Application of remote sensing and analytical hierarchy process (AHP) for developing landslide vulnerability zone in Boja District, Kendal Regency, Central Java Province

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Abstract. Landslide is one of geomorphology process that can be a natural hazard for humans. An area has internal parameters that can cause landslide occurrences such as slope, lithology, rainfall, and hydrology. Furthermore, human activities can increase susceptibility for the landslide. Thus, the landslide vulnerability mapping is required to obtain potential of landslide susceptibility of an area. The study area is located in the Boja District. The goals are to determine the weight of internal factors which can cause vulnerable for landslide and to develop vulnerable landslide zone. The methods were remote sensing analysis using Digital Elevation Model (DEM) data and Analytical Hierarchy Process (AHP) to define the weight of internal parameters which cause a landslide. The results show that there are three levels of the vulnerable zone i.e. low, moderate, and high vulnerable levels of the landslide.

1. Introduction

Landslide is one of several geological processes that can become a disaster. Indonesia as a tropical country has a greater likelihood of happening, it is necessary more vigilance. Natural factors that play a role in controlling the presence of a disaster [1] include geological, edaphic, and climatological aspects that are very fulfilled by the conditions of the regions in Indonesia. Generally, in Indonesia landslide occurrence caused by relatively high rainfall, weathered rock, and steep slope. Its conditions are different between each location. Recorded by BNPB, in 2018 there have been 615 cases are scattered in Indonesia and 153 of them occurred in Central Java [2].

Boja Subdistrict is one of the sub-districts in Kendal Regency, it has encountered 3 landslides occurrence during 2014 - 2019, including December 29, 2014, in Pasigitan; November 10, 2016, at Ngabean and March 14, 2018, in Bebengan [2]. Referring to Kendal District Landslide Hazard Map [2], sub-districts in the southern part of Kendal Regency had moderate to high landslide potential hazards (Figure 1). Furthermore, Boja Subdistrict has vulnerability level to multi-disaster (flood, landslides, and drought) from low to moderate [3].

Based on the description above Boja sub-district has the potential for landslides, it is necessary to do a detailed study on the potential for landslide hazard in it. Due to remote sensing has been selected because of the large covering sub-district area, besides it's useful to identify visual changes in area due to landslides based on multitemporal imagery. The results of the remote sensing analysis need to be validated with field data to strengthen the results of the study.

2. Method

2.1. Study Area

Boja Subdistrict is astronomically located at 7°02′58″ LS to 7°08′53″ LS and 109°58′09″ BT to 110°21′85″ BT, with an area of 64.10 km2. Boja Sub-district located in the eastern part of the district
Kendal morphologically bounded by highs in the north and lower in the south, consisting of 18 sub-covering including Purwogodo, Kaligading, Salamsari, Blimbing, Bebengan, Boja, Metesih, Trisobo, Campurejo, Tampingan, Karangmanggis, Ngabean, Kliris, Puguh, Medono, Pasigitan, Leban and Banjarejo (Figure 2) [4].

Figure 1. Landslide hazard map of Kendal Regency, reddish-brown color indicates landslide hazard area tends to be high [2].

Figure 2. Topography map of the study area.

2.2. Image Processing
Remote sensing is a science or method that is useful to know the object information, territory, or natural phenomena in a place without the need of contact on-site [5]. Image processing is one of a method in remote sensing. On this research, image processing was carried out on Landsat 8 OLI/TIRS by comparing land use in Landsat images of 2017 with 2018. Landsat images of 2017 overlaid on Landsat images of 2018 to determine the initial of land use that indicates the landslide area. Systematically image processing performed from pre-processing, selecting the region of interest, supervised classification and
image interpretation. The stage of pre-processing is performed using the software ENVI 5.1 including atmospheric correction, image enhancement, and radiometric correction. Atmospheric correction using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH), due to the correction of this type can describe the condition of the target research areas corresponding actual conditions when capturing the image data [6]. The process of image enhancement works to increase the resolution of image quality by combining the composition of the low-resolution multispectral image with a high-resolution panchromatic image [7]. Gram Schmidt Pan Sharpening was chosen for the image sharpening process because theoretically, this process is able to soften the appearance of images by combining low-resolution multispectral images with high degree panchromatic imagery through the mechanism of simulation, replacement, and transformation of image data. The conversion value obtained from the initial resolution of 30 meters can be more accurate to a value of 8 meters resolution [8]. Radiometric correction is done because it has a role to eliminate radiometric distortion which decreases image quality. Radiometric distortion may occur due to the wide range and angle between satellites in space with the earth's surface also the position of the sun, thus affecting the ability of satellite sensors to record the object reflectance of the earth [9].

