Geographica: Science and Education Journal
GSEJ
Website: http://usnsj.com/index.php/geographica
Email: geographica_gsej@usn.ac.id

LANDSLIDE SUSCEPTIBILITY ZONATION, KABILA BONE SUB-DISTRICT, BONE BOLANGO DISTRICT, GORONTALO PROVINCE

AUTHORS INFO

I Gede Sindu Pratama
Department of Earth and Science Technology
Universitas Negeri Gorontalo
sindupratama1212@gmail.com

Sri Maryati
Department of Earth and Science Technology
Universitas Negeri Gorontalo

Ronal Hutagalung
Department of Earth and Science Technology
Universitas Negeri Gorontalo

ARTICLE INFO

ISSN: 2716-4837
Vol. 3, No. 2, December 2021
URL: http://usnsj.com/index.php/geographica

Suggestion for the Citation and Bibliography
Citation in Text:
Pratama et al. (2021)
Bibliography: Pratama, I. G.S., Sri, M., Ronal, H. (2021). Landslide Susceptibility Zonation, Kabila Bone Sub-district, Bone Bolango District, Gorontalo Province. *Geographica: Science & Education Journal, 3* (2, December). 53-68.

Abstract

The research area is administratively located in the Kabila Bone Sub-district, Bone Bolango District, Gorontalo Province which has an area of 143,51 km^2. Natural factors such as slopes, soil and rock conditions, and rainfall make several places in Kabila Bone District prone to landslides. Of course, these events must be prevented early so as not to cause large losses. The purpose of the research is determine landslide susceptibility zonation of Kabila Bone Sub-district, Bone Bolango District, Gorontalo Province. The method used in this research is geological survey method and analysis of geographic information system (mapping, scoring and overlay technique). The parameters used refers to Regulation of the Minister of Public Work No. 22/PRT/M/2007, which includes of slope, soil condition, lithology, rainfall, slope water system, seismicity, and vegetation. The result of research show that Kabila Bone Sub-district consists of a zone with a low level of susceptibility which has an area of 1258,76 ha, a zone with a medium level of susceptibility which has an area of 4026,90 ha, and a zone with a high level of susceptibility which has an area of 502,03 ha. Zones that have a high level of susceptibility are distributed in several villages, namely Botubarani Village with an area of 117,92 ha, Huangobotu Village with an area of 89,35 ha, Bintalahe Village with an area of 64,22 ha, Oluhuta Village with an area of 119,98 ha, and Olele Village with an are of 104,01 ha.

Keywords: Zonation, Geographic Information System, Landslide Susceptibility

A. Introduction

Indonesia is a country with unique tectonic conditions, located between the confluence of three major world plates, namely the Eurasian plate, the Pacific plate, and the Indo-Australian plate. The bad impact caused makes Indonesia a country that is often hit by disasters every year, both in terms of hydrometeorological disasters and geological disasters (BNPB, 2016).

Landslides are one of the geological disasters that often occur in several places that can claim lives. This process is characterized by the displacement of the mass of soil or rock from its original position due to gravity in a relatively tilted direction. One of the factors causing landslides is human activity, which includes clearing agricultural land, loading slopes, mining processes, and so on. The danger of landslides will be higher if it is influenced by other factors from nature which include high rainfall, earthquakes, slopes, soil texture, weathering of rocks, geological structures, and so on (Highland and Bobrowsky, 2008).

Gorontalo is a province located in the northern part of the Sulawesi arm, which is tectonically the center of the meeting of three convergent plates, due to the interaction of the three main earth's crust (plates) in the Neogene period (Simandjuntak, 1992). These conditions make most of the Gorontalo area high mountains with very steep slopes. The southern area of Gorontalo Province mainly covers part of the Bone Bolango Regency, when viewed from the division of physiographic zones into the Southern Mountains Zone (Bemmelen, 1949).

