Utilization of Geographic Information Systems (GIS) for Mapping Landslide Prone Areas in Kendari City

La Ode Amaluddin1*, Rahma Musyawarah1, La Il2, Akbar Tanjung1
1 Department of Geography Education, Halu Oleo University, Kendari
2 Department of Primary Teacher Education, Halu Oleo University, Kendari

*laode.amaluddin@uho.ac.id

Abstract. Landslides that occurred in Kendari City from the past few years have caused casualties, precisely in 2017 in Kampung Salo, Kendari District. The occurrence of landslides is influenced by several factors, namely from the type of soil, rainfall, slope and land use. This research aims (1) To map landslide prone zones using geographic information systems; and (2) To produce information to find out landslide-prone zones so that they can be avoided. The research method used was overlay method of analysis techniques, which was through scoring and weighting. The results of the landslide-prone map study were made using GIS with ArcSIG 10.1 software application through the overlay process in the form of shp format. Furthermore, adding up all parameter scores so that the minimum and maximum values of the city of Kendari are obtained for areas not prone to landslides of 3405.09 ha or 12.69% covering the sub-districts of Kambu, Baruga, Poasia, Mandonga and some regions, the area is prone to landslides of 5574.34 ha or 20.78% covering the Abeli sub-district, Baruga, Puwatu area which is quite prone to landslides of 12041.48 ha or 45% covering the Abeli sub-district, Baruga, a small portion of Kaida, Kambu, Mandonga, Puwatu, and Wua-Wua in areas that dominate potential prone to landslides of 40.78 ha or 1.27% covering parts of Abeli, Kendari and Kendari Barat sub-districts, while areas that are very prone are 4038.34 ha or 15.05%, which include Kendari, Kendari Barat, Mandonga, Abeli and part small sub-districts of Poasia, Puwatu, and Baruga.

1. Introduction
Landslide is a phenomenon that moves as forming slopes, shattered materials, soil, or mixed materials, moving down or out of the slope [1]. This phenomenon is caused by natural and anthropogenic factors [2]. Landslides are included in the category of geological natural disasters that can cause fatalities and huge material losses, such as silting, disruption of traffic lanes, damage to agricultural land, settlements, bridges, irrigation channels and other physical infrastructure [3]. Furthermore, studies conducted by the Center for Research on the Epidemiology of Disasters (CRED) revealed that landslides caused more than 2.5 million people to become homeless during the first decade of the 21st century [4]. Indonesia is included in disaster prone areas, including landslides. This relates to Indonesia's geographical location in the highlands, hills and mountains. The National Disaster Management Agency states 40.9 million people live in landslide-prone areas [5]. Areas with a large potential for landslides are Central Java, West Java and East Java [6]. The National Disaster Management Agency noted that up to 2019 there had been 539 landslide disasters that caused 5,457 fatalities, 1,191 damaged and submerged houses, and 43 public facilities were damaged [7].

Kendari City is located in the southeast of Sulawesi Island. Based on data, during 2017-2018 there were at least 2 landslide incidents that resulted in 6 houses of residents severely damaged in Gunung Jati and Tipulu Kelurahan [8]. In addition, the disaster also caused 1 resident in the Tobuha District to die [9]. Landslides that occur in these areas, due to the topography of this region is a combination of plains, hills and coastal areas. Kendari City area is dominated by slope of 3-40%. In addition, Kendari City has high rainfall intensity in February-June [10] which can be a trigger for landslides in the region. What's more, rampant deforestation, forest encroachment and land clearing activities that cause rainwater cannot be absorbed so that it falls carrying slope material.

One effort to mitigate landslides is by mapping disaster-prone areas. Mapping of landslides can be done through the use of Geographic Information Systems (GIS) with overlapping or overlay methods of landslide parameters. These parameters include climate, relief, geomorphological processes, rocks and their structures [11]. The land use is only used as an indication in terrain analysis [11][12].
Mapping landslide-prone areas can certainly provide information to the community to recognize the typology of landslide prone slopes, the initial symptoms of slopes will move, and formulate efforts to anticipate early on disasters that can occur at any time.

