Remote Sensing Analysis of Lineaments using Multidirectional Shaded Relief from Digital Elevation Model (DEM) in Olele Area, Gorontalo

A G Abduh¹, F C A Usman¹, W M Tampoy², I N Manyoe¹*

¹Geological Engineering, Universitas Negeri Gorontalo, B.J. Habibie Street, Bone Bolango Regency, 96119 Indonesia
²Aquatic Resources and Management, Universitas Negeri Gorontalo, Jend. Sudirman Street, Gorontalo City, 96128 Indonesia

*intan.manyoe@ung.ac.id

Abstract. The Gorontalo fault zone is an active fault that crosses Gorontalo Province with a movement of about 11 mm/year. The existence of this fault zone affects the morphological lineaments and offsets along its path and increases the potential of geological disaster hazards. The Olele area is located in the Gorontalo fault zone that makes it potential to landslide disaster. This study aims to analyze the lineaments of the Olele area and its surroundings. The results of this analysis will help to determine the geological structures distribution pattern that develops in the study area and its impact on the mitigation of landslide disasters in the study area. This study uses a spatial analysis method using Digital Elevation Model (DEM) image to analyze slope and lineaments data in the study area. The results of the analysis will be correlated with regional geological structures and give recommendations for geological disaster mitigation that can be implemented. The results showed that the slope class in the study area was dominated by the range of 16-35° and even in several places with a slope of 35-55°. The results of the extraction and processing of lineaments data get 203 data. The lineaments direction is relatively NNW - SSE. This direction indicates that mostly the morphologies are influenced by the existence of the Gorontalo fault zone. The existence of the Gorontalo fault zone makes this area prone to landslide disasters in the case of Gorontalo fault movement. Some prevention recommendations are to increase the slope stability level.

Keywords: Lineaments, Spatial Analysis, Gorontalo Fault, Landslide

Introduction
The North Arm of Sulawesi is a Tertiary magmatic arc that has experienced a complex series of tectonic events [1]. The process of subduction, rotation, and collision results in a diverse distribution of geological structures in the Gorontalo area [2] and forms the Gorontalo Fault Zone. The Gorontalo Fault Zone directing Northwest - Southeast and passes through the middle of Gorontalo province, cutting the North Arm of Sulawesi.
The Gorontalo fault zone is an active fault that divides Gorontalo Province with a movement of about 11 mm/year [3][4] and is still active today. The existence of this fault which crosses several areas in Gorontalo is the cause of the occurrence of earthquakes and landslide disasters in the areas it crosses. Gorontalo Province is an area that has potential of shallow to medium depth earthquakes. The potential for earthquakes that can occur ranges from light earthquakes (4-5 SR) to moderate earthquakes (5-6 SR) [5]. Besides, the existence of this fault zone affects the configurations of lineaments and offsets along its path and also increases the level of geological hazards, such as landslides.

The research was conducted in Olele and its surrounding area, Bone Bolango Regency, Gorontalo Province. This area is included in the Gorontalo fault zone so that it has the potential to experience landslide disasters. Several landslide events have been recorded in the study area, which generally occurs in a relatively steep slope and located across the highway. Reported from Madani [6] in Republika.co.id, the latest landslide event on a road has blocked transportation access since July 31, 2020. This condition is caused by unstable soil structures which results in difficulty clearing the area using heavy equipment. Gorontalo province is vulnerable to landslide disasters in various forms and mechanisms. Several studies were conducted to identify the landslide [7][8][9] with various methods. The results of these studies can be references to determine the prevention steps of the landslide disaster.

Landslide is generally influenced by morphological, lithological, and geological structures in an area [10]. This indicates the need for research related to geological structural patterns and their relation to morphology in the Olele area. Of course, this is intended as an initial identification for determining landslide disaster mitigation steps in the Olele area and its surroundings, Bone Bolango Regency, Gorontalo Province.

This study aims to analyze the morphological lineaments of the Olele area and its surroundings. Lineaments analysis is carried out semi-automatically, which automatically using the software analysis, and manually based on observations on the shaded relief image. The results of this analysis will help to identify the geological structure patterns that develop in the study area and provide recommendations related to disaster mitigation of landslide in the study area.

