RESEARCH ARTICLE

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Determination of Landslide Potential in Trangkil Gunung Pati Based on Groundwater Flow Pattern

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Semarang Municipality has an area with geological condition firmly controlled by fault and fold, leading to greater potential of landslide, as may be evidenced in Meteseh, Jabungan, Sukorejo, Karangrejo, and Kandiri Villages. Therefore, a strategy is necessary to mitigate the landslide disaster. One of strategical approaches to such problem is prevention of land and rock saturation. The investigation of the landslide and rock saturation is determined based on shallow groundwater (unconfined) flow pattern. Such strategic pattern is applied to landslide prone area like Trangkil settlement. In determining the potential location of the landslide, a geological mapping is needed to examine the surface position and the direction of the unconfined (phreatic). The potential location of the landslide was mostly found in the east area where the groundwater flow is slow. A slow groundwater flow in clay-silt lithology can causes greater rock mass weight, while this lithology depends on impermeable clay. Such condition has caused non-compacted granule-silt-clay of unit easy to experience a sliding in the direction of the clay surface.

Keywords: Groundwater Flow, Landslide.

1. INTRODUCTION

Fault geological structure in Semarang Municipality has been proven its existence and believed to cause many problems, in particular those related to unstable land and road damage. The similar problem is found in Sekaran, Gombel, Sigarbencah, and Semarang-Ungaran toll highway in Gedawang. In early 2014 landslides occurred in these areas. Half of Sekaran-Sampangan road was covered by the landslide. In Gombel, the landslide disaster caused damages of some houses and on death, leading to relocation of the settlement in Trangkil.

According to Volcanology and Geological Disaster Mitigation Directorate,[1] landslide can be referred as land movement. It is defined as a mass of land or mixed materials (granule, sands, and siltas well as clay), which moves along the slope or outside the slope due to earth gravity.

There are many definitions of a landslide. In commonly accepted international usage the term landslide refers to "the movement of a mass of rock, debris or earth down a slope."[2] The land movement (landslide) is a product of slope balance disorder, which caused movement of the land or rock mass to lower area.[3] Force that bears this land mass along the slope is affected by land physical characteristics and inner angle of land shift defense that work along the slope.

Geological factors will determine the vulnerability of the avalanche area. These factors are the topography is steep, rock types are volcanic young and not yet perfect compact, condition lithology relative has happened weathering strong, stratigraphy mutually alternating between rock impermeable (lava) with a layer of rock layers vulcanoes more, the number of discontinuous form of fracture/fault.[4]

Geological condition is one of factors that affect landslide incidence. To detect the geological condition of the landslide prone area, an approach of method that determines the unconfined-water flow direction is necessary.

2. REVIEW OF LITERATURE

2.1. Trangkil Geological Characteristics

2.1.1. Morphology

The study observed that the morphology of the research location was an undulating hill area with slope ranging from 15° to 45°. Structural landform unit-denudasional step hill lithology constituent sandstones, conglomerates, carbonates clay, and breccia.[5] Processes that occurred in the area dealt with slope erosion and rock mass movement. Vegetation growing in this area were trees and bushes and land use management appeared were settlement and field.

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2.1.2. Lithology

The study found two lithology according to the mapping result, i.e., volcanic breccia and carbonates clay. The volcanic breccia had dark gray megascopic feature and gravel-to-clod-sized andesitic fragment (2–4 mm to > 256 mm). Matrix found was lapilli-sized tufa (2–64 mm), with poor sortation, open closure, and medium-to-severe weathering. At some study observed there were fractures of the vertical volcanic breccia. These fractures were probably caused by rock loading due to water absorption into the rock body and had a potential of becoming surface water tract, accelerating the weathering and erosion of the areas nearby the fractures. This incidence caused rock mass movement, and, therefore, landslide. The volcanic breccia in the research location was part of Kaligetas Formation (Qpkg), which was probably sediment as lava.[6] This rock formation had a distribution rate close to 90% of the research location.

