Landslide hazard and risk assessment for Ambon city using landslide inventory and geographic information system

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Abstract. Ambon Island is a volcanic arc and included in the territory of the archipelago of small islands that have a degree of high vulnerability to natural disasters, such as erosion and landslides on the slopes of certain conditions. Landslides that occur various in the city of Ambon, usually occurs during the rainy season so that the impacts that occur not only occurs on site but also off site with amount of large sedimentation. This paper presents the application of digital image analysis techniques and tools Geographic Information Systems to describe the degree of landslide hazard and risk areas in locations Ambon City, Moluccas. The cause of the landslide is analyzed through various thematic layers attribute data for the study area. Landslide hazard zonation assessment is done by using historical data, while the landslide risk analysis is done by using the results of landslide hazard assessment and socio-economic factors by using geospatial models. The risk assessment of landslides can be used to estimate the risk to the population, property and infrastructure. The study results in the form of a map of landslide hazard and the risk of landslides that act to support urban spatial planning based on disaster mitigation.

1. Introduction

Ambon Island is part of the Moluccas islands are volcanic arc [1] and included in the territory of the archipelago of small islands are associated with subduction zones that have a high degree of vulnerability to natural disasters, such as erosion and landslides on the slopes of certain conditions [2].

The study of landslides mostly done by means of theoretical, case studies and the use of advances in technology have been proposed and published in the journal articles, conference proceedings and books. One application of technological advances associated with landslides is the overlay spatial analysis techniques using geographical information systems (GIS) to produce vulnerable and not-vulnerable zones. GIS is a form overlay method that analyzes the factors that influence the distribution of ground motion hazard or landslides [3]. While Raster-based GIS has an important role in the assessment of landslide hazard [4-6]. In Indonesian of vulnerability to landslides utilizing GIS based application system has been widely used as was done by Kurniawan [7], Hasnawir [8], Destriani and Pamungkas [9], Nugroho [10] and others. While there are some researchers have mapped landslide hazard zonation based on historical data as proposed by Chau [11], Guzzetti [12], Faizana [13], and others. Likewise, susceptibility of landslide in the city of Ambon on Wai-Ruhu watershed has been done by Pattiselalo [14], but does not reach the entire region of Ambon city and also not based on the inventory of landslides.

Preliminary study, shows Ambon Island region is an area that is prone to landslide hazards with catastrophic avalanche and flood intensity from year to year is estimated to increase by more than 60%
During the years 2010 - 2013, landslides and flooding in the region has resulted in loss of life, destruction of homes, displacement and land use change. Landslide that occurred in scattered in five subdistricts of Ambon city namely, the Bay of Ambon, bay of Ambon Baguala, South Leitimur, Sirimau and Nusaniwe with landslide in number as many as 113 (Figure 1). Given the landslide in the Ambon city from year to year is high enough then do mapping the distribution of landslide hazard by using GIS to be used to provide information of locations that have a risk of landslide hazard, and also serve to prevent potential risks to minimize the impact of landslide hazard, and even serve as land use planning.

Figure 1. Location of the study areas in the Ambon city, Moluccas Indonesia

2. Theory and method
Landslides are a displacement of material forming of the slope [16], may be the original rock, soil weathering, material pile or a combination of these materials [17] which moves downward and out to the slopes or falling towards the foot of the slopes [18] because control gravity. Type landslides based by landslide material is divided into three sections [19], the rocks, debris material and soil. Landslides of this type much happening in Ambon city. While the main group of mass movement according to Hutchinson [20] consists of creep and landslide which are further divided into sub-groups slides, flows, falling and slide. According Zaruba and Mencl [21], the cause of landslides is a change in the level of slope, slope material weakening due to weathering, increased water content, changes in the vegetation cover of the slope and the excess load. Landslides in the area of research is the type of slide rotation and flow of rocks, which are identified from soil cracks due to the penetration of rain water and land alteration [2].

Ambon City area is geographically located between 03°43′14.73″ south latitude to 03°41′20.95″ south latitude and 128°4′41.35″ east longitude until 128°18′6.31″ east longitude, with an area of approximately 359.48 square kilometers (Figure 1) and a population of 390,825 people [1, 2]. Topographical conditions of Ambon city, amounting to 73% of the mainland region can be classified hilly to steep slope, with a slope of over 20% (Figure 2). While 17% of the land area can be classified more flat or gently sloping with a slope of less than 20% [2]. In geomorphology research area is organized into three groups of units,
namely i) unit hilly lowland (slope 3°-8°), composed by alluvium of mostly wetlands, coral limestone, conglomerates occupy lowland fragments covering the foothills to the area beach; ii) unit undulating hills (slope 80-150) who occupy the legs of the mountains with a gentle slope, is occupied by sedimentary rocks klastika like sandstone, clays and conglomerates; and (iii) unit undulating hills coarse (slope 150-300), found in approximately 73% of Ambon Island. Generally formed by volcanic rock like lava, volcanic breccias, which generally characterize rock breakthrough in the form of a steep hill with narrow valleys [22]. Based on the geological map of the Ambon city (figure 3 [22]), its stratigraphic formations composed by oldest to youngest are as follows: Limestone coral (Ql), Alluvium (Qa), Granite Ambon (Ti), volcanic rocks Ambon (Tpav), Formation Kanikeh (TRJk) and ultramafic rocks (JKU).

