Analysis of Environmental Vulnerability in The Landslide Areas (Case Study: Semarang Regency)

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Abstract. The Land conversion can increase the risk of landslide disaster in Semarang Regency caused by human activity. Remote sensing and geographic information system to be used in this study to mapping the landslide areas because satellite image data can represent the object on the earth surface in wide area coverage. Satellite image Landsat 8 is used to mapping land cover that processed by supervised classification method. The parameters to mapping landslide areas are based on land cover, rainfall, slope, geological factors and soil types. Semarang Regency have the minimum value of landslide is 1.6 and the maximum value is 4.3, which is dominated by landslide prone areas about 791.27 km². The calculation of the environmental vulnerability index in the study area is based on Perka BNPB No. 2/2012. Accumulation score of environmental vulnerability index is moderate value, that means environment condition must be considered, such as vegetation as ground cover and many others aspects. The range of NDVI value shows that density level in conservation areas (0.030 - 0.844) and conservation forest (0.045 - 0.849), which rarely until high density level. The results of this study furthermore can be assessed to reduce disaster risks from landslide as an effort of disaster preventive.

Key words : Environmental Vulnerability, Landslide, Landsat 8, NDVI

1. Introduction

Landslide is one of the disasters that often occurred in several locations in Indonesia. Semarang Regency is one of the potential locations of landslide disaster, because that regency is dominated by hills and mountains landform. Landslide almost as erosion with a large mass of soil and rocks s down from mountain or cliff. Based on data of Regional Disaster Management Agency (BPBD), in Semarang Regency recorded 38 landslide disasters of 113 total accumulation disasters in 2014. Meanwhile, in 2015 recorded 132 landslides of 305 total accumulation disasters, and in 2016 recorded 87 incident of landslides from 199 disasters. The recorded data indicate that landslides disaster has occurred frequently in Semarang Regency, this is because of high rainfall intensity and also the topographic condition of Semarang Regency is dominated by hills and mountains landform with a degree of the slope about (2-40%). Landslide is affected by two factors that are nature aspects and human aspects. Basically, a landslide can be prevented by cultivating plants which have strong roots due to the function of the plants as a ground cover and aggregate soil binder if soil received pressure by high rainfall. The development of human activities caused some landuse changed that function from conservation area to cultivation area or residential area that can increase the risk of landslide disaster. Plants in the cultivation area not
forming a dense network of roots so can not hold the soil when heavy rain occurred with high rainfall intensity. In addition, the development of settlements that not follow the rules of conservation can increase the risk of landslide disaster.

Assessment of environmental vulnerability in landslide prone areas is necessary for the identification and assessment of hazards, so that in the research, environmental susceptibility analysis in landslide areas is conducted using remote sensing and geographic information system method. In this study, mapping of potential landslide areas is done previously by scoring and weighting of the parameters landslide. The parameters to mapping landslide areas in Semarang Regency are based on land cover, rainfall, slope, geological factors and soil types. The high human activity caused some changes in land cover, so to obtain actual land cover in study areas using remote sensing is based on Landsat 8 imagery processing. The use of satellite imagery to mapping land cover is very effective due to the wide study area is 95020.67 Ha or about 2.92 % of the total area in Central Java. Scoring and weighting method is spatial analysis which utilizes geographic information system. Values of scoring and weighting are based on the relevant literature review and regulations such as the regulations from Directorate of Volcanology and Disaster Mitigation to mapping accurate landslide areas in Semarang Regency.

The result of landslide prone areas that be analyzed to know about the environmental susceptibility in landslide areas. The vulnerability can be defined as exposure multiplied by sensitivity. Exposed assets such as physical structures and ecological or environmental areas. Each of assets has its own sensitivity, which varies for each type of disasters. Land cover and vegetation density will be analyzed to obtain the environmental vulnerability index in landslide areas. The calculation of the environmental vulnerability index in the study area is based on Perka BNPB No. 2/2012. The results in this study, furthermore can be assessed to reduce disaster risks from landslide as an effort of disaster preventive.

2. Data and Study Areas

Data in this study uses Landsat 8 Imagery to get land cover by supervised classification processing and vegetation density by NDVI algorithm. In addition, to mapping landslide area in Semarang Regency also needs some others data such as rainfall data from Indonesia Agency for Meteorology, Climatology and Geophysics in 2016, geological factors, soil types and slope which is processed from DEM SRTM.