Mapping of land-use changes using the supervised classified method of maximum likelihood classification. This classification is based on the type of interpolation conducted delineation of areas that have specific land-use areas and describe the spectral appearance in other parts that have similarities in areas that have been conducted delineation. Land use classification that is interpreted includes forest heterogeneous, homogeneous forests, rice fields/plantations, settlements, and seating/moor. Furthermore, based on the classification process, land-use changes will be identified. Distribution of new open areas will be identified as potential landslide areas.

2.3. Analytical Hierarchy Process (AHP)
Landslides may occur as a result of natural and man-made factors. An area has geological characteristics which form slopes, both of it if interacting with rain will make an area has a vulnerability to landslide [1]. For that, in this study the parameters to be calculated using the AHP such as slope, geology characteristics, and rainfall. AHP is a process in decision making, in its calculation the parameters that influence decision making will be weighted [10]. In this study, the AHP calculation process was carried out using Expert Choice software 11.

Each parameter is created in the map view. In each map contains information for each criterion in the parameter value (determined in the range of 1 to 5). For example in the slope parameter consists of 5 criteria, each criterion is rated according to the effect on landslides. Furthermore, the entire parameter map that has been made is overlayed. For example in the slope parameter consists of 5 criteria, each criterion is rated according to the effect on landslides. This process was carried out with the help of ArcMap 10.3 software.

Delineation of landslide vulnerability zones is carried out by overlapping parameter maps, then calculated with the following calculations:

\[
\text{Landslide Vulnerability} = ((PV1 \times WV1) + (PV2 \times CV2) + (PV3 \times CV3))
\]

Where,
PV : Parameter Value
CV : Criterion Value

3. Result and Discussion
3.1. Land-use Changes
3.1.1. Images Correction
Identification of land use changes begins with correcting selected images. Landsat 8 OLI / TIRS imagery in 2017 and 2018 is obtained from USGS. Image correction process using ENVI 5.1 software. The
correction stage starts with atmospheric correction and image sharpening. Figure 3 can be an atmospheric correction image and image sharpening has been done. The results are superbly corrected images showed a better resolution.

![Figure 3](image)

**Figure 3.** Comparison of spectral features of Landsat 8 imagery in Boja District. (A) 2017 imagery and (B) 2018 imagery that has not been corrected. (C) 2017 imagery and (D) 2018 image that has been corrected.

Furthermore, the image correction process is followed by a radiometric correction to reduce radiometric distortion in the image. Table 1 presents image radiometric correction data expressed in the Digital Number (DN). DN value converted into the reflectance is shown in Table 2.

**Table 1.** Minimum and maximum Landsat Digital Number (DN) data values of 8 multispectral channels from the years of data acquisition 2017 and 2018.

| Band Number     | 2017          | 2018          | 2017          | 2018          |
|-----------------|---------------|---------------|---------------|---------------|
|                 | Min (DN)      | Max (DN)      | Min (DN)      | Max (DN)      |
| Band 1 (Coastal Aerosol) | 1691          | 10711         | 1808          | 12908         |
| Band 2 (Blue)   | 631           | 9705          | 359           | 11550         |
| Band 3 (Green)  | 646           | 10692         | 737           | 12639         |
| Band 4 (Red)    | 217           | 12216         | 217           | 14285         |
| Band 5 (NIR)    | 262           | 6561          | 135           | 8346          |
| Band 6 (SWIR 1) | 205           | 12462         | 64            | 15364         |
| Band 7 (SWIR 2) | -166          | 14287         | -281          | 17383         |

**Table 2.** Minimum and maximum Reflectance data value ($P_\lambda$) Landsat 8 multispectral channels from the year of data acquisition 2017 and 2018.

| Band Number     | 2017          | 2018          | 2017          | 2018          |
|-----------------|---------------|---------------|---------------|---------------|
|                 | Min ($P_\lambda$) | Max ($P_\lambda$) | Min ($P_\lambda$) | Max ($P_\lambda$) |
| Band 1 (Coastal Aerosol) | 0.169         | 1.000         | 0.181         | 1.000         |
| Band 2 (Blue)   | 0.063         | 0.971         | 0.036         | 1.000         |
| Band 3 (Green)  | 0.065         | 1.000         | 0.074         | 1.000         |
| Band 4 (Red)    | 0.022         | 1.000         | 0.022         | 1.000         |
Band Number | 2017 | 2018 |
|-------------|------|------|
|              | Min ($P_{\lambda}$) | Max ($P_{\lambda}$) | Min ($P_{\lambda}$) | Max ($P_{\lambda}$) |
| Band 5 (NIR) | 0.026 | 0.656 | 0.014 | 0.835 |
| Band 6 (SWIR 1) | 0.021 | 1.000 | 0.006 | 1.000 |
| Band 7 (SWIR 2) | 0.000 | 1.000 | 0.000 | 1.000 |