Based on the foregoing, this regional analysis can be used to compile a disaster management information system that is used as input for regional planning and development as well as improving regional spatial planning.

2. Methods

2.1 Research Time and Location
This research was conducted in December 2018-January 2019 with the research location in Kendari City, Southeast Sulawesi.

2.2 Data Analysis Technique

2.2.1 Weighting Analysis and Scoring Parameters of Landslide Prone
Scoring is based on the influence of the class on events. The greater the effect on events, the higher the score. The most influential parameter will get a greater weight than the less influential parameter. Determination of the level of the threat of landslides is done by combining and weighting slope parameters, soil type, rainfall and land use. Below is a breakdown of the weighting of each parameter

2.2.1.1 Type of Soil
For parameters of soil type or erodibility (level of soil sensitivity to erosion) are grouped into three classes, namely high, medium and low. For more details can be seen in table 1 below.

| Type of Soil            | Class  | Weight (W) | Score/Value Weight (VW) | Total Weight (TW) |
|-------------------------|--------|------------|-------------------------|-------------------|
| Andosol                 | High   | 20         | 0,4                     | 8                 |
| Mediterranean           | intermediate | 20       | 0,3                     | 6                 |
| Aluvial, Latosol, Grumusol | Low   | 20         | 0,2                     | 4                 |

Source: [13],[14]

2.2.1.2 Land Use
The classification of types of land use in relation to landslide threats are grouped into 6 classes, namely settlements, rice fields, fields, fields, plantations and settlements. For more details can be seen in table 2 below.

| Land Use       | Weight (W) | Score/Value Weight (VW) | Total Weight (TW) |
|----------------|------------|-------------------------|-------------------|
| Forest         | 30         | 0,01                    | 0,3               |
| Rice fields    | 30         | 0,06                    | 1,8               |
| Settlement     | 30         | 0,09                    | 2,7               |
| Mixed gardens  | 30         | 0,21                    | 6,3               |
| Plantation     | 30         | 0,25                    | 7,5               |
| Dry-land Farming | 30         | 0,38                    | 11,4              |

Source: [13][14]
2.2.1.3. Rainfall
Rainfall are grouped into 3 classes, namely high, medium, and low. For more details can be seen in table 3 below.

| Rainfall (mm/month) | Class       | Weight (W) | Score/Value Weight (VW) | Total Weight (TW) |
|---------------------|-------------|------------|-------------------------|-------------------|
| >301 mm             | High        | 10         | 0,4                     | 4                 |
| 101-300 mm          | Intermediate| 10         | 0,3                     | 3                 |
| 0-100 mm            | Low         | 10         | 0,2                     | 1                 |

Source: [13][14]

2.2.1.4. Slope
Slope are classified in 5 classes, namely flat, sloping, slightly steep, steep, and very steep. For more details can be seen in table 4 below.

| Slope Class Parameter (%) | Slope Shape  | Weight (W) | Score/Value Weight (VW) | Total Weight (TW) |
|---------------------------|--------------|------------|-------------------------|-------------------|
| 0-8                       | Flat         | 40         | 0,02                    | 0,8               |
| 8-15                      | Sloping      | 40         | 0,07                    | 2,8               |
| 15-25                     | Slightly Steep| 40       | 0,15                    | 6                 |
| 25-40                     | Steep        | 40         | 0,32                    | 12,8              |
| >40                       | Very Steep   | 40         | 0,45                    | 18                |

Source: [13][14]

2.2.2 Analysis of Landslide Prone Levels
Weighting is arranged on the basis of understanding the causative factors and trigger factors for landslides. The factor that causes landslides is the force of gravity acting on a mass of soil or rock. In the field, the influence of gravity on the mass of the soil and / or rock is determined by the magnitude of the slope angle. Therefore, in assessing the level of landslide vulnerability, the slope factor is given the highest weight compared to other factors. The following equation is used to determine the value of a natural hazard level based on the Bogardus scale method:

\[
\text{Vulnerability rate} = \sum (\text{Weight} \times \text{Score}) \quad [15]
\]

