Determination of slope susceptibility in hydrothermally altered rocks region with a case study in wonotirto district, blitar regency, east java province, indonesia

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Abstract. The significance of slope susceptibility study in hydrothermally altered area is to determine which area that geological landslide hazard is potentially occurred. This study is aimed to develop a geological hazard map based on overlaying of slope data and types of hydrothermal alteration, with the case study in Wonotirto district, Blitar regency, East Java province. Wonotirto district lies on a high topographic terrain covered up by hydrothermally altered volcanic rocks. To achieve these aims, this study was performed a suite of research methods, which are conducted through four work stages including geological mapping and slope observation, sampling, laboratory analysis and data interpretation. Slope data measurement is based on DEM data and verified in the field. Laboratory analyses consist of petrography, XRD (X-Ray Diffraction) and geomechanical properties analysis for the representative samples. The hydrothermal alteration occurred in study area consists of 4 (four) alteration types i.e. silicification, advanced argillic, argillic and propylitic alteration. Overlaying of slope data, geomechanical properties of rocks and the provided alteration map by using ArcGIS software leads the determination of slope susceptibility of the area. The area covered by extensive argillic-altered rocks shows highest slope susceptibility. On the map, the high slope susceptibility places on the northernmost sector of the study area. Meanwhile, the moderate slope susceptibility area occupies the central part of the map and the southernmost part has the lower slope susceptibility. Argillic altered rocks contain abundant clay minerals such as smectite and illite. Smectite, particularly, is a clay mineral type which has high swelling potential index. The abundantly presence of the clay minerals in the altered rocks may trigger the formation of geological landslide failure/hazard in the region.

1. Introduction
Tropical countries included Indonesia intensively undergo rocks weathering that further will be a cause of geological hazard such as landslide. As well as rocks weathering, the hydrothermally altered rocks could cause a landslide. The study area is Wonotirto district, Blitar regency, East Java province, Indonesia. The area becomes fascinating to research because it lies on a high topographic terrain and it’s covered up by a hydrothermally altered volcanic rocks. Previous study in Kasisihan District, Pacitan Regency, East Java explained that clay minerals such as smectite/illite or mixed-layer minerals triggered the landslide occurrence [1]. The objective of this study is to develop a geological hazard map based on overlaying of slope data and types of hydrothermal alteration, with the case study in Wonotirto district, Blitar regency, East Java province.
Southern Mountain zone, where the study area takes place, is one of geologic terrain of East Java province which the tertiary volcanic rocks are exposed. This zone extends from Parangtritis, Special Region of Yogyakarta to Ujung Purwo, East Java [2][3]. The oldest exposed rock units (Mandalika formation) in study area is volcanic rock with ages ranging from late Oligocene to early Miocene. Mandalika formation is composed of porphyry andesite with intercalated tuff and polymic breccia. The younger rock which intruded Mandalika formation is identified as Dacite. The hydrothermal alteration which mostly covers the study area is generated from the younger intrusion and altered the Mandalika formation. Later on, within middle Miocene – late Miocene, unconformably lied Wonosari formation. Wonosari formation consists of grainstone (clastic limestone) [4].

2. Methods
We collected the rock samples during fieldworks which had been held in January 2019. Total of 18 rock samples were analyzed using petrography, X-Ray Diffraction, and point load test to obtain the rock strength. The result of petrography and X-Ray Diffraction analyses show types of minerals, both primary and secondary minerals, which composed the rock [5][6][7]. Meanwhile, the point load test provides information which rocks will give a big impact to geological hazard. All laboratory analyses had been carried out in Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada.

We also processed raster imagery of study area to create slope analysis map by using ArcGIS. To create the slope failure susceptibility map, we integrate the slope analysis map and the alteration map of study area.

3. Result and Discussion
We have arranged comprehensive laboratory analyses such as petrography and XRD (X-Ray Diffraction) to determine the type of alteration (Figure 1). Based on mineral assemblages, there are 4 types of hydrothermal alteration, i.e. silicification, advanced argillic, argillic, and propylitic alteration. The silicification alteration appears as spotted zone. The advanced argillic pervasively occurred in the study area. Meanwhile the argillic alteration covered up the northeast part and the propylitic alteration zone covered the northwest part of the study area.

![Figure 1. Hydrothermal alteration map of study area based on mineral assemblages](image)
Silicification alteration is primarily composed of quartz. The occurrence of quartz causes this alteration to appear as prominent topography which makes it hard to erode. Other minerals are alunite, diaspore, and kaolinite. The advanced argillic alteration consists of sericite and quartz. The argillic alteration consists of less quartz with abundant smectite and illite while propylitic alteration comprises chlorite and epidote (inner propylitic) and illite, chlorite, carbonate or chalcedony (outer propylitic).

To provide an information of rock mass strength we need the point load test to obtain the Uniaxial Compressive Strength (UCS). UCS is used to identify the strength of intact rock. The result of point load test showed that each alteration types has their own rock intact characteristic.

The table below provides the information of rock intact strength of each alteration types.

| Sample code | Type of alteration            | UCS (MPa) | BS5939 (1999) |
|-------------|-------------------------------|-----------|----------------|
| SDM/084     | Advanced argillic (highly oxidized) | 10.49     | Moderately weak |
| SDM/040     | Advanced argillic (less oxidized) | 41.36     | Moderately strong |
| SDM/043     | Argillic                      | 0.83      | Very weak       |
| SDM/018     | Outer propylitic              | 8.08      | Very weak       |

Based on result, we see that the advanced argillic are classified into the highly oxidized and less oxidized reflecting the different rock strength. The highly oxidized advanced argillic alteration has lower rock strength due to the abundance of hematite. Mostly this typical advanced argillic alteration is widespread in the study area. However, in some areas, the advanced argillic contains more quartz so that increasing the rock strength. The argillic alteration contains more smectite which is categorized as high potential swelling index clay mineral (Fig. 3 and Fig. 4). So, this type of clay mineral is easy to expand while there is additional water enter its mineral structure. Meanwhile chlorite and illite which composed the propylitic alteration has no significance potential to swell. The potential swelling index mentioned in Table 2.

| ESI-1     | Rating   | Mineralogy         |
|-----------|----------|--------------------|
| <1.15     | Low      | Kaolinite          |
| 1.15 – 2.15 | Moderate | Illite/mixed layer minerals |
| >2.15     | High     | Smectite           |

Figure 2. Outcrop of argillic-altered rock. The yellow dashed line is identified as landslide plane.
**Figure 3.** Photomicrograph of altered rock. From both view (left: plane polarized and right: cross polarized), the rock is totally altered into illite and secondary quartz. Hematite appears as supergene minerals which shows intensively surficial process.

**Figure 4.** Clay minerals identification using X-Ray Diffraction analysis showing illite of mixed-layered with smectite.
By integrating field data such as alteration map, slope distribution map and laboratory test/analysis, the study area are classified into three (3) zones of slope failure (Fig. 5 and Fig. 6). The high risk slope failure area is in the northernmost part (Fig. 2). Meanwhile the center part has quite resistant slope and the western part has no significance potential slope failure.

**Figure 5.** Slope analysis map of the study area
4. Conclusion

It is concluded that mineralogical composition could affect the strength of rock intact. The advanced argillic altered-rock which contains more quartz tends to be more stable because of quartz resistance. Meanwhile the rocks which contain more illite-smectite and less quartz tend to have low strength of rock intact among others. This type of rocks mostly occupied the steep slope area which is in the northernmost part of the study area. This part of area has the highest risk slope failure. Thus, hydrothermal alteration which contains more clay minerals is the main factor which triggers the occurrence of landslide in the study area.

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