![Figure 2. Topographical map of the study areas in the Ambon city](image)

To determine the distribution of hazard and the risk of landslides in the Ambon city, used GIS with weighting techniques and overlay. The determination of the types class of landslides potential are divided into two groups of criteria [14], ie: (a) Group of criteria is based on the natural physical aspects (aspects of vulnerability) include slope, soil, rocks making up the slope, rainfall, land use, seismicity and fault. (b) Group criteria based aspect of human activity (aspects of risk) include cropping, cutting slopes, construction, and population density.

To measure the level of landslide hazard can be determined based on seven natural physical parameters consisting of slope, soil, rocks making up the slope, rainfall, land use, seismicity and fault. These parameters are then given a weighting according to the size of the effect of these parameters on the occurrence of landslides which refers to the Ministry of Public Works [14]. In detail, the weighting for these parameters are presented in Table 1.
The assessment of landslide hazard level towards of the physical aspects of nature done via summation of value weighting of the seven indicators on the physical aspect of nature. Then do the quantitative methods that utilize spatial analysis, namely using GIS overlay method, using a prediction model of the zonation of landslide hazard with equation [3,23,24] following:

\[
L_{HZ} = (0.3 \times F_{\text{LE}}) + (0.2 \times F_{\text{CH}}) + (0.15 \times F_{\text{GL}}) + (0.1 \times F_{\text{G}}) + (0.1 \times F_{\text{JT}}) + (0.05 \times F_{\text{P}})
\]  

where: \(L_{HZ}\): landslides hazard zonation, \(F_{\text{LE}}\): slope, \(F_{\text{CH}}\): rainfall, \(F_{\text{GL}}\): land use, \(F_{\text{G}}\): rocks making up the slope, \(F_{\text{JT}}\): soil type, \(F_{\text{G}}\): seismicity, and \(F_{\text{P}}\): fault.

Once generated new spatial data, data classification is done on certain criteria to the data studied by giving a score is divided into four classes, then in the totalizing and by dividing the difference between the value of the four classes (zones) level of susceptibility to landslide hazards in areas landslide hazard obtained by the formula [25]:

\[
\text{Class Interval} = \frac{N_t - N_r}{n_{\text{class}}}
\]

where \(N_t\): maximum data, \(N_r\): minimum data and \(n_{\text{class}}\): the amount of the desired class.

Map of the distribution of landslide hazard used as reference landslide hazard mapping. The value of the risk of landslides that resulting from the summing of value the hazard and scores of density (space settlement). Mathematically, the value of the risk of landslides is calculated by the formula [11] below:

\[
R = H + E
\]

with \(R\) = risk, \(H\) = hazard and \(E\) = exposure (population density).
### Table 1. Weighting natural physical parameters

| Parameter                                | Verification               | Weight | Score |
|------------------------------------------|----------------------------|--------|-------|
| **Slope**                                | > 40 %                     | 5      | 5     |
|                                          | 20 – 40 %                  | 4      |       |
|                                          | 10 – 20 %                  | 3      |       |
|                                          | 0 – 10 %                   | 2      |       |
|                                          | 30 %                       | 3      |       |
| **Rainfall**                              | > 200                      | 5      |       |
|                                          | 180 – 200                  | 4      |       |
|                                          | 160 – 180                  | 3      |       |
|                                          | 140 – 260                  | 2      |       |
|                                          | < 140                      | 1      |       |
| **Land use**                              | Settlement, airports       | 5      |       |
|                                          | Farmlands, gardens, shrubs | 4      |       |
|                                          | Thickets, open land        | 3      |       |
|                                          | Prairie                    | 2      |       |
|                                          | Forest                     | 1      |       |
| **Rocks making up the slope**             | Alluvium, Ambon volcanic rocks, limestone coral | 5 |       |
|                                          | Granite Ambon              | 10 %   | 3     |
|                                          | Ultramafic rocks and formations | 15  |       |
|                                          | kanikeh                    | 1      |       |
| **Type of soil**                          | Regosol                    | 5      |       |
|                                          | Kambisol and gleisol       | 3      |       |
|                                          | Alluvial, litosol          | 1      |       |
| **Seismicity**                            | > 5 SR                     | 5      |       |
|                                          | 4 – 5 SR                   | 4      |       |
| **Fault**                                 | Yes                        | 5 %    | 5     |
|                                          | No                         | 1      |       |