To determine the interval class of the disaster-prone level using 5 (five) classifications, namely from not prone, rather prone, quite prone, prone, and very prone to be done using the arithmetic method. The formula used to create interval classes [16]:

\[
K_i = \frac{K_t - K_r}{K}
\]

Notes:
K_i = Interval Class
K_t = High Data
K_r = Low Data
K = Number of Classes desired

2.2.3 Making Thematic Maps of Landslide Prone Levels
Making thematic maps of disaster-prone levels is done by using SoftwareArcGIS 10.1. After making thematic maps of hazard level for all landslides, conclusions can be drawn based on the results of research and the objectives that have been set, namely determining the level of landslide hazard for each district, and making thematic maps of landslide hazard prone levels in landslides in Kendari City. The general picture flow chart in making thematic maps is drawn in a flowchart as shown in Figure 1 below.
3. Results and Discussion

3.1 Factors Causing Landslides in Kendari City

3.1.1 Rainfall
Rainfall stations/posts in the city of Kendari are found in Kendari District. The average monthly rainfall from 2008-2017 was 175.8 mm/month. The total rainfall class Kota Kendari can be seen in Table 5 below.

| Rainfall Class | Average Monthly Rainfall | Total Area (Hectar/%) |
|----------------|--------------------------|-----------------------|
| High           | 0                        | 0                     |
| Medium         | 175.8                    | 26819.44              |
| Low            | 0                        | 0                     |

Source: ArcGIS Processed Data, 2019
Based on figure 2 it is known that the entire area of Kendari City has a monthly average rainfall that is included in the medium class that is 100%, and none is included in the low and high classes.

### 3.1.2 Soil Type
Kendari city consists of 8 types of land. For more details can be seen in table 6 below.

| Soil Type                                      | Total Area |
|-----------------------------------------------|------------|
| Low humicgley, acid sulfat soils              | 3573.4     |
| Regosol                                        | 1.48       |
| Regosol, latosol                               | 7492.78    |
| Gray brown podsolc, Latosol                   | 5426.14    |
| Latosol, Regosol                               | 8199.66    |
| Latosol, Regosol, Low humicgley               | 1881.59    |
| Acid sulfat soils                              | 230.58     |
| Low humicgley, alluvial, acid sulfat soils     | 13.81      |
| **Total**                                      | **26819.44**|

Source: ArcGIS Processed Data, 2019

Based on the results of data analysis in the city of Kendari, it is known that the Latosol soil type, Regosol is the most identified with an area of 8199.66 ha (30.6%), while Regosol is the least identified type of land, which is 1.48 (0.005%).
Figure 3 shows that in the Baruga the area consists of 3 types of soil (Low humic gley; acid sulfate soils; Latosol, Regosol; Low humic gley; and Latosol, Regosol). In Kambu consists of 4 types of soil (Latosol, Regosol; Acid sulfate soils; Latosol, Regosol; and Low humic gley, acid sulfate soils). In the West Kendari region consists of 4 types of soil (Regosol, latosol; Gray brown podsolic, Latosol; Low humic gley,acid sulfate soils; and Regosol, latosol). Mandonga consists of 3 types of low humic gley soils, acid sulfate soils; Gray brown podsolic, Latosol; and Regosol, latosol). Poasia consists of 3 types of soil (Latosol, Regosol, Low Humic Gley; Latosol, Regosol; and Regosol, Latosol). The Wua-Wua area consists of 3 types of soil (Low humic gley, acid sulfate soils; Gray brown podsolic, Latosol; and Latosol, Regosol). The Abeli area consists of 3 types of soil (Latosol, Regosol, Low Humic Gley; Latosol, Regosol; and Regosol, Latosol). The Kadia area consists of 4 types of soil (Low humic gley, acid sulfate soils; Latosol, Regosol, Gray brown podsolic, Latosol; and Latosol, Regosol). Kendari area consists of 1 type of land, namely Regosol, Latosol. And finally the Puuwatu consists of 2 types of soil (Gray brown podsolic, Latosol and Latosol, Regosol).

