Early mitigation of landslide prone areas with remote sensing and analysis of slope stability in ampera, south jayapura district, papua province

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Abstract. Ampera, located in the eastern slope of Cycloop Mountains, Papua Province had a landslide disaster on March 17, 2019. Landslides in Ampera is caused by the steep slope. Landslides occur due to lack of early mitigation which results in material loss and death. Early mitigation was carried out by remote sensing aimed at mapping landslide-prone areas in Ampera. The determination of landslide-prone areas is based on several parameters and weighting of remote sensing. The parameters are based on the provisions made by the author with secondary data. Weighting is used based on the results AHP method. Parameters and weighting using rainfall (44%), slope gradient (31%), NDVI (15%), slope water density (7%), and road density (3%). This parameter is processed into raster data which is then combined with weighting. The results, Ampera has a moderate to high vulnerability for landslides. Three high vulnerability areas was made a modeling incision to determine safety factor value for slope stability. Modeling was done using characteristics of Podzolic Soil type, obtained from the Soil Distribution Map of Papua Province. Based on the results of the modeling, the average value of the safety factor of slope stability in three areas with high vulnerability is 0.5 (unstable).

1. Introduction
Papua Province, Jayapura Regency, South Jayapura District, Ampera is geographically located on the eastern slope of the Cycloop Mountains. The Cycloop Mountains have a length of about 36 km, with the highest peak of 1,960 masl. Ampera area is administratively located in the Numbay Village with an area of 9.49 hectares and a population of 8,893 inhabitants. The location map of the research area is shown in the red square of Figure 1.

The Ampera area on March 17, 2019, suffered a landslide disaster. The main cause of landslides in the Ampera is due to the intensity of moderate rainfall (150-200 mm/month), and it is supported by the steep slope of the Cycloop Mountains. The impact of the landslide resulted in material losses and fatalities for residents of the Ampera Region. Initial mitigation is needed in the Ampera to anticipate the possibility of landslides. The mitigation is carried out without visiting the Ampera area directly, by conducting a review through analysis of remote sensing images. The review aimed to map landslide-prone areas in the Ampera. Areas that have a high vulnerability for landslides in the Ampera will be analyzed the slope stability to obtain the value of slope safety factors. This value can be used as material for evaluation and consideration for residents around the Ampera, whether the area is safe to be used as a residential area.
Landslide can occur on any terrain given the right conditions of soil, moisture, and angle of slope [4]. Anthropogenic activities can increase the vulnerability of natural disasters. Landslides are one of the potential hazards that cause disasters on community, livelihoods, human settlements, livestock, and environment [5, 6]. A landslide is a natural phenomenon which consist the process of displacement or movement of soil, rock or vegetation, from its original position under the influence of gravity. This movement can occur in many ways. It can be a fall, topple, slide, spread or flow [1, 2, 3]

The problem that arises is that the parameters used for slope stability analysis are not obtained directly through field data, but rather the results of case studies conducted through several official journals.

2. Methods
The research was carried out by analyzing the parameters of the secondary data sourced from SRTM DEM, USGS-LANDSAT 8 OLI with acquisition time of 28 February 2019, RBI (Indonesian Topography Map) of Irian Jaya from BIG (Geospatial Information Agency), and December 2018 Rainfall Map from LAPAN (Indonesian National Institute of Aeronautics and Space). These data used in making slope stability analysis originated from case studies of several official scientific works. Making maps of landslide-prone areas is based on several parameters and weighting of remote sensing determined by the author, with weighting values based on the results of the Analytic Hierarchy Process (AHP) method. The parameters and weightings used included rainfall (44%), slope gradient (31%), normalized difference vegetation index (15%), slope water density (7%), and road density (3%). Combining and weighting parameter map is done by using ArcGIS 10.3.1 software. Results of the combined and weighting will be modeled to determine the safety factor of slope stability by using PLAXIS 8 Software.