3. **Results and discussions**

The distribution mapping of the landslides hazard of Ambon city conducted in 2015 based on data from the years 2010–2014. After establishing the value of the distribution of avalanche danger, then the landslide hazard zone index is calculated for all parameters in every cell. Using the number of landslide hazard zone for each cell, prepared distribution maps of landslide hazard study area (Figure 4). Based on the cumulative value of distribution of landslide hazard, the area of landslide is classified into 4 zones relative instability. Here are the results of recapitulation of landslide hazard value on different zones are presented in Table 2.

Results of the assessment and classification of landslide hazard level that dominant in the study area is spread to the subdistricts cells is calculated based on the total area of Ambon city (Table 3) are levels of low or stable capacity (8.12%), level of moderate or unstable capacity (30.30 %), level of high capacity or unstable (47.12%) and levels of very high capacity or critical (14.46%).
Table 2. Landslide hazard values on different zones

| Landslide Hazard Zonation | Landslide Hazard                          | Area, (sq.km) | Area, (%) |
|---------------------------|-------------------------------------------|---------------|-----------|
| 2.10 – 2.73               | Very highly hazardous (critical)          | 51.77         | 14.46     |
| 2.74 – 3.38               | Highly hazardous (unstable)               | 168.72        | 47.12     |
| 3.39 – 4.02               | Moderately hazardous (unstable)           | 108.48        | 30.30     |
| 4.03 – 4.65               | Low hazardous (stable)                    | 29.08         | 8.12      |
| Total                     |                                           | 358.05        | 100.00    |

Figure 4. Landslide hazard map of Ambon city

Map of the distribution of the landslide hazard has been filed, used as reference of landslide hazard risk mapping in residential space. Assessment of the hazard risk map can be valid until the next five years. The dynamics of Ambon city with a population will reach over 450 thousand inhabitants in the coming years would bring the impact fulfillment of basic infrastructure facilities and other types of new activities. One of the most basic needs are settlements. To meet these needs, the government of Ambon perform spatial planning appropriate settlement area defined in the RTRW [1]. Where the settlements area is divided into two patterns of space, namely a) rural settlement areas with major agricultural activities including natural resource management, government services, social services and economic activity, and b) urban settlement area with the composition as a function of the area of urban settlements, centralization and distribution of government services, social services and economic activities. However, of the analysis results overlay between RTRW Ambon map with maps of landslide hazard distribution, indicate that some areas designated as settlements areas located in areas with high landslide hazard and potential as presented in Figure 5 and Table 4.
### Table 3. Recapitulation of attribute data of the landslide hazard distribution in Ambon city

| Subdistrict             | The Area of Landslide Hazard Zones, (sq.km) | Low hazardous | Moderately hazardous | Highly hazardous | Very highly hazardous |
|-------------------------|--------------------------------------------|---------------|----------------------|-----------------|-----------------------|
| Teluk Ambon             | 6.27                                       | 33.12         | 44.66                |                 | 9.37                  |
| Teluk Ambon Baguala     | 5.63                                       | 14.45         | 19.97                |                 | 0.06                  |
| Leitimur Selatan        | 8.44                                       | 19.16         | 20.74                |                 | 2.17                  |
| Sirimau                 | 6.36                                       | 22.57         | 40.39                |                 | 16.34                 |
| Nusaniwe                | 2.38                                       | 19.18         | 42.96                |                 | 23.83                 |
| Total                   | 29.08                                      | 108.48        | 168.72               |                 | 51.77                 |
| Area, (%)               | 8.12                                       | 30.30         | 47.12                |                 | 14.46                 |

**Figure 5. Landslide risk map of Ambon city**

In addition that to the development of the area designated as settlement areas can be identified closure of land which include gardens, forests, settlements, fields and moor. As a result, there will be forests and gardens were converted into settlements, and this of course is a policy that needs to be considered given the area located in areas with high landslide hazard.
Table 4. Recapitulation of attribute data of the landslide hazard risk in Ambon city

| Subdistrict             | The Area of Landslide Risk Zones, (sq.km) | Low risk | Moderately risk | Highly risk | Very highly risk |
|-------------------------|------------------------------------------|----------|-----------------|-------------|------------------|
| Teluk Ambon             |                                          | 19.06    | 54.66           | 6.16        | 13.54            |
| Teluk Ambon Baguala     |                                          | 12.12    | 21.31           | 4.34        | 2.34             |
| Leitimur Selatan        |                                          | 20.20    | 26.51           | 3.74        | 0.06             |
| Sirimau                 |                                          | 15.57    | 29.26           | 26.18       | 14.65            |
| Nusaniwe                |                                          | 16.98    | 35.96           | 16.61       | 18.80            |
| Total                   |                                          | 83.93    | 167.70          | 57.09       | 49.39            |
| Area, (%)               |                                          | 23.44    | 46.84           | 15.93       | 13.79            |