**Literature Review**

**Regional Geology**

The research area is located in Olele and its surroundings, Bone Bolango Regency, Gorontalo Province. Physiographically, the research area is located in the Southern Mountain area of Gorontalo which is composed of sedimentary volcanic rocks of Eocene-Oligocene age and intrusion bodies in the form of Pliocene granite, granodiorite, and diorite, some of which contain metamorphosed limestone. The slope in this zone ranges from 25-35° [11].

Based on the regional geological map of Kotamobagu sheet by Apandi and Bachri [12], the rock formations in the study area are composed of Bilungala Volcanics (Tmbv), Pinogu Volcanics (TQpv), and Coral Limestone (Ql). Bilungala volcanics are composed of volcanic breccia, tuff, and lava. These volcanic rocks are generally gray to dark gray. Pinogu volcanics are composed of tuffs, lapilli tuffs, breccias, and lava. Limestone Reefs are composed of uplifted reef limestones and clastic limestones with the main component of being coral.
The regional geological structure in the study area is a dextral shear fault with a relatively Northwest-Southeast direction. This fault is interpreted as a minor fault from the Gorontalo fault zone due to its direction that relatively similar.

More detailed mapping by Bahutala [13], found that the Olele area and its surroundings were composed of Andesitic Lava, Dacitic Lava, Volcanic Brecias, Reef Limestone, and Alluvial Deposits. The geological structure found was a normal fault that trending relatively Northwest-Southeast. This normal fault is interpreted as a minor fault of the Gorontalo fault zone. This is indicated by the direction of the fault which is relatively similar to the Gorontalo fault zone.

Figure 2. (a) Regional Geology Research area[12]; (b) Geological Map of the Research area[13]

Satellite Images
Satellite imagery has been a new breakthrough in science. Satellite imagery helps capture images of the earth's surface by utilizing wavelengths and the electromagnetic spectrum (EMS) [14]. One of the frequently used images is DEM (Digital Elevation Model) and Bathymetry. DEM is a satellite image showing the surface topography, while bathymetry is used to display the underwater topography. The satellite imagery used is DEMNAS (DEM Nasional) and BATNAS (Batimetri Nasional) created by the Geospatial Information Agency (BIG) in 2018. This image uses IFSAR, TERRASAR-X, ALOS PALSAR, and Shipborne data. A resolution of up to 5 meters can produce detailed 3D topographic models that are close to the original.

Lineaments
Lineaments are defined as a relatively straight earth surface formation, which can be in the form of a ridge, valley, river, or contrasting topographic differences. The existence of lineaments can be an indication of the geological structures that control the study area [15].

Lineaments analysis utilizing Digital Elevation Model (DEM) satellite imagery that has been processed to produce a shaded relief model can help determine the lineaments distribution more clearly. The use of multi-dimensional shaded relief can make the lineaments extraction process tend to be accurate because the light source comes from 8 directions. Lineaments extraction parameters refer to Thannoun [16] which consists of RADI (radius filter), GTHR (gradient threshold), LTHR (length threshold), FTHR (line fitting error threshold), ATHR (angular difference threshold), and DTHR (linking distance threshold).

Location and Research Method
Geographically, the research area is at coordinates 0°23'41,52"- 0°26'17,5"N and 123°7'22,06"-123°11'7,24"E. The research area is located administratively in the Kabila Bone District, Bone Bolango Regency, Gorontalo Province. The research area is about 29 km from Gorontalo City and can be reached in 50 minutes using a motorized vehicle.
This study uses a spatial analysis method of Digital Elevation Model (DEM) image data to analyze slope and lineaments data in the study area. Slope analysis showed in the slope map of the study area. Lineaments data obtained from the morphological shape observed in the Shaded Relief image in the study area. The results of the lineaments data analysis will be correlated with the regional geological structure of the study area. The Shaded Relief image processed from DEMNAS image from BIG [17] with a resolution level of up to 8 meters.