2.1. Landsat 8 Imagery

Landsat 8 imagery that used in this study is LIT type products which available to users is a radiometrically and geometrically corrected image. The result is a geometrically rectified product free from distortions related to the sensor (e.g., view angle effects), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature, relief). The image is also radiometrically corrected to remove relative detector differences, dark current bias, and some artifacts [1]. The Level 1 image is presented in units of DN, which can be easily rescaled to TOA reflectance. Values of TOA reflectance in the image are used as input values to obtain land cover by supervised classification processing and NDVI algorithm to get vegetation density. Landsat 8 have the OLI (Operational Land Imager) sensor that collects image data for 9 shortwave spectral bands over a 190 km swath, with a 30 m spatial resolution for all bands except the 15 m panchromatic band and TIRS (Thermal Infrared Sensor) that 2 spectral bands with a 100 m spatial resolution for all band. Figure 1 shows Landsat 8 image, which is used in this study with path/row 120/65 and date acquired in 19 August 2016.

2.2. Study Areas

In this study, environmental vulnerability analysis be done in Semarang Regency. Ungaran is regency capital in study area. Semarang Regency located at the geographic positions of 110\textdegree\;14'\;54.74" - 110\textdegree\;39'\;3" East Longitude and 7° 3' 57" - 7° 30' 0" South Latitude. Administratively, Semarang Regency is divided into 19 districts, 27 sub-districts and 208 villages [7]. Semarang Regency is directly adjacent to Semarang City and Demak Regency in north; Boyolali Regency and Magelang Regency in south; Grobogan Regency and Boyolali Regency in east; and Temanggung Regency and Kendal Regency in west. Location of Semarang Regency which is study area in this research that shown in Figure 2. The
study area is located at an altitude about 500-2000 m above sea level. The lowest altitude is in the Candirejo Village in Priangapus District and while the highest in Bantur Village in Getasan District.

![Figure 1. Landsat 8 Image with path/row 120/65 and date acquired in 19 August 2016. The image uses composite band 432, which true colour composite. The red square in this image shown study areas in Semarang Regency.](image1)

![Figure 2. Location of Semarang Regency with the boundary areas and 19 district in study area.](image2)

3. Methods

Basically, the methods that is used to obtain the environmental vulnerability index in the study area, which based on Perka BNPB No. 2/2012. Potential landslide areas in Semarang Regency must be mapped previously with scoring and weighting of the parameters, which included in the spatial analysis. The results of potential landslide areas in Semarang Regency be classified by the level of prone landslide. To calculation value of index environmental vulnerability in landslide areas, which based on forests, shrubs and swamps land cover in study area. In addition, vegetation density in that locations can be known by NDVI algorithm processing. Overall step or methods that used in this study can be seen in Figure 3.

3.1. Pre-processing

DEM SRTM must be pre-processing to obtain degree of slope from altitude values from raster data. Images pre-processing must be done for Landsat 8 to get values of TOA reflectance in Semarang Regency, before processed to the next stage. Units of DNs can be converted to TOA reflectance using the reflectance scaling factors provided in the metadata file. The following equation is used to convert DN values to TOA reflectance:

\[
\rho_{\lambda'} = M \rho \ast Q\text{cal} + A \rho
\]  

(1)
where:

\[ \rho_{\lambda'} = \text{TOA Planetary Spectral Reflectance, without correction for solar angle.} \]

\[ M_{\rho} = \text{Reflectance multiplicative scaling factor for the band.} \]

\[ A_{\rho} = \text{Reflectance additive scaling factor for the band.} \]

\[ Q_{\text{cal}} = \text{L1 pixel value in DN} \]

\[ \rho_{\lambda} = \frac{\rho_{\lambda'}}{\sin(\theta)} \]  

(2)

where:

\[ \rho_{\lambda} = \text{TOA Planetary Reflectance} \]

\[ \theta = \text{Solar Elevation Angle (from the metadata, or calculated)} \]

3.2. **Supervised Classification**

Image classification is a process of compiling, sorting or grouping the pixels into the particular criteria or object categories. Image classification is divided by two types, Supervised Classification and Unsupervised Classification [2]. In this type of classification the image analyst “supervises” the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of known cover type, called training areas, are used to compile a numerical interpretation key that describes the spectral attributes for each feature type of interest. The resulting classification is necessary to test the accuracy of object classification to the real objects on earth surface. Determination the accuracy of classification can be done by looking at the evaluation values, which calculated by the confusion matrix.