The validation process of landslide hazard zone by comparing the modeling of the threat of landslides with landslides inventory 2010-2014. With the value of the villages/wards represent the whole territory of the village/wards although there are some villages threatened by landslides. This data validation is also carried out site surveys in each village/wards based on the hazard zone (Figure 6). From the location survey there is a topographic difference, natural conditions and land alteration which reflects the landslide hazard zone of the location. The distribution of occurrences of landslides in Ambon occurred around 113 events over the past four years in five subdistricts (30 villages and 20 wards) that suitable modeling of landslides distribution maps. Modeling results are made using data of the 2015 years while the data validation using the previous four years. The analysis results obtained by hazard zone of landslide occurrences of the total landslide occurrences in Ambon city as presented in Table 5.

Table 5. Validation of the Landslide hazard zone values of all cells in the study area

| Subdistrict             | Validation of the Landslide Hazard Zonation | Low hazardous | Moderately hazardous | Highly hazardous | Very highly hazardous |
|-------------------------|---------------------------------------------|---------------|---------------------|------------------|-----------------------|
|                         | $\Sigma_{\text{Landslides}}$ | %             | $\Sigma_{\text{Landslides}}$ | %               | $\Sigma_{\text{Landslides}}$ | %               | $\Sigma_{\text{Landslides}}$ | %               |
| Teluk Ambon             | 4                                           | 3.54          | 9                   | 7.96            | 2                     | 1.77            |
| Teluk Ambon Baguala     | 6                                           | 5.31          | 8                   | 7.08            |                       |                 |
| Leitimur Selatan        | 3                                           | 2.65          | 7                   | 6.19            | 2                     | 1.77            |
| Sirimau                 | 7                                           | 6.19          | 21                  | 18.58           | 10                    | 17.70           |
| Nusaniwe                | 2                                           | 1.77          | 7                   | 6.19            | 15                    | 13.27           |
| Total                   | 22                                          | 19.47         | 52                  | 46.02           | 39                    | 34.51           |

In a systematic study of landslide risks can be assessed and managed through mitigation measures are appropriate. Maps of the hazard and risk landslide usually the end product of the landslide mapping as a basis for decision making. This decision is usually in the form of technical preventive measures, management regulation or a combination of both. The results provide a scientific background to estimate the landslide risk areas, to assist management slope and land use planning in the area of research, and can be used as a basis for decision making for the authorities. The method used in this study can be used for the planning and assessment of hazard management, though less accurate in the specific scale when
viewed from the heterogeneity of the local geology and geography. However, to reduce the level of vulnerability in areas with degree of certain vulnerability, necessary efforts mitigation landslide hazard to enhance protection of the region from the threat of landslides. These efforts include the technical engineering and structures of artificial such as retaining walls landslide as a retaining wall and drainage channels to reduce the saturation level of water in the soil at certain points, terracing of land to reduce soil erosion, planting a tree with strong roots bind the soil but trunked light on the upper and middle slopes are steep, and so forth. As well as the efforts of the engineering mindset of communities to have a high awareness in applying the principles of sustainability in the use of space through education, information dissemination, training, etc.

4. Conclusions

The very high parameter in influencing the threat of landslides in Ambon city is the slope, rainfall and types of rocks making up a layer of soil. Slope of more than 40% by lithology clay or silt has a great influence on the occurrence of landslide hazards. Subdistricts that have a region that is under threat of

Figure 6. Several Documents of occurrences landslides in Ambon city
high landslide hazard are the subdistrict Sirimau and Nusaniwe, because it has a steep slope and lithology constituent consisting of clay or silt. Both these areas also occupy a high landslide risk zone.

Based on modeling methods of vulnerability level of the landslide inventory is known that 39 cases (34.51%) landslide belong to the critical vulnerability, 52 cases (46.02%) at the level of high vulnerability, and 22 cases (19.47%) included in a moderate vulnerability.

Mitigation is required to avoid the occurrence of landslides on record the location of frequent landslides with regional planning converted into green open spaces and reforestation landslide area, as well as a basis for decision making for the authorities to the arrangement and construction of residential space conservation.

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