The condition of the cliffs with rocks that are no longer fresh make most areas in the Southern Mountains prone to landslides. Areas that have the potential for landslides can be found in the southern part of Gorontalo, especially in the Tanjung Keramat area and Kabila Bone Sub-district. Landslides that occur in the Tanjung Keramat area are influenced by geological structural mechanisms, mainly controlled by the distribution of joints. The joint orientation is mostly directed relative to the West which is in the direction of the slope (Manyoe et al, 2020).

Kabila Bone District when viewed from the topographical form is an area where most of the area is mountains or highlands with steep slopes (Badan Pusat Statistik Kecamatan Kabila Bone, 2017). Natural factors such as slopes, soil and rock conditions, and rainfall make several places in Kabila Bone Sub-district prone to landslides. This incident must be prevented from an early stage so as not to cause big losses. One of the efforts that can be done is to conduct research and analysis related to landslide-prone zoning in the area. Research conducted should be able to reduce the risk of losses incurred.

B. Methodology

1. Research Design

The research methods used in this study are generally field geology methods and geographic information system (GIS) analysis. The field geology method is used when collecting field data to determine the geological condition of the research area, which includes lithology and geological structure. GIS analysis is used at the stage of making a landslide-prone parameter map, scoring, overlay, and landslide-prone zoning maps.

2. Instruments

The tools used in this study include a geological hammer, GPS, compass, and laptop as a data processor equipped with ArcMap 10.3 and Dips Portable 6.0 applications. The materials used in this study include DEMNAS data (Digital Elevation Model or raster data), Landsat 8 data (band 4 and band 5), rainfall data, and seismic data.

***3**. Technique of Data Analysis*

Data from all indicators that cause landslides that have been collected will be processed using the ArcMap 10.3 application to be used as a map. The maps that will be made include slope maps, soil type maps, geological maps, rainfall maps, slope water system maps, seismic maps, and vegetation maps. Geological structure data in the form of joints will be processed using the Dips Portable 6.0 application to determine the direction of the main stress. All maps of the indicators that cause landslides that have been made are then given score according to predetermined criteria. The score criteria for the indicators that cause landslides refer to the Regulation of the Minister of Public Work No. 22/PRT/M/2007.

All maps of the landslide cause indicators that have been score are then overlaid using the ArcMap 10.3 application to obtain the final map in the form of a landslide-prone zoning map of the research area. In the process of overlapping (overlay) in the ArcMap 10.3 application, it will be adjusted to the total score on the criteria for the level of landslide susceptibility which refers to the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The criteria for the total score value based on the Regulation of the Minister of Public Work No. 22/PRT/M/2007 is presented in Table 1.