3.1.3 Slope
Kendari city consists of 4 types of slope class. For more details can be seen in table 7 below.

| Slope Class  | Hectar     | %        |
|--------------|------------|----------|
| 0-8%         | 5,699.37   | 21.25    |
| >8-15%       | 5,426.15   | 20.23    |
| >15-25%      | 8,199.66   | 30.6     |
| >40%         | 7,494.26   | 27.94    |
| Total        | 26819.44   | 100      |

Source: ArcGIS Processed Data, 2019

Based on the results of data analysis, it is known that the slope class> 15-25% dominates the Kendari City area with an area of 8,199.66 (20.6%) and the slope class> 8-15% is the narrowest namely 5426.15 (20.23%).
Figure 4 shows that in the Baruga region are included in the slope category of 0-8%, 8-15%, and 15-25%. Furthermore, the Kambu area is included in the slope category of 0-8% and 15-25%. The West Kendari Region is included in the category of slope 0-8%, 15-25% and >40%. Mandonga area is included in the category of slope 0-8%, 8-15% and >40%. Poasia region is included in the category of slope 0-8%, 8-15% and >40%. Wua-Wua region is included in the category of slope 0-8%, 8-15% and 15-25%. Abeli area is included in the category of slope 0-8%, 8-15% and >40%. The Kadia region is included in the slope category of 0-8%, 8-15%, and 15-25%. Kendari area is included in the category of slope >40%. Puuwatu region is included in the slope category of 8-15% and >40%.

3.1.4 Land Use

Land use in Kendari City consists of 11 types of land use, namely dry land agriculture, bush/shrub, secondary mangrove forest, settlement and place of activity, secondary dry land forest, mixed dry land agriculture, wetland seasonal crops, saltwater ponds / ponds, river, open / empty land, primary dry land forest. The total area of land use in Kendari City can be seen in table 8 below.

| Land Use                                | Total Area | %   |
|-----------------------------------------|------------|-----|
| Dryland agriculture                     | 6,197,53   | 23,08|
| Shrubs                                  | 9,966,97   | 37,16|
| Secondary mangrove forests              | 62,81      | 0,23 |
| Settlement and Place of Activity        | 2,653,84   | 9,9  |
| Secondary dry land forest               | 2,082,69   | 7,8  |
| Dry land farming mixed                  | 3,704,61   | 13,81|
| Wetland annuals                         | 517,85     | 1,93 |
| Fishpond                                | 811,8      | 3,02 |
| River                                   | 60,22      | 0,22 |
| Vacant land                             | 11,98      | 0,04 |
| Primary dry land forest                 | 725        | 2,7  |
| **Total**                               | **26819,4**| **100**|

Source: ArcGIS Processed Data, 2019
Based on the results of data analysis, it is known that the most land use in the area of Kendari City is shrub area of 9,966.7 ha (37.16%) and the least is vacant land area of 11.98 ha (0.04%) of the total land use area of 26,819.4 ha.

![Map of Land Use In Kendari City](image)

**Figure 5. Map of Land Use In Kendari City**

(Public Works Department In Southeast Sulawesi, 2018)

Figure 5 shows that in the Baruga region consists of 5 types of land use (annual crops, agricultural wetlands, dry land, settlements and places of activity). Furthermore, in the Kambu region consists of 5 types of land use (mixed plantations, ponds and saltwater ponds, dry land agriculture, settlements and places of activity, as well as shrubs). The West Kendari area consists of 2 types of land use (settlement and place of activity, as well as shrubs). In the Mandonga region there are 4 types of land use (saltwater ponds and ponds, settlements and places of activity, dry land agriculture, shrubs). The Andonohu area consists of 4 types of land use (settlements and places of activity, secondary dryland forests, dryland agriculture, primary dryland forests). The Wua-Wua region consists of 3 types of land use (dry land agriculture, settlements and places of activity, shrubs). The Abeli area consists of 4 types of land use (settlements and places of activity, shrubs, mixed plantations, secondary dryland forests). The Kadia area consists of 2 types of land use (shrubs and settlements and places of activity). Kendari area consists of 3 types of land use (settlement and place of activity, shrubs, dry land agriculture). And finally, the Puuwatu region consists of 4 types of land use (settlements and places of activity, mixed plantations, shrubs, dry land agriculture).