The clay at the research location had a gray megascopic feature (<1/256 mm), carbonates cement, as evidenced by bubbles appearance due to HCl drops, and high weathering rate. This rock formation had a distribution rate of 10% and was located in the east area.[7] The unit was outcropped under the volcanic breccia nearby seasonal river, which was only filled by water in the rainy season. The clay is an impermeable rock formation because it cannot allowed the water to form the landslide spots.

2.1.3. Shallow Groundwater Flow

Unconfine water is a contributing factor to groundwater, leading to the loss of land shift strength when it has been abandoned in the landslide area. Water saturation as the position of water table has a significant effect on the slope stability. Therefore, this position is important to find out the slope stability of particular area.

Groundwater is a moving water under the surface, filling spaces between soil particles or in rock fractures. It is one of a series of processes in a hydrological cycle. The source of the groundwater is infiltrated rain water, subtracted by evaporation from the surface as well as transpiration.[8]

The existence of the groundwater greatly depends on the characteristic of the rock layers under it. The rock layers that are easy to be infiltrated by the water are so called permeable layers, consisting of lose rocks, such as gravel and sand. These layers are also referred as aquifer layers.

The impermeable rock layers, on the other hand, consist of soils with clay texture. Different layers within the rock formation caused the difference in capacity rate of the layers against the water.

The areas with higher rate of aquifer (groundwater) include alluvium terrain, area between volcanoes, limestone formation, and delta. Naturally, the elevation of the groundwater surface fluctuates. It is always in a stable state. The fluctuation of the groundwater surface occur due to as the followings:

a. Groundwater collection for fulfilling the needs of household, industry, and agriculture;

b. Season change, in which the groundwater surface increases during the rainy season and gradually decreases during the dry season.

Groundwater plays a significant role in fulfilling the needs of daily life. However, it can also cause landslide at some locations.

3. EXPERIMENTAL DETAILS

Method used for constructing the groundwater flow networks according to the unconfined flow map, which consisted of three stages of activity, i.e.,

(1) geological mapping,
(2) mapping for unconfined water table position, and
(3) determination of groundwater flow direction, can be illustrated in a block diagram as follow (Fig. 1).

Mapping the position of the groundwater table is done by measuring the coordinates of the point of dug wells and groundwater table position. Coordinate measurement dug conducted by Global Positioning System (GPS). Furthermore, the position of the ground water level in the wells is measured by reference to the average sea level. Measurement method to determine the elevation of the ground surface using altimeter and depth of the well water level is measured by the depth meter. Elevation groundwater level is reduced ground surface elevation depth of the well water surface.

Determining the direction of groundwater flow is done on the basis of a map of the position of the groundwater table has been prepared. Groundwater flow direction is perpendicular to the contour of the ground water level position at any point being reviewed. Depiction of the groundwater flow direction on a base map maps the position of the groundwater table will produce a map unconfined flow networks.

4. RESULTS AND DISCUSSION

4.1. Technical Geology of Research Area

The morphology of the research location, Trangkil Settlement, is part of undulating hill composed of tertiary sediment and quarter volcanic formation. Field observation and shallow drilling revealed that the area had three lithological units (Fig. 2.), i.e., clay, breccia, and granule-silt. The clay was located in the lowest stratigraphy layer with dark gray, compact, fairly soft, and breakable features. The breccia unit was characterized by dark gray color, medium-to-soft sand matrices, 5–30 cm fragments, and andesite. The granule-silt unit was characterized by browned-gray color, composed by gravel and clod features. According to the drilling data, the lithology was observed in a rather spreading condition, containing timber, waste, red brick, can, and suffering from erosion, in particular in the northeast direction. A geoelectrical analysis explains that such lithology has a thickness from

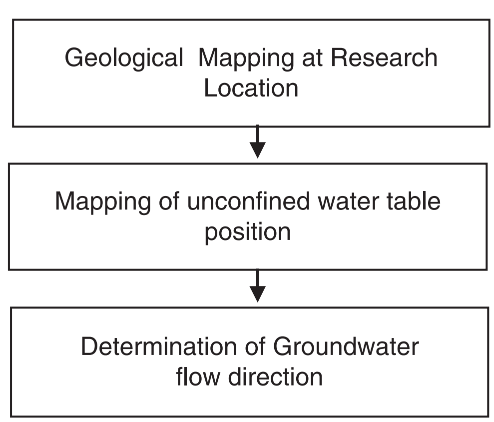

Fig. 1. Research flowchart and stages.