Primary data in this study are slope angle data and morphological lineaments configuration in the study area. Slope data is obtained from DEMNAS image data which is processed using Geographic Information System (GIS). DEM data is created as a multi-directional hillshade. This is done to obtain optimal lineaments with irradiation from 8 directions. This multi-directional hillshade is then processed using the PCI Geomatica 2015 software to automatically extract the lineaments. The input parameters used are shown in table 1.

Table 1. The value of each parameter used in the LINE algorithm

| No. | Extraction Parameters                        | Score |
|-----|---------------------------------------------|-------|
| 1   | RADI (Radius Filter)                        | 10    |
| 2   | GTHR (Gradient Threshold)                   | 75    |
| 3   | LTHR (Length Threshold)                     | 25    |
| 4   | FTHR (Line Fitting Error Threshold)         | 3     |
| 5   | ATHR (Angular Difference Threshold)         | 1     |
| 6   | DTHR (Linking Distance Threshold)           | 40    |

The extracted data will then be corrected and verified using a Geographical Information System (GIS). The correction and verification process is carried out to eliminate lineaments that are not following morphology and to add lineaments that are not automatically detected.

The lineaments data that have been corrected are then processed to determine the value of lineaments density and the dominant direction in the study area. Lineaments density analysis was carried out to determine the distribution of lineaments density in the study area. Density analysis using Geographic Information Systems (GIS). The results of the analysis will be displayed in the form of a lineaments density map in the study area.

The analysis continues by identifying the dominant lineaments direction using the rosette diagram contained in the Rockworks 16 software. The results of the analysis will be correlated with the influence of regional geological structures and geological disaster mitigation recommendations that can be implemented in the study area. The final stage of the research is the stage of writing research articles to be published.
Result and Discussion

Slope Analysis
The slopes in the study area were classified based on the Van Zuidam [18] slope classification. The research area is dominated by hilly morphology with relatively steep slopes (figure 5). This can be seen from the slope classes in the study area which are dominated in the range of 16-35° and several places with a slope of 35-55°.

Lineament Analysis
Lineaments data obtained from extraction on hillshade images with 8 irradiation directions, namely at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The results of extraction and processing of lineaments data get 203 data results. The direction of lineaments data is relatively NNW - SSE trending with some NE - SW trending (figure 5). This direction is interpreted as the influence of the Gorontalo conjugation fault as described by Surmont et al, [19]. This conjugation fault forms a fault zone trending NW - SE (Gorontalo fault zone) and a fault zone trending NE - SW. This direction indicates that generally the morphology in the study area is influenced by Gorontalo fault zone and forms several unidirectional lineaments pattern. This lineaments pattern can be a clue regarding the geological structure pattern in the study area so that it needs to be verified directly in the field.

The lineaments recorded are generally the morphological lineaments of ridges, streams, valleys, and scarps in the DEM image. Morphological lineaments are generally observed on hilly ridges and some are observed in valleys in the study area. This is shown in figure (5).

The lineaments density in the study area uses the parameter of the number of lineaments in an area. The lineaments density in the study area varies from low to high. Low-density values were observed in areas with relatively few numbers of lineaments and marked in green on the map (Figure 6). The high-density value is observed in the area with a relatively numerous of lineaments and marked in red on the map (Figure 6).

In the Olele area, the lineaments intensity varies from moderate to high. This condition is due to a large number of morphological lineaments in the Olele area and makes this area as an area with active tectonic conditions. The more lineaments in an area will increase the value of the lineaments density of the area. The high density of lineaments can affects the potential for landslides in the study area. Some of the lineaments are even on the highway in the study area, so they can cause landslides that lead to cut off access to land transportation.

The existence of the Gorontalo fault line makes this area prone to landslide disasters when there is movement in the Gorontalo fault. The movement of this fault will release energy to the surface and reduce the stability of the slope around the study area which is generally relatively steep. The Olele area itself is composed of 80% hilly areas with relatively steep slopes making it prone to the dangers of the landslide.