The deviation of DN value does not give any indication in the next process. However, in the supervised classification of object reflectance values on the earth's surface from electromagnetic waves emission is needed [11]. In general, objects that have a smoother surface and are not affected by surface water have a higher reflectance value than objects with rough surfaces and are affected by surface water. Objects with a rough texture reflecting electromagnetic waves are not parallel to the sensor, while the water absorption of electromagnetic waves. Both of these trigger a decrease in the intensity of the reflection of the electromagnetic waves that the satellite will later receive.

3.2. Supervised Classification

Once the image correction is completed the next stage is to perform image processing such as supervised classification. The purpose of the classification is to map the condition of the land-use in Boja District area which is the target of research. Stage processing that is performed includes selecting the Region of Interest (ROI) and processing the data based on ROI. Identification and selection of ROI refer to the spectral appearance of each object. Restrictions on classification classes are divided into 5 classes including heterogeneous forests (class 1), homogeneous forests (class 2), rice fields / plantations (class 3), settlements (class 4), and exposed areas / moor (class 5). Each object that is being targeted ROI analysis was bounded to an area totaling 30 units, meaning that in each Landsat 8 corrected it has 150 units of ROI (Figure 4).

In making ROI, it must fulfill three fundamental aspects including the similarity of spectral appearance, limited reference data quantity or ROI, and variation in reflectance value for each channel. The first two aspects have been done before, then the third aspect is obtained from the results of the delineation process with a range of minimum and maximum reflectance values averaged on each channel which is limited by ROI (Table 3). In the supervised classification process Maximum Likelihood types, reflectance values will be considered as part of a class of objects (Figure 5).

| Band Number | Reflectance Value Year 2017 | Reflectance Value Year 2018 |
|-------------|-----------------------------|-----------------------------|
|              | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
| Band 1      | 0.212   | 0.225   | 0.228   | 0.272   | 0.238   | 0.189   | 0.197   | 0.201   | 0.232   | 0.208   |
| Band 2      | 0.063   | 0.072   | 0.078   | 0.122   | 0.089   | 0.082   | 0.087   | 0.093   | 0.123   | 0.102   |
| Band 3      | 0.105   | 0.113   | 0.135   | 0.168   | 0.140   | 0.093   | 0.099   | 0.112   | 0.132   | 0.121   |
| Band 4      | 0.052   | 0.059   | 0.075   | 0.139   | 0.115   | 0.055   | 0.060   | 0.071   | 0.111   | 0.115   |
| Band 5      | 0.299   | 0.288   | 0.393   | 0.221   | 0.194   | 0.303   | 0.284   | 0.335   | 0.201   | 0.178   |
| Band 6      | 0.127   | 0.162   | 0.195   | 0.211   | 0.123   | 0.129   | 0.153   | 0.157   | 0.191   | 0.098   |
| Band 7      | 0.053   | 0.071   | 0.090   | 0.179   | 0.074   | 0.056   | 0.068   | 0.074   | 0.154   | 0.056   |
The results of the supervised classification process are converted into maps. Each map contains information on 5 object classes (heterogeneous forests, homogeneous forests, rice fields/plantations, settlements, exposed areas/moor) studies. Each object class overlaid on an open area class. Furthermore, the presence of landslides identified from changes in objects into open areas (Figure 6). Changes in class values are described as follows class 1 to 5 (value 6), class 2 to 5 (value 7), class 3 to 5 (value 8), class 4 to 5 (value 9), and the combination of the existence of the same open area (value of 10), and the existence of a new open area or expansion from the previous year (value 5 from the data in 2018). Analysis results indicate that almost all areas in Boja Subdistrict which are indicated to have potential landslides. The extent of land-use change into an exposed area is presented in Table 4.
Table 4. The value of land-use area change resulting from overlay images in 2017 and 2018 which is processed using ArcMap software 10.3.

| Area Typical/Class                        | Value | Area (km²) |
|-------------------------------------------|-------|------------|
| Total area in Boja District               | -     | 63.82      |
| Heterogeneous forest into an exposed area | 6     | 0.45       |
| Homogeneous forest into an exposed area   | 7     | 0.37       |
| Field/plantation into an exposed area     | 8     | 4.76       |
| Settlement into an exposed area           | 9     | 0.44       |
| Initial exposed area                      | 10    | 2.87       |
| Expanding or newest exposed area          | 5 (from 2018 Landsat data) | 4.25 |