3.3. **NDVI (Normalized Difference Vegetation Index) algorithm**

Vegetation density in this study has been done using NDVI algorithm to get values of vegetation index. NDVI (Normalized Difference Vegetation Index) is a sensitive vegetation measurement using spectral energy disparity is reflected by vegetation canopy in red electromagnetic spectrum wave and near-infrared spectrum [5]. The NDVI transformation follows the equation:

\[ \text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}}} \]  

(3)

where:

\[ \rho_{\text{NIR}} = \text{Near-Infrared Canal Reflectance Value} \]

\[ \rho_{\text{RED}} = \text{Red Canal Reflectance Value} \]

3.4. **Environmental Vulnerability Index**

Based on Perka BNPB No. 2/2012, indicators of environmental vulnerability consist of forests, shrubs and swamps parameters in study area. Each parameters of environmental vulnerability in this study as a results of supervised classification that shown by land cover in landslide areas. The calculation of the environmental vulnerability index follws the equation [3]:

\[ \text{Environmental Vulnerability} = (0.4*\text{Scoring of Conservation Forest}) + (0.4*\text{Scoring of Natural Forest}) + (0.1*\text{Scoring of Mangrove Forest}) + (0.1*\text{Scoring of Shubs}) \]  

(4)

where:

values of scoring are determined by wide areas for each parameters in environmental based on Perka BNPB No. 2/2012.
4. Results and Discussion

4.1. Slope
Slope become an important factor that causing the landslide though it should be concerned other factors, which affect each other. Slopes that have ≥40% degree of slope, generally potential of landslide but not necessarily slopes with these conditions causing a landslide. The stability of slope influenced by motion force and restrain force in the slopes. Motion forces are forces that attempt to make the slope slide, while restrain forces are forces that maintain the stability of the slope. If the restrain force greater than motion force, the slope will not be disturbed. Scoring of slope to mapping potential landslide area in this study based on Ministry of Public Works Decree No. 22/PRT/M/2007 about Guidelines for Spatial Planning of Landslide Prone Areas. The slope in Semarang Regency from the results of DEM SRTM processing have (0–40%) degree of slope, which is dominated by (0–8%) degree of slope (845.04 km²) and (9–15%) degree of slope (127.63 km²). In Figure 4 shows that slope in this study area.

4.2. Geological Factors
Geological factor is one of the important parameters that causing a landslide, this is because the mass of rock and soil that do the movement. Geological structure, characteristic of rocks, loss of soil adhesives due to natural processes, and earthquakes are the geological factors that influence the landslides. Geological structure that influences a landslide is the contact of bedrock and weathering rocks, cracks or fracture, layers rock and fractures. In this study, to mapping potential landslide areas using type of rock and characteristic of rock to get values of geological factors. Geological data is obtained from Systematic Geological Map. Type of rocks in this study consist of surficial deposit, volcanic rocks, sedimentary rocks, and intrusive rock. Semarang Regency is dominated by 12 type of volcanic rocks, 6 type of sedimentary rocks, 1 type of surficial deposit, and 1 type of intrusive rock. Surficial deposit in study area is an aluvium (Qa); intrusive rock is an andesit (Tma); volcanic rocks are Gajahmungkur
Volcanics (Qhg), Kaligesik Volcanics (Qpk), Jongkong Formation (Qpj), The Kemalon and Sangku Volcanics (Qks), Volcanic Breccla (Qvb), Undifferentiated Volcanic Rocks (Qvu), Sumbing Lava (Qls), Gilipetung Volcanics (Qg), Andong & Kendil Volcanics (Qak), Deposit of Cinder Cones (Qcc), Telomoyo Volcanics (Qte) and Qba; Sedimentary rocks are Kaligetas Formation (Qpkg), Kalibeng Formation (Tmkp), Kerek Formation (Tmk), Many Member of Kalibeng Formation (Tmkb), Penyatan Formation (Qtp), Payung Formation (Qp). In Figure 5 shows that distribution type of rocks in the study area.

Figure 4. Slope in this study area by DEM SRTM processing.

Figure 5. Type of rocks in this study as geological factor parameter.