### 3.1.5 Map of Landslide Prone

The area of hazard classification can be seen in table 9 below.

| Hazard Classification | Hectar | (%) |
|-----------------------|--------|-----|
| Not prone             | 3405.09| 12.69|
| Rather prone          | 5574.34| 20.78|
| Quite prone           | 12041.48| 45   |
| Prone                 | 40.78  | 1.27 |
| Very prone            | 4038.34.00| 15.05|
| **Jumlah**            | **26819.44**| **100**|

Source: ArcGIS Processed Data, 2019
Table 9 showed that most of the Kendari city area was included in the “rather prone” class with an area of 5574.34 ha (20.78%). This “rather prone” area is spread in the Kec. Kambu, Poasia, Kadia, a part of Abeli and Poasia. Whereas the area classified as “prone” is spread out at least in the area of 40.78 (1.27%).

The following is broad classification of vulnerability per district:

| No. | District     | Not Prone | Rather Prone | Quite Prone | Prone | Very Prone |
|-----|--------------|-----------|--------------|-------------|-------|------------|
| 1.  | Abeli        | 54.76     | 1.824,95     | 1.636,75    | 19.83 | 446.99     |
| 2.  | Baruga       | 785.09    | 2.195,31     | 1.924,84    | 0     | 157.21     |
| 3.  | Kadia        | 180.64    | 320.85       | 182.71      | 0     | 0          |
| 4.  | Kambu        | 534.82    | 706.54       | 886.92      | 0     | 0          |
| 5.  | Kendari      | 0         | 0            | 12.05       | 159.59| 1.242,4    |
| 6.  | Kendari Barat| 161.8     | 3.18         | 56.49       | 156.69| 1.578,75   |
| 7.  | Mandonga     | 449.59    | 107.76       | 1.167,03    | 2.9   | 516.61     |
| 8.  | Puuwatu      | 240.93    | 158.48       | 3.306,55    | 1.77  | 463.49,00  |
| 9.  | Poasia       | 984.42    | 946.05       | 1971.75     | 0     | 96.38      |
| 10. | Wua-Wua      | 13.04     | 257.27       | 896.39      | 0     | 0          |

Total: 3,405.09  | 5,574.34  | 12,041.48   | 340.78      | 4,038.34 |

Source: ArcGIS Processed Data, 2019

Table 10 shows that in Kendari City consists of 10 sub-districts, namely Abeli, Baruga, Kadia, Kambu, Kendari, West Kendari, Mandonga, Puuwatu, Poasia, and Wua-Wua. Judging from the value of the area, the area included in the classification of “not prone” is the broadest district of Poasia with an area of 984.42 ha. Furthermore, the “rather vulnerable” area of Baruga sub-district is 2,195.31 ha. The region is “quite prone”, namely the district of Puuwatu covering an area of 3,306.55 ha. The “prone” area is Kendari district with an area of 159.59 ha and the “very vulnerable” area is the West Kendari district with an area of 1,578.75 ha.

Figure 6. Map of Landslide Prone Areas in Kendari City (Geospatial Information Agency, 2015; Public Works Agency of Southeast Sulawesi Province, 2018; Meteorology Climatology and Geophysics Agency of Kendary City, 2018).
Figure 6 shows that most of the West Kendari and Kendari areas are in the “very prone” category, while the Kambu, Poasia, Kadia and Abeli regions are included in the “rather prone” category.

3.2 Discussion

Landslides are the most widespread and destructive impacts among several natural disasters that often occur in the world [17][18][19][20][21]. Therefore mitigation efforts are needed. One of the mitigation efforts that can be done is by mapping landslide-prone areas using Geographic Information Systems so that the affected areas can be identified and identified to reduce damage [21][22]. Geographic information systems can be loaded with various geospatial information related to various factors causing landslides. Maps for landslide-prone areas can be done using various applications or mapping software in GIS, such as by using ArcGIS with various types[23].

Maps of landslide prone areas in Kendari City using geography information system are prepared based on several parameters, namely rainfall, soil type, slope, and land use. This is in line with studies conducted by Dwikorita [25] that physical environmental factors that affect landslides include slope, geological conditions (rock type, fault, thickness, and rock weathering level), soil texture and permeability, plasticity index, climate (rainfall and temperature), and water management.