3. Result and discussion
The parameters used in making maps of landslide-prone areas, each of which has a subparameter with different values. The parameters used are as follows;

3.1. Rainfall
Rainfall is the main factor causing landslides in Ampera. Water originating from rain will infiltrate into the soil, the infiltration of excess water will cause the soil to become saturated, consequently, the pressure of pore water will exceed the normal stress of the soil and result in a decrease in soil shear strength, resulting in reduced soil stability. The rainfall subparameter values will be shown in Table 1. The Rainfall Map of the research area will be shown in Figure 2.
Table 1. Rainfall subparameter.

| Rainfall       | Vulnerability Level | Scoring |
|----------------|---------------------|---------|
| 150-200 mm/month | Medium              | 2       |

3.2. Slope Gradient

The slope gradient is increasingly steep, causing soil gravity to increase and resulting in a decrease of soil shear strength so that soil stability decreases. The slope subparameter values according to the proposed Landslide Hazard Evaluation Factor (LHEF) rating scheme for slope gradient [7], will be shown in Table 2. The slope gradient map of the research area will be shown in Figure 3.

Table 2. Slope gradient subparameter.

| Slope Angle     | Vulnerability Level | Scoring |
|-----------------|---------------------|---------|
| Low (0° - 15°)  | Low                 | 1       |
| Medium (15° - 30°) | Medium             | 2       |
| High (30° - >45°) | High               | 3       |
3.3. Normalize Difference Vegetation Index
The vegetation index is an optical measurement of the greening of the vegetation canopy, composite properties of leaf chlorophyll, leaf area, structure, and cover of vegetation canopy [8]. The lower level of vegetation, and the less binding factor of soil particles causes the easier of the pore pressure to exceed the normal soil stress so that soil stability decreases. The vegetation index of the study area is sourced from USGS-LANDSAT 8 OLI. The vegetation index of the subparameter values will be shown in Table 3. Map of the Normalized Difference Vegetation Index (NDVI) the research area will be shown in Figure 4.

| Vegetation Index | Vulnerability Level | Scoring |
|------------------|---------------------|---------|
| 1 High           | Low                 | 1       |
| 2 Medium         | Medium              | 2       |
| 3 Low            | High                | 3       |
3.4. Slope Water Density
Slope water density is obtained from the delineation of river networks in the study area. The river network of research area was obtained from the Indonesian Topography Map (RBI) of Irian Jaya, the source of Indonesia Geospatial Portal (BIG). The assumption that the higher of the slope water density, the more not resistant rock will be in the zone and will make it more easily eroded so that the level of landslide vulnerability will be even higher. The subparameter values of the slope water density [9] will be shown in Table 4. The slope Density Map of the research area will be shown in Figure 5.

| Slope Water Density | Vulnerability Level | Scoring |
|---------------------|---------------------|---------|
| 1 Low               | Low                 | 1       |
| 2 Medium            | Medium              | 2       |
| 3 High              | High                | 3       |

Figure 4. NDVI Map

Figure 5. Slope Water Density Map
3.5. Road Density
Road density is obtained from the delineation of road networks in the study area. The assumption that the higher the road density, the greater the role of humans in the zone and causes an increasing in external factors for landslides, so that the level of vulnerability to landslides will be higher. The subparameter value of road network density will be shown in Table 5. The Road Network Density Map of the research area will be shown in Figure 6.

| Road Density | Vulnerability Level | Scoring |
|--------------|---------------------|---------|
| 1 Low        | Low                 | 1       |
| 2 Medium     | Medium              | 2       |
| 3 High       | High                | 3       |