4.3. Soil Types
Friable soil conditions will more easily to erosion and landslide because of water circulation into the cross-section soil more easily than massive soil. Land which has potential landslide can be assessed by soil erosion sensitivity (K). K factor is soil erodibility factor which represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. This value indicates that soil eroded easily or not based on the physical and chemical characteristic soils. Smaller the values as a smaller sensitivity of the erosion. The values of soil erodibility in this study can be seen in Table 1, K factor values are obtained by study literature that based on Puslitbang Pengairan Bogor, 1985. Soil types in this study have been shown in Figure 6.

Table 1. K factors in each soil type in study area based on Puslitbang Pengairan Bogor, 1985

| Soil Types                                      | K factor |
|------------------------------------------------|----------|
| Dark Brown Alluvial Soil                       | 0.193    |
| Dark Brown Andosols Soil                       | 0.278    |
| Grey Grumusols                                 | 0.176    |
| Red Latosols                                   | 0.075    |
| Complex of Dark Grey Andosols and Litosols     | 0.271    |
| Complex of Grey Regosols and Dark Grey Grumusols| 0.302    |
| Association of Brown Latosols                  | 0.175    |
| Association of Yellowish Red Latosols, Dark Brown Latosols, and Litosols | 0.062 |
| Reddish Brown Litosols                         | 0.075    |
| Dark Brown Mediterranean Soils                 | 0.323    |
4.4. Land Cover
Human activities cause the change functions of landuse, that changes can be a control factor of ground movement or increase the risk of landslide. This is based on landuse that will be affect land cover conditions. Plants in forest land cover will be able to reduce erosion. When less vegetation covered some areas, the function of roots to hold soil or aggregate soil binder decreases. So, land cover is one of the important factors that causing a landslide. Land cover in study area is processed by supervised classification in Landsat 8 image. The overall accuracy of classification is 88.41 % from the results of the confusion matrix. Percentage of overall accuracy has shown that classification results can represent true land cover in earth surface. Figure 7 shows that land cover in study areas.

4.5. Rainfall
Rainfall is the amount of rain that fell to earth by one unit surface area at a certain time period. The volume of rainfall that falls in particular area over long period relatively, indicates that the amount of rainfall intensity. So, the unit of rainfall used m³/unit area and expressed in water level (mm) generally. The rainfall that sinks into the clay soil on the slopes will be restained by more compact and impermeable rocks. The amount of rainfall intensity causes that volume of retained water become increase, so that waters is pressing the soil aggregate and leading sandy clay soil to move. The rainfall in this study was obtained by 8 rainfall observer station that is spread evenly in Semarang Regency. Because of rainfall data is a point, so to mapping rainfall areas in this study uses interpolation method by Inverse Distance Weighted (IDW). The interpolation is a simple deterministic method by considering the surrounding points. The assumption of this method is the value of interpolation will be more similar to the near sample data, besides that farther one. The weight will change linearly according to the distance of sample data [4]. The rainfall intensity in study area about 2591 – 4276 mm/year that can be seen in Figure 8.
4.6. Analysis of Environmental Vulnerability in Potential Landslide Areas

Potential of Landslide disaster in study area shows that Semarang Regency has 3 categories of the landslide are less prone, prone and extremely prone. The classification based on the regulations from Directorate of Volcanology and Disaster Mitigation, 2004. The calculation that uses to obtain the values of landslide prone areas using scoring and weighting by each parameters, which has been described earlier. Rainfall parameter is given the greatest weight (30%), while for geological factors and soil type given weight (20%), and for land cover and slope parameters given weight (15%). The value of landslide prone level in this study is acquired by summing the multiplication of weights with the scores in each parameters. Semarang Regency have the minimum value of landslide is 1.6 and the maximum value is 4.3. In this study, that cumulative score is classified in 3 categories are less prone ($\leq$ 2.5); prone ($\geq$ 2.6 and $\leq$ 3.6); and extremely prone ($\geq$3.7). Distribution of landslide prone areas in Semarang Regency can be known by that classified. Figure 9 shows that landslide prone areas in Semarang Regency, which is dominated by prone areas about 791.27 km$^2$. Extremely prone areas spread in several locations, such as Suruh District, Pabelan District, Bancak District, Ungaran Timur District, and Bergas District. Some extremely prone areas are located at production forest land cover. The highest cumulative score is located in Bancak District. The result has been validated with data from Regional Disaster Management Agency (BPBD) in 2016, that data shows of the most landslide recorded in some location with prone category areas in Banyubiru District and Jambu District. While, period January until Mei in 2017, the amount of landslide incident has increased (154 incident of 208 total accumulation disasters), if compared with landslide incident in 2016. Most of the incident is located in prone and extremely prone areas, that spread in several districts are Ungaran Timur District, Ungaran Barat District, Sumowono District, Banyubiru District, Suruh District, Getasan District and Bringin District.