Figure 6. Distribution of land-use changes of Boja District from 2017 to 2018

3.3. Determination of Parameter Class Weight Using AHP

Determination of the weight of each parameter using the AHP method was carried out on 3 parameters affecting the landslide in the study area. The three parameters are geological characteristics, slope, and rainfall. The geological characteristics are represented by lithology based on regional geology. Determination of weight is done by using Expert Choice 11 software. Determination of the dominance of the weight values of each parameter and data collection (qualitative and quantitative) was done by filling the semantic differential questionnaire. Questionnaires were given to 14 respondents including 7 academics, 3 government (as policyholders) and 4 public respondents.

The questionnaire results are entered into Expert Choice 11 software to obtain the ratio inconsistency before proceeding to the next stage. In this software, the input results are processed automatically by
considering the dominance value of each parameter that appears. The ratio inconsistency of 14 respondents was generally below 0.1 (Table 5). The final results of processing at the stage of appearance of the AHP weight value in the form of four data graphs which include: performance sensitivity graph, dynamic sensitivity graph, gradient sensitivity graph, and head to head sensitivity graph. Each of the graphs has its own role in drawing conclusions about the value of the data obtained. The type of performance sensitivity graph shows the tendency to dominate the highest parameter values with others in the bar graph. The type of dynamic sensitivity describes the deviation of the results of each alternative result from one another. The gradient sensitivity type shows the intersection of the highest criterion value with the highest alternative. Type to find out the alteration between alternatives results if there is a difference in value in the form of a graph head. The results of the four graphs that appear can be seen in Figure 7.

Through the results are shown in Figure 7, the weight value distribution of each parameter that is raised. Premises parameter value weighting based on calculation sequentially AHP: annual rainfall of 34.6%; the slope of 33.8% and lithology of 31.6%. These results provide an indication that according to the questionnaire distributed, the problem that is likely to affect landslides in the target area is rainfall as the most influential factor in landslide events.

3.4. Geological Characteristic

The geological characteristics of this research are represented by lithology area of research. The lithology of the research area was identified from the regional geological map of the Magelang-Semarang sheet [12]. In the study area, there are 5 formations including Gajahmungkur Volcanic Rock (Qhg), Jongkong Formation (Qpj), Kaligesik Formation (Qpj), Kaligesik Formation (Qpk), Kaligetas Formation (Qpkg), and Kerek Formation (Tmk). Every rock formation has a special characterization that gives rise to different class assessments. Descriptions of class values in each formation are based on the conditions of formation members in the field and the tendency towards landslides. The Kerek Formation (Tmk) is the oldest formation in the study area but many are exposed on the surface in various conditions (weathered - fresh) given grade 5. The claystone is the acting as a sliding field triggering a landslide, especially if the rocks above are not resistant or weathered. In a sequence, the grades 4 and 3 are given to the Jongkong Formation (Qpj) and the Gajahmungkur Volcanic Rock (Qhg) because they are found in moderately weather to highly weathered conditions. The Kaligetas Formation (Qpkg) with
volcanic rock members slightly weathered conditions until the moderately is given class 2 value, while the Kaligesik Formation with slightly weathered lava members is given a grade 1 grade. Lithology class divisions illustrated in Figure 8.

Table 5. Criteria and class values of lithology parameters refer to regional geological formations.

| Code | Affiliation | Value of Ratio |
|------|-------------|----------------|
| R1A  | Geology Engineering student from Universitas Diponegoro | 0.0088 |
| R2A  | Lecturer in Geology Engineering from Universitas Diponegoro | 0.0511 |
| R3A  | Lecturer in Geology Engineering from Universitas Diponegoro | 0.0000 |
| R4A  | Lecturer in Geology Engineering from Universitas Diponegoro | 0.0511 |
| R5A  | Geology Engineering student from Universitas Diponegoro | 0.0511 |
| R6A  | Geology Engineering student from Universitas Diponegoro | 0.0511 |
| R7A  | Geology Engineering student from Universitas Diponegoro | 0.0511 |
| R1S  | An Employee of Dinas Lingkungan Hidup dan Kehutanan, Semarang | 0.0511 |
| R2S  | An employee of Dinas Energi dan Sumberdaya Mineral, Semarang | 0.0511 |
| R3S  | Mijen District Apparatus | 0.0511 |
| R1M  | Residents of Jatisari Urban Village | 0.0511 |
| R2M  | Residents of Ngabean Village | 0.0174 |
| R3M  | Residents of Kliris Village | 0.0511 |
| R4M  | Residents of Pasigitan Village | 0.0700 |