Figure 4. (a) Map of the Slope of the Study Area; (b) Lineaments Density Map of the research area
Conclusion
The results show that the slopes in the study area were dominated by steep slopes with an angle ranging from 33-55°. The dominant alignment in the study area is relatively NNW - SSE. This direction indicates that lineaments configuration is influenced by the existence of the Gorontalo fault zone. High lineaments density was observed at several points of the road section and around the Olele area. This condition increases the level of landslide hazards in the study area. It is necessary to take preventive solutions for landslide disaster in the study area by using appropriate and efficient prevention methods.

References
[1] Leeuwen TM Van, Muhardjo (2005) Stratigraphy and tectonic setting of the Cretaceous and Paleogene volcanic- sedimentary successions in northwest Sulawesi, Indonesia: implications for Cenozoic evolution of Western and Northern Sulawesi. J Asian Earth Sci 25:481–511
[2] Silver EA, McCaffrey R, Smith RB (1983) Collision, Rotation, and the Initiation of Subduction in the Evolution of Sulawesi, Indonesia. J Geophys Res 88:9407–9418
[3] Socquet A, Simons W, Vigny C, McCaffrey R, Subarya C, Sarsito D, Ambrosius B, Spakman W (2006) Microblock rotations and fault coupling in SE Asia triple junction (Sulawesi, Indonesia) from GPS and earthquake slip vector data. J Geophys Res 111:1–15
[4] Molnar P, Dayem KE (2010) Major intracontinental strike-slip faults and contrasts in lithospheric strength. Geosphere 6:444–467
[5] Manyoe IN, Lantu, Arif S, Lahay RJ (2019) Earthquake Damage Level Of Gorontalo Area Based On Seismicity And Peak Ground Acceleration. Jambura Geosci Rev 1:7–12
[6] Madani MA (2020) In Picture: Longsor di desa Olele, Gorontalo. Gorontalo
[7] Patuti IM, Rifa’i A, Suryolelono KB (2017) Mechanism and Characteristics of the Landslides in Bone Bolango Regency, Gorontalo Province, Indonesia. Int J GEOMATE 12:1–8
[8] Usman FCA, Manyoe IN, Duwingik RF, Kasim DNP (2018) Rekonstruksi Tipe Longsoran Di Daerah Gorontalo Outer Ring Road (GORR) Dengan Analisis Stereografi. J Geomine 6:42–48
[9] Manyoe IN, Usman FCA, Taslim I, Mokoginta M, Napu SSS, Salama TH (2020) Geological Structure Analysis For Potential Landslide Disaster And Mitigation At Tanjung Keramat Area, Gorontalo. J Sains Inf Geogr 3:37–44
[10] Kusky T (2008) Landslide; Mass Wasting, Soil, and Mineral Hazards. Fact on File, Inc., New York, USA
[11] Bemmelen RW Van (1949) Geology of Indonesia Vol. IA. The Hague, Netherlands
[12] Apandi T, Bachri S (1997) Peta Geologi skala 1:250.000 Lembar Kotamobagu. 2011:
[13] Bahutala I (2016) Geologi daerah Olele dan Sekitarnya, Kabupaten Bone Bolango, Provinsi Gorontalo. Universitas Negeri Gorontalo
[14] Gupta RP (2003) Remote Sensing Geology, 2nd ed. Springer-Verlag, Berlin
[15] Hung LQ, Batelaan O, De Smedt F (2005) Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery. Case study: Suoiimuoi tropical karst catchment, Vietnam. Remote Sens Environ Monit GIS Appl Geol V 5983:59830T
[16] Thannoun RG (2013) Automatic Extraction and Geospatial Analysis of Lineaments and their Tectonic Significance in some areas of Northern Iraq using Remote Sensing Techniques and GIS. Int J Enhanc Res Schience Technol Eng 2:1–11
[17] Geospasial BI (2018) Digital Elevation Model Nasional (DEMNAS).
[18] Van Zuidam RA (1985) Guide to Geomorphology, Serial Photographic Interpretation & Mapping. ITC, Enschede, Netherlands
[19] Surmont J, Laj C, Kissel C, Rangin C, Bellon H, Priadi B (1994) New paleomagnetic constraints on the Cenozoic tectonic evolution of the North Arm of Sulawesi, Indonesia. Earth Planet Sci Lett 121:629–638