Results of making maps of the five parameters are then combined by entering the weighting value of each parameter. Weighting values are entered in accordance with the results of the AHP (Analytic Hierarchy Process), to obtain a Landslide-Prone Areas Map. The results of making Landslide-Prone Areas Map are classified into 3 zones which include; zones prone to low landslides, zones prone to moderate landslides, and zones prone to high landslides. Landslide-Prone Areas Map in the research area will be shown in Figure 7.
Areas classified as zones prone to high landslides in the Ampera will be modeling into a slope stability analysis. Incisions were made on three points scattered in the Ampera. The length of each incision is 100 meters. The parameters used for modeling are based on the assumption that the common condition of a slope is prone to landslides, due to the absence of original field data. The assumption used by the author is that in a landslide system there are two things that are commonly considered, that is the slope load and the slip plane. Bed rock is added as the base layer of a slope. The slope load used in the modeling uses surface soil with a thickness of ± 5 meters, with the characteristic type of Podzolic soil. Slip field used in the modeling uses clay material with a thickness of ± 3 meters. The material properties used in making modeling will be shown in Table 6. Modeling slope stability will be shown in Figure 8.

**Table 6.** Material properties for modelling slope stability.

| Layer       | $\gamma$ unsat (kN/m$^3$) | $\gamma$ sat (kN/m$^3$) | Permeability (m/day) | $E_{ref}$ (kN/m$^2$) | $\mu$ (nu) | $C_{ref}$ (kN/m$^2$) | $\phi$ (phi) | $\Psi$ (psi) |
|-------------|-----------------------------|-----------------------------|----------------------|------------------------|-------------|----------------------|--------------|--------------|
| Podzolic soil | 14                          | 16                          | 0.5                  | $2 \times 10^4$        | 0.3         | 5                    | 21           | 0            |
| Clay        | 16                          | 18                          | $2 \times 10^{-5}$   | $5 \times 10^3$        | 0.35        | 10                   | 1            | 0            |
| Bed rock    | 17                          | 20                          | $1 \times 10^4$      | $4 \times 10^4$        | 0.2         | 200                  | 50           | 20           |
Modeling results of slope stability on the three scattered points in Ampera obtained the safety factor values for each point. The safety factor is determined as the value of the ratio between the resisting forces and the driving forces [10]. The range value of the safety factor will be shown in Table 7.

![Figure 8. Modeling Slope Stability](image)

**Table 7. Range Value of Safety Factor (Bowles, 1991)**

| Safety Factor Values | Landslides Intensity                      |
|----------------------|-------------------------------------------|
| 1 \ F < 1.07         | Unstable slopes or landslides frequently happened |
| 2 \ 1.07 ≤ F ≥ 1.25  | Critical slopes or landslide have occurred |
| 3 \ F > 1.25         | Stable slopes or landslide rare occurred   |

The value of the safety factor for the first slope is 0.55 F, the second slope is 0.57 F, and the third point is 0.37 F. The safety factor values of the three points are based on the classification of Slope Safety Factors [11], classified as unstable slopes or landslides frequently happened. Based on the value of the low safety factor and included as the type of unstable slope, the authors suggest doing slope reinforcement in areas that have a high level of landslide vulnerability. Strengthening of slopes is intended to prevent the occurrence of recurrence of landslides, so as to minimize material losses and casualties for residents of the Ampera.
4. Conclusions
Based on the research that has been done, it can be concluded that weighting carried out by the Analytic Hierarchy Process (AHP) method, obtained 5 parameters namely; rainfall (44%), slope gradient (31%), normalized difference vegetation index (15%), slope water density (7%), and road density (3%). Making maps of landslide-prone areas, classified into three zones including; zones prone to low landslides, zones prone to moderate landslides, and zones prone to high landslides. Analysis of slope stability carried out on three high landslide-prone points in the Ampera obtained a safety factor value for the first slope obtained 0.55 F, the second slope obtained 0.57 F, and the third slope obtained 0.37 F, where the value is classified as unstable slope, with intensity landslides is frequently happened.

Based on the results of this study, suggestions for further research are a similar study at the same research location using the addition of parameter data taken directly at the study site to get a more accurate result of the Landslide Area Distribution Map. Material property data used in making modeling using data taken directly at the research site to obtain a more accurate value of slope stability safety factor.

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