3.5. Rainfall

The making of the annual rainfall map is based on the 2014 Jragung Tuntang Pemali Comal Balai PSDA climatology data. The reference data totals 14 data recording points spread from the western to the eastern regions of the northern coast of Central Java, especially around large watersheds. From a total of 14 points, there are 8 points that are located close to the research area where the data can be interpolated by the distribution of values. The results of the interpolation of annual rainfall data (Table 6) are divided into 5 classes as in Figure 9.
Figure 8. Lithological Map variations based on regional geological formations and the class score for each criterion.

Table 6. Annual rainfall data from the climatology post around the study area.

| Easting  | Northing | Code | Value | Location             |
|----------|----------|------|-------|----------------------|
| 415575.6 | 9231444  | 1    | 1813.4| Kr. Tengah / Kaliwungu |
| 415972.1 | 9231445  | 2    | 2260.8| Mangkang Waduk       |
| 411276.6 | 9213787  | 3    | 4008.6| Kali Gading          |
| 404548.8 | 9224910  | 4    | 2193  | Juwero / Bd. Juwero  |
| 442995.3 | 9221389  | 5    | 2231.8| Pucanggading         |
| 410769.6 | 9214291  | 6    | 2144.3| Karangroto           |
| 433127.7 | 9230283  | 7    | 2212.9| Post BPSDA Jratun    |
| 430075.4 | 9216937  | 8    | 2799.4| Gunung Pati          |

3.6. Slopes
In general, the Boja sub-district has flat morphometry to sharp hilly with an elevation of 139.6 to 1479.8 above sea level (Figure 10). The slope class classification was made using slope analysis tools in Arc Map 10.3 software based on the image of the Digital Elevation Model (DEM) obtained from the DEMNAS with a resolution of 5 meters. Slopes are classified into 5 classes according to percent rise with a range of values from grades 1 to 5 as follows 0 -10%, 10.1 - 20%, 20.1% -30%, 30.1% -40% and> 40% (Figure 11).
Figure 9. Distribution of annual rainfall and class score for each criterion.

Figure 10. 3D view of Boja Subdistrict based on DEM without scale.
3.7. Landslide Vulnerability Zone

Determination of landslide vulnerability zones is done by calculating using ArcMap 10.3 software raster calculator method. The whole map parameter is converted into a raster form, then the calculation is performed by equation (1). From the calculation results obtained range values from 1.32 to 4.67. The range of values is then distributed to make classes according to the level of vulnerability. Distribution is made as follows: the values of 1.32 to 2 are areas with low landslide vulnerability; values of 2.01 to 3 have moderate levels; values 3.01 to 4 have high levels, and a value of 4.01 to 4.67 is categorized as very high vulnerability. Distribution of range value classes can be seen in Figure 12.

Verification of the results of the landslide vulnerability zone interpretation based on remote sensing and AHP calculations is carried out in past landslides. Historically, landslides have occurred in Pasigitan, Ngabea, and Bebengan. The Pasigitan and Bebengan Village Areas have a low to high vulnerability, while Ngabea Village is low to intermediate. However, some areas in other villages that have a high level of vulnerability did not experience landslide. The three locations that have experienced landslides are in the annual rainfall class of 4. Based on this, it can be concluded that the most influential factor in landslides in the study area is rainfall. This is in accordance with the weighting that has been done with AHP.

The Boja Sub-district landslide zonation map can be used as a reference in making landslide mitigation policies. Furthermore, to find out the level of landslide susceptibility in the study area, further studies are needed. Addition of human factors is needed to ensure the level of vulnerability of landslides because landslides are very influential on humans.
4. Conclusion

Boja several villages in the district have the potential for disaster is high enough when compared with districts in Kendal Regency. Changes in land use from 2017 to 2018 can be seen from remote sensing and can use for preliminary study for landslides vulnerability. The distribution of regions that changes in land use is quite significant, spreading evenly across the area in District Boja both have a history of disaster or not. AHP weighting was carried out on three landslide parameters, namely: slope (33.8%), geological characteristics (31.6%) and rainfall (34.6%). The weighting of the three parameters influencing landslides shows that the most influential factor on landslides in Boja Subdistrict is rainfall (34.6%). Landslide vulnerability in Boja Subdistrict is divided into 4 classes, namely low (1.32-2), medium (2.01-3), high (3.01-4) and very high (4.01-4.67).

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