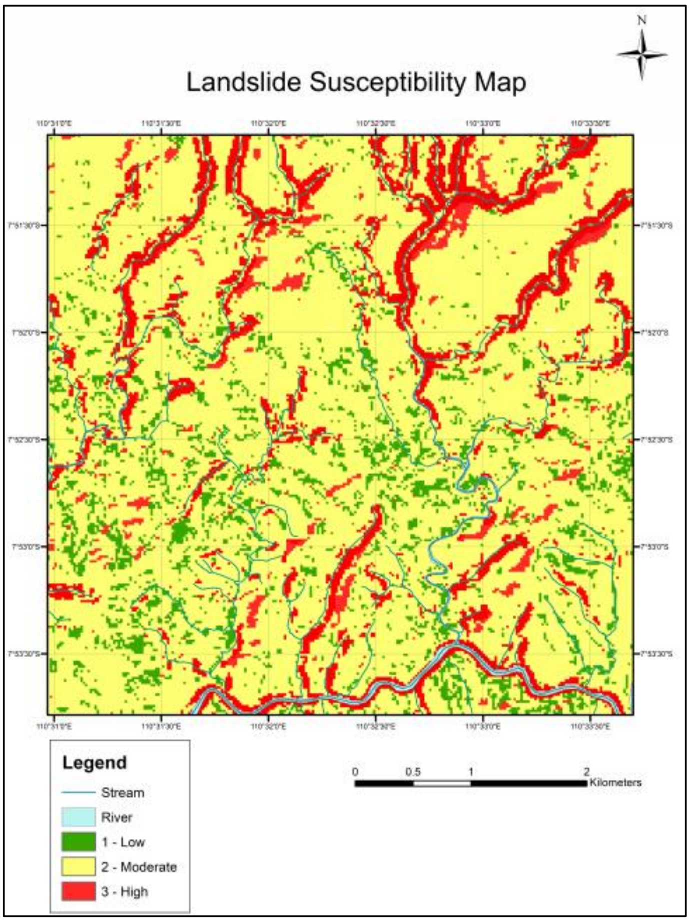


**Figure 7.** Landslide Susceptibility Map of the Putat Area

**Table 2.** Susceptibility of landslide hazard in the study area

| Susceptibility Class | Risk | Area Percentage (%) |
|---|---|---|
| Low | 0 – 50% | 15 |
| Moderate | 50 – 75% | 75 |
| High | > 75% | 10 |

Table 2 shows the susceptibility class for the landslide hazard in the study area. Slope, lithology and drainage density plays an important role and becoming the parameters that highly influence in landslide susceptibility analysis. Slope with steeper angle has higher the tendency for landslide to occur. The lithology also influences the landslide as the rock and soil that formed in the area have different porosity and void. The intensity of drainage density shows that the hydrological factor can cause landslide as most of the high tendency to occur landslide occurs along the river and stream. Vegetation, land use and aspect moderately influence the landslide phenomenon.

By referring to the landslide susceptibility map, the landslide is more vulnerable along the stream and river. This is probably due to the moderate to high stream density. It shows in the northern area that Nglanggeran and Patuk areas with moderately steep to very steep slopes, with volcanic breccia and lava lithologies also have medium to high landslide susceptibility. Landslides easily occurred when weathered lava rocks area became soil with bedrocks at the bottom. The surface exposure of lava contributes to weathering compared to the rock buried beneath the surface. Wind and water become weathering mechanism that creates instability to the soil. Nglanggeran Formation's weathered lava has plenty of voids and soil pores.

When heavy rainfall pouring in the study area, it filled the porosity between the soils. When the bottom layer of interflow is bedrock, the excessive amount of water flows and caused rotational debris slide. The failure of the land structure caused sliding of earth mass. The heavy rainfall and earthquake triggered the landslide to occur especially at the northern part with high elevation and steep slope. Other than that, at the southern part of the study area, it shows high potential of landslide especially along Oyo River. The lithology of that area is dominated by sandstone carbonate and limestone. Most common landslide occurs at limestone and sandstone although the areas were low elevation. The stream flows actively eroding the angle of the slope in the Oyo River basement and loosing soil and rock strength. Thus, the areas were identified as vulnerable to landslide.

## 4. Conclusion

In the study area, rainfall intensity and earthquake is identified as the main factor that triggered landslide to occur every year. Excessive rainfall can triggered landslide especially in an area with thick and weathered soil. When rainfall poured intensely and filled the porosity and void in the soil, it leave the excessive amount of water that slides through the bedrocks, causing landslide. Clay with high plasticity leading to high pore pressure in the soil with small shear angle will cause a landslide [1].Earthquake can trigger the mass movement of soil. The earthquake and landslide cause destructive natural disaster where the rapid shaking of the earth breaks the rocks at underground and steep slope. The study area is near to major fault such as Opak fault, Bunder fault, Kembang fault and Ngalang fault. The movement of fault may be less an inch a year but causing earthquake. In this study, the landslide susceptibility map of the study area was generated using most causative factors such as lithology, slope, aspect, vegetation & land use and drainage density. By using weighted overlay method in ArcGIS, a susceptibility maps was generated and reclassified into three classifications which is low, medium and high potential of susceptibility to landslide. Generally, the study areas were vulnerable to landslide with 10% of low, 15% of high, 75% of medium susceptibility. Although Indonesia is a country that always faces the geohazard, in many regions, like Gunungkidul, mitigation activities are not working well. The high geohazard case reported and potential area like Desa Putat, Desa Nglegi and Desa Gedangsari has Early Warning System (EWS). EWS help in monitoring and anticipating landslide. It is one of the mitigation systems done in the study area. By doing this research, the lack of awareness of the villagers can be reduced as the prediction of potential susceptibility area was done. With accuracy of the map produced, it will help any decision makers, contractors and local authorities in mitigation and disaster planning. Local authorities may use it in implementing policies and strategies that aim to mitigate landslide hazards. The decision of any development after spatial planning can be considered especially in high risk area.

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