Value of Environmental Vulnerability Index in Landslide areas is calculated by equation 4 in the methods section. Previously, its necessary to classified areas that belong to environmental vulnerability areas. That area consists of conservation forests (1472.29 Ha); conservation areas (1404.82 Ha), swamps (1351.87 Ha) and shrubs (12382.71 Ha), which can be seen in Figure 10. Delineation of that area based on the land cover by Landsat 8 image processing and refers to region map from Forest Ministry. Accumulation score of environmental vulnerability index in study areas is moderate value, that means
environment condition must be considered, such as vegetation as ground cover and many others aspects. Some conservation forest and conservation areas are located in prone landslide areas, such as in Getasan District, Ungaran Barat District, and Sumowono District. Based on environment factors, that districts must be considered because of recorded data landslide incident in period January until Mei (2017) shown 16 landslide incidents located in Getasan Districts, 18 landslide incident in Ungaran Barat District, and 18 landslide incident in Somowono District. The most amount landslide incident in 2017 is located in Ungaran Timur District, but the environmental vulnerability score is smaller because some areas consist of production forest and shrubs. Vegetation density by NDVI algorithm processing in conservation areas in Getasan Districts about (0.030 - 0.844), while in conservation forest about (0.045 - 0.849). The range of NDVI value shows that density level, in conservation areas and conservation forest have rarely until high density level. Based on The Ministry of Forestry Republic of Indonesia, (2003), divided by density level are rarely (-1.0 – 0.32); moderate (0.32 – 0.42) and high (0.42 – 1) [6]. The rare vegetation density areas both in conservation areas and conservation forest should be done preventive efforts to minimize or reduce the risk of landslide disaster.

![Figure 9. Landslide Prone Areas in Semarang Regency based on the regulations from Directorate of Volcanology and Disaster Mitigation.](image)

![Figure 10. Environmental vulnerability areas in Semarang Regency](image)

5. Conclusions
Mapping of the potential landslide areas is needed to reduce the risk of disaster. Remote sensing and geographic information system to be used in this study to mapping the landslide areas and analysis of environmental vulnerability. The parameters to mapping landslide areas based on land cover, rainfall, slope, geological factors and soil types. The high human activity caused some changes in land cover, so to obtain actual land cover in study areas using remote sensing is based on Landsat 8 imagery processing. Scoring and weighting method is a spatial analysis which utilizes geographic information system. Values of scoring and weighting are based on the relevant literature review and regulations such as the regulations from Directorate of Volcanology and Disaster Mitigation to mapping accurate landslide areas in Semarang Regency. The result of landslide prone areas that be analyzed to know about the environmental susceptibility in landslide areas. Based on Perka BNPB No. 2/2012, indicators of
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References
[1] Department of the Interior U.S. Geological Survey. 2016. *Landsat 8 (L8) Data Users Handbook. Version 2*. Sioux Falls, South Dakota.
[2] Lillesand, T.M., Kiefer, R.W., and Chipman J.W. 2004. *Remote Sensing and Image Interpretation*. Fifth Edition. New york : John Wiley & Sons.
[3] National Disaster Management Agency (BNPB) Decree. No 2/2012 about *General Guidelines for Disaster Risk Assessment*.
[4] Pramono, G. H. 2008. Akurasi Metode IDW dan Kriging Untuk Interpolasi Sebaran Sedimen Tersuspensi. *Forum Geografi*, Vol. 22, No. 1, Juli 2008: 97 – 11.
[5] Taufik, M., Utama, W., and Firdaus, H.S. 2013. Environmental Baseline Imaging For Geothermal. Bandung : Proceedings, 2nd ITB Geothermal Workshop.
[6] The Ministry of Forestry Republic of Indonesia. 2003
[7] Urban Land Use Plan Semarang Regency 2011 – 2031