Table 1. Criteria for Total Score Value for Potential Landslide Zone

Total Score Value	Class
2,40-3,00	High
1,70-2,39	Medium
1,00-1,69	Low

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

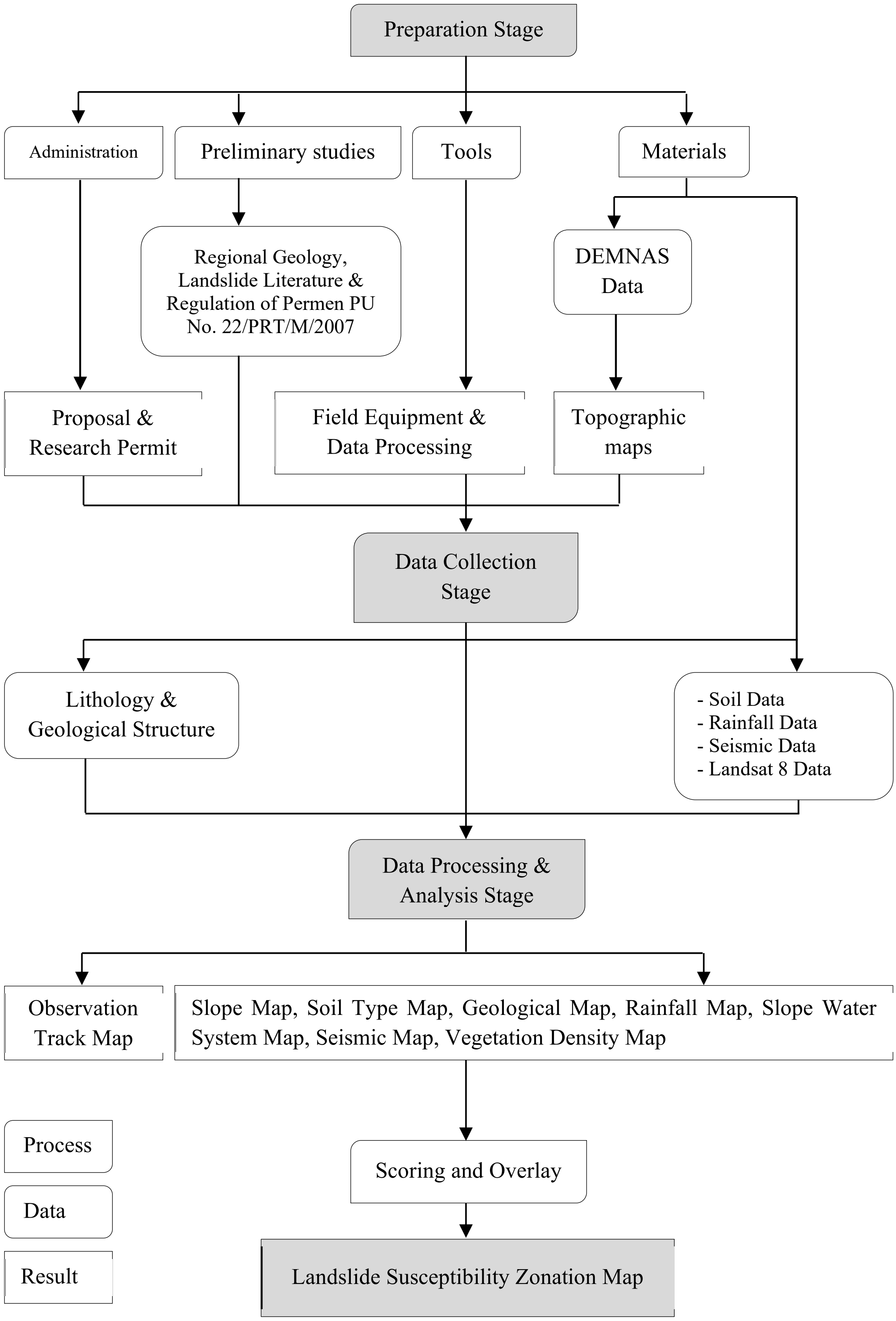

Figure 1. Research Flowchart

C. Findings and Discussion

1. Findings

1.1. Lithology

Lithological observations in the study area were carried out at 58 observation stations. The distribution of lithology observed in the study area consists of 7 rock types, namely andesite, porphyry dacite, granodiorite, basalt, pyroclastic breccia, limestone, and alluvial deposits. Lithology or rocks found in Kabila Bone Sub-district have a large enough influence on landslides. This influence can be seen through the physical condition of the rocks that make up the slopes in Kabila Bone Sub-district. Physical conditions can be in the form of weathering of rocks, the higher the level of weathering of rocks on the slopes, the greater the possibility of landslides.

a. Bilungala Andesite Unit

Bilungala andesite units generally occupy areas with rather steep to steep reliefs such as hills and mountains from the research location. Megascopically, the rock from Bilungala andesite lava has a dark gray color to light greenish gray, hypocrystalline, aphanitic porphyry, consisting of hornblend minerals, biotite, plagioclase. This unit based on its physical characteristics in the field, can be compared with the Bilungala Volcano Formation, which was deposited in the Late Miocene (Apandi and Bachri, 1997).

Figure 2. Bilungala Andesite Outcrop at Station SP2.6

b. Porphyry Dacite Unit

Porphyry dacite units are scattered in the east to southeast of the research location, precisely in Oluhuta Village and Olele Village. Megascopically, dacite porphyry rock is light gray, Hypocrystalline, Inequigranular, Porphyritic, consisting of orthoclase, hornblend and quartz minerals. Based on the physical characteristics of the rocks in the field, the porphyry dacite units were compared with the Bilungala Volcano Formation which has an Early Miocene – Late Miocene age (Apandi and Bachri, 1997).