Based on the results of data analysis, the most potentially causing landslides in Kendari City is the slope. The city of Kendari is dominated by slopes with a slope of> 15-25% and> 40% with an area of 8,199.66 ha and 7,494.26 ha in the districts of Kendari and West Kendari, respectively (Figure 4 and Table 7). The topography of the city of Kendari is indeed a combination of hilly, flat and coastal areas with heights between 0-472 meters above sea level (masl). Where the Nipa-nipa Mountains with a slope> 40% and the highest altitude of 472 meters above sea level and Kendari Bay as a coastal area with a slope of 0-8%, provide a prominent feature for the Kendari City area [26].

Generally, slopes with a slope of 15% (slightly steep) to> 40% (very steep) are located on the top or middle part of a hill or mountain slope. As for slopes with a slope of 0-8% (flat) to 8-15% (sloping) located at the bottom or the foot of the hill.

The speed of movement of soil and rocks on the slopes varies greatly. This depends on the magnitude of the slope and slope position. The initial symptoms of landslides are cracks in the form of elongated arches (usually in the form of horseshoe) along slopes that will slide, cracks in foundations, floors and walls of buildings, sloping trees and electric poles on the slopes, and the appearance of seepage water seepage on slopes after rain. In addition to slope slopes, another factor affecting landslides is the intensity of high rainfall, [27]. In Kendari City the rainfall intensity was 175.8 mm / month and the peak of the rainy season in this region occurred in February-June [10]. This eventually causes the soil to no longer be able to withstand raindrops and eventually slip down. Landslides do not always occur during heavy rains, but can also occur when it has been low (drizzle) for several hours. Further explained, rain water is easier to pass on clay and sand types of soil. These characteristics make the soil gain weight when it is hit by rain water and more so if the soil is above water-resistant rocks at a certain
slope, the soil will increasingly have the potential to slip into a landslide. Materials that form landslide deposits often show different textures relative to the surrounding terrain [28].

Land use that is not in accordance with the rules of soil conservation, indirectly also triggers landslides. Based on observations, the people of Kendari City who live in the highlands or the mountains often make terraces on the side of the road, causing soil and soil layers to become unstable. Further explained soil instability occurs due to several things, including the loss of plants or trees in the highlands that have the function of binding soil grains while keeping the soil pores underneath so that rainwater infiltration runs smoothly and exploitation of sloping land that is not appropriate for development settlement by cutting off cliffs or taking up soil or sand in excess of the lower regions. Based on the results of the analysis, the area of Kendari City which frequently experiences landslides generally occurs on mixed garden land use and shrubs (Table 8 and Figure 6). This is caused by the existing root system that is not yet able to bind the soil. In addition to the parameters described, according to Beddingfield et al. [28] Most likely landslides can also be caused by seismic activity as a result of tectonism or volcanism.

Landslides certainly have the potential to harm the community [29]. Directly, landslides affect civil infrastructure (transportation corridors, roads and rails, power production, water, wastewater) or built environment (housing and business premises) [30]. For this reason, mapping of landslide-prone areas in Kendari City is very important as one of the efforts to mitigate disasters and can be used as a basis for designing a disaster recovery framework.

4. Conclusions

After adding all the parameter scores and doing the analysis using the geographic information system, the minimum and maximum values of the city of Kendari were obtained. areas that are not prone to landslides 3405.09 ha or 12.69% which cover the sub-districts of Kambu, Baruga, Poasia, Mandonga and a number of regions, these areas are prone to landslides covering 5,774.34 ha or 20.78% covering the sub-district area Abeli, Baruga, Puwatu which is quite prone to landslides covering 1,201.48 ha or 45% covering the Abeli, Baruga districts, a small part of Kaida, Kambu, Mandonga, Puwatu, and Wua-Wua in areas that dominate the potential for landslide prone areas of 40, 78 ha or 1.27% or 15.05% covers most of Abeli, Kendari and West Kendari sub-districts, while the very prone areas are 4038.34 ha or 15.05%, which includes Kendari, West Kendari, Mandonga, Abeli and a small proportion of the sub-districts of Poasia, Puwatu, and Baruga.