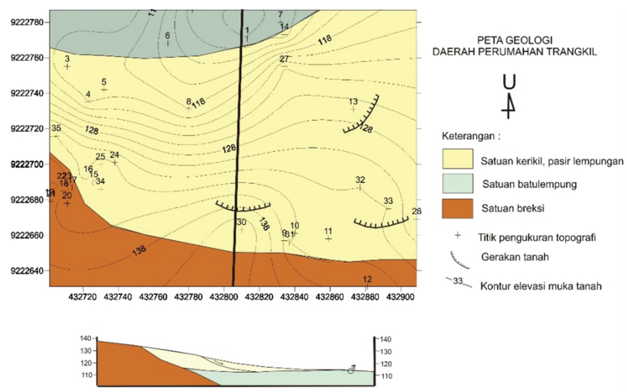

Fig. 2. Technical geological map of Trangkil settlement.

1 to 2 m in the north and 2–15 m in the south.[7] According to physical condition and lithological distribution, such gravel unit is caused by a landfill during the land use for settlement.

4.2. Groundwater Flow Networks

The measurement of phreatic water table position at the research location directed downward to northeast and closure of the upstream. It proved that the pattern of the groundwater flow directed to the upstream (Fig. 3). The figure shows that the unconfined water flow from the south to the north and from the southwest to the northeast, forming a riverhead at the upstream. The condensed contour caused the water debit in the west was higher than that of the east. It proved that the groundwater flow in the west was more frequent. The lithological feature from the shallow drilling proved that the west area had a granule-silt-clayed, whereas the east area was dominated by clay, so that the permeability was better.

The unconfined water flowed within the pores of granule-silt and made a contact with outcropped clay rock, forming a groundwater-borne upstream. Such condition proved that the clay is in an impermeable condition.

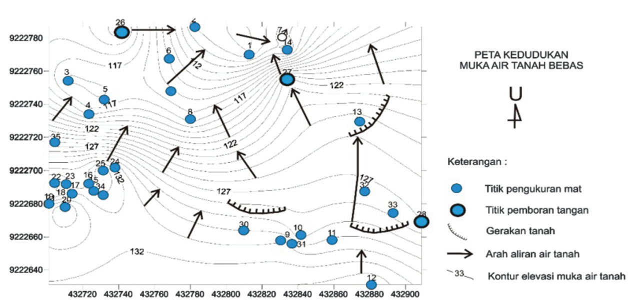

Fig. 3. Unconfined flow networks at research location.

4.3. Groundwater Flow Pattern and Landslide Prone Locations

Locations of the former land movement area in the past and signs of the potential landslides are illustrated in Figure 3. One part in the middle-south and two parts in the west were considered landslide prone. The field observation proved that the land movement as lengthened cracks was in a curvy form. Such symptom was mostly found in the west, which had a slow groundwater flow. The slow groundwater flow in the clay lithology cause greater rock mass weight, while this clay depends on impermeable clay. Such condition made the non-compacted gravel formation to be easy to slide following the clay rock surface (Fig. 3). In rainy season, water absorb into the water through the existing cracks, downward to the surface of the clay, causing stronger waterflow. Erosion then occurred in the rock mass above the unit.

5. CONCLUSION

The potential landslide in the east with slower groundwater flow was greater. The clay-silty gave a greater rock mass loading, whereas the lithology greatly depends on impermeable clay. This condition caused the granule-silt-clay was easier to slide.

The phreatic (unconfined water table) flow at the research location directed from south to north and from southwest to northeast, and finally formed a riverhead at the upstream. According to contour density, the flow debit in the west was higher than that of the east. It proved that the groundwater flow in the west was more frequent and stable. The lithological analysis from the shallow drilling revealed that the west side of the location had granule-silt-sand and the east location had a granule-silt-clay with less permeability than the west.

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