Figure 3. Porphyry Dacite Outcrop at Station SP1.1A

c. Granodiorite Unit

The granodiorite units are scattered in the northwest part of the research area, precisely in Huangobotu Village and Botubarani Village. Granodiorite units can also be found in the northeastern part of the research area, to be precise in the northern part of Olele Village (Bahutala, 2016). Megascopically the rock in this unit has a light gray color, holocrystalline, faneritic, equigranular, massive, consisting of hornblend, plagioclase, biotite, and quartz minerals. According to Apandi and Bachri (1997), the granodiorite unit is compared to the Bone Diorite formation, where this unit was deposited in the Late Miocene.

Figure 4. Granodiorite Outcrop at Station SP3.3B

d. Pinogu Andesite Unit

The Pinogu andesite unit occupies the western part of Botutonuo Village, spreading west to northwest from Modelomo Village, Biluango Village, and Huangobotu Village. A clear outcrop was found at station SP3.2C, which was megascopically dark gray to brownish in color, hypocrystalline, aphanitic, porphyritic textured in several places, the observed mineral was plagioclase. Based on the similarity of physical rock characteristics in the field, the Pinogu andesite unit was compared with the Pinogu Volcanic Formation, which was deposited at the Pliocene age (Apandi and Bachri, 1997).

Figure 5. Pinogu Andesite Outcrop at Station SP3.2C

e. Basalt Unit

Basalt unit occupies the western part of the study area, precisely in the village of Botubarani. Outcrops of basalt rock can be found at the SP3.5 observation station, megascopically it has a dark to blackish color, hypocrystalline, aphanitic, minerals difficult to observe directly. Based on the similarity of rock physical characteristics, the basalt unit was compared with the Pinogu Volcano Formation, which was deposited at the Pliocene age (Apandi and Bachri, 1997).

Figure 6. Basalt Rock Outcrop at Station SP3.5

f. Pyroclastic Breccia Unit

The pyroclastic breccia units are scattered in the southern part of the study site, east to west and occupy almost all of the southern hills of the study site. Megascopically, the pyroclastic breccia rock has dark gray color, the size of the gravel – boulder fragments, half angled – angled, poorly sorted, open packed, tuff matrix, monomic fragments with porphyry andesite type. Based on the physical characteristics of rocks in the field, the pyroclastic breccia units were compared with the Pliocene – Pleistocene Pinogu Volcano Formation (Apandi and Bachri, 1997).

Figure 7. Pyroclastic Breccia Outcrop at Station SP2.8

g. Reef Limestone Unit

The reef limestone unit occupies the southern part, especially in the coastal area of the study site. One of the reef limestone outcrops can be found at the SP3.6 observation station, which megascopically has a light gray color, coral composition, carbonate matrix, calcite cement and is partially compact. Based on the similarity of physical characteristics in the field, reef limestones were compared with the Holocene Reef Limestone Formation (Apandi and Bachri, 1997).

Figure 8. Reef Limestone Outcrop at Station SP3.6

h. Alluvial Deposits Unit

The alluvial deposit unit is a deposit of loose material in the size of clay to lumps, which occupies the southern part of the study site, especially the plains and downstream rivers. The alluvial deposit unit can be compared with the Holocene Alluvium Formation and Coastal Sediment (Apandi and Bachri, 1997), and the deposition process is still ongoing today.

Figure 9. Alluvial Deposits at Station SP3.3C

1.2. Geological Structure

Tension fracture measurements were performed at each observation station SP1.13 on porphyry dacite rock type, SP2.6 on andesite rock type, SP2.9 on andesite rock, SP3.1B on andesite rock, and SP3.2C on andesite rock. Based on the results of processing using a rosette diagram, each station has the same main force direction, which is northwest – southeast.