Acknowledgments

Thank you to several related agencies, namely the Geospatial Information Agency, the Southeast Sulawesi Provincial Public Works Office, the Kendary City Climatology and Geophysics Agency and the Kendari City Revenue Service. Furthermore, we also agree to thank the leader of the Faculty of Teacher Training and Education for supporting and giving us permission to conduct this research. Lastly, thank you for the editorial team dan reviewer of the 2nd International Conference on Geography and Education (ICGE) 2019.

References

[1] Beddingfield C B, Beyer R A, Singer K N, McKinnon W B, Runyon K, Grundy W, … Young L 2020 Landslides on Charon. Icarus 335 113383 https://doi.org/10.1016/j.icarus.2019.07.017
[2] Bowman E T 2015 Small Landslides—Frequent, Costly, and Manageable. Dalam Landslide Hazards, Risks and Disasters 405–439 https://doi.org/10.1016/B978-0-12-396452-6.00012-4
[3] Sulaeman Cecep 2011 Bencana Geologi di Indonesia Tahun 2011 Bulletin Vulkanologi dan Bencana Geologi 6 43–54
[4] Central Bureau of Statistics Kendari City 2017 Kendari City in Figures 2017 https://kendarikota.bps.go.id/publication/download.html?rbv7e=caHRoeCM6Ly9tZmV5YXJpL290YS5icHMuaHRtbA%3D%3D&
twoadfnoraf=afMjAxOSwNi0wNyAxMTo1OTo0OA%3D%3D (Accessed on January 2019)

[5] Centre for Research on the Epidemiology of Disasters (CRED) 2011 *The OFDA/CRED International Disaster Database* Brussels: Université Catholique de Louvain

[6] Chen W, Li W, Hou E, Bai H, Chai H, Wang D, Cui X, Wang Q 2015 Application of frequency ratio, statistical index, and index of entropy models and their comparison in landslide susceptibility mapping for the Baozhong Region of Baoji, China *Arab J. Geosci.* 8 1829–1841 https://doi.org/10.1007/s12517-014-1554-0

[7] Davies T 2015 *Landslide Hazards, Risks, and Disasters* in LANDSLIDE HAZARDS, RISKS AND DISASTERS 1–16 https://doi.org/10.1016/B978-0-12-396452-6.00001-X

[8] Demir Gökhan 2019 GIS-based landslide susceptibility mapping for a part of the North Anatolian Fault Zone between Reşadiye and Koyulhisar (Turkey) *Catena* 183 104211 https://doi.org/10.1016/j.catena.2019.104211.

[9] Karnawati Dwiorikita 2001 Sistem Peringatan Dini Tanah Longsor dengan Pemberdayaan Masyarakat presented in Lokakarya Nasional: Pengembangan Sistem Peringatan Dini, Yogyakarta

[10] Faizana F, Nugraha A L, Yuwono B D 2015 *Jurnal Geodesi Undip* 4 12

[11] Firdaus H S, Sukojo B M, 2015 Pemetaan Daerah Rawan Longsor dengan Metode Penginderaan Jauh dan Operasi Berbasis Spasial, Studi Kasus Kota Batu Jawa Timur *Jurnal Geosaintek* 1 25–34

[12] Guerra A J T, Fullen M A, Jorge M C O, Bezerra J F R, Shokr M S 2017 Slope processes, mass movements and soil erosion a review *Pedosphere* 27 27–41 https://doi.org/10.1016/S1002-0160 (17)60294-7

[13] Harto Moch Fauzan Dwi, Adhitama Rachman, Putri Rida L, Maulidah Aisyah, Haris Purna W, Nathasya Abigail, Fadlillah Nur R, Widya Utama 2017 Pemetaan Daerah Rawan Longsor dengan Menggunakan Sistem Informasi Geografis Studi Kasus Kabupaten Bondowoso *Jurnal Geosaintek* 03

[14] Kusratmoko et al. 2002 *Aplikasi Sistem Informasi Geografis untuk Penentuan Wilayah Prioritas Penanggulangan Bahaya Erosi Studi Kasus DAS Citaru* Jakarta: Jurusan Geografi dan Pusat Penelitian Geografi Terapan Fakultas MIPA Universitas Indonesia

[15] Liputan6.com 2018 *Mahasiswa Kendari Tewas Tertimpa Longsor Usai Pulang Kuliah* https://www.liputan6.com/regional/read/3578159/mahasiswa-kendari-tewas-tertimpa-lands-ongkor-usai-pulang-kuliah?utm_expid=.9Z4i5ypGQeGiS7w9arwTvQ.0&utm_referrer=https%3A%2F%2Fwww.google.com%2F

[16] Li Y and Mo P 2019 A unified landslide classification system for loess slopes: A critical review *Geomorphology* 340 67–83 https://doi.org/10.1016/j.geomorph.2019.04.020

[17] Morino C, Conway S J, Sæmundsson Þ, Helgason J K, Hillier J, Butcher F E G, … Argles T 2019 Molards as an indicator of permafrost degradation and landslide processes *Earth and Planetary Science Letters* 516 136–147 https://doi.org/10.1016/j.epsl.2019.03.040

[18] Nazir M 2003 *Metode Penelitian* Jakarta: Ghalia Indonesia

[19] Nicu C I 2018 Application of analytic hierarchy process, frequency ratio, and statistical index to landslide susceptibility: an approach to endangered cultural heritage *Environ. Earth Sci.* 77 79 https://doi.org/10.1007/s12665-018-7261-5

[20] Purba J O, Subiyanto S, Sasmito B, Soedarto J 2014 *Jurnal Geodesi Undip* 3 13

[21] Rahmad R, Suibi, Ali Nurman 2018 Aplikasi SIG untuk Pemetaan Tingkat Ancaman Longsor di Kecamatan Sibolangit, Kabupaten Deli Serdang, Sumatera Utara *Majalah Geografi Indonesia* 32 1-13 http://doi.org/10.22146/mgi.31882

[22] Dwinda Reiny 2019 *BMKG: Kendari Rawan Banjir Sepanjang Mei-Juni.* https://nasional.republika.co.id/berita/nasional/daerah/ps5n22414/bmkg-kendari-rawan-banjir-sepanjang-mejini (Accessed on January 2019)

[23] Febrianito Samuel 2017 *6 Rumah Rusak Tertimpa Longsor di Kendari* https://www.tribunnews.com/regional/2017/06/02/6-rumah-rusak-tertimpa-104211.012021.
[24] Setyaningsih W, and Sholeh M 2010 Pemetaan Daerah Rawan Bencana Gerakan Tanah di Wilayah Grabag Kabupaten Magelang Propinsi Jawa Tengah *Jurnal Sains dan Teknologi (Sainteknol)* **8** https://doi.org/10.15294/sainteknol.330

[25] Sturges H A 1926 The Choice of a Class Interval *Journal of the American Statistical Association*

[26] Vulcanological Survey of Indonesia 2005 *Pengenalan Gerakan Tanah* https://www.esdm.go.id/assets/media/content/Pengenalan_Gerakan_Tanah.pdf (Accessed on January 2019)

[27] VOA Indonesia 2019 *BNPB: 40.9 Juta Warga Indonesia Tinggal di Daerah Rawan Longsor* https://www.voaindonesia.com/a/bnpb-40-9-juta-warga-indonesia-tinggal-di-daerah-rawan- longsor/4725859.html (Accessed on January 2019)

[28] National Disaster Management Agency 2019 *Indonesian Disaster Information Data* http://dibi.bnpb.go.id/ (Accessed on January 2019)

[29] Van Zuidam 1979 *Terrain Classification Using Aerial photograph: A Geomorphological Approach* Enschede: International Institute for Aerospace Survey and Earth Sciences (ITC)

[30] Youssef A M, Pourghasemi H R, El-Haddad B A, Dhahry B K 2016 Landslide susceptibility maps using different probabilistic and bivariate statistical models and comparison of their performance at Wadi Itwad Basin, Asir Region, Saudi Arabia *Bull. Eng. Geol. Environ.* **75** 63–87 https://doi.org/10.1007/s10064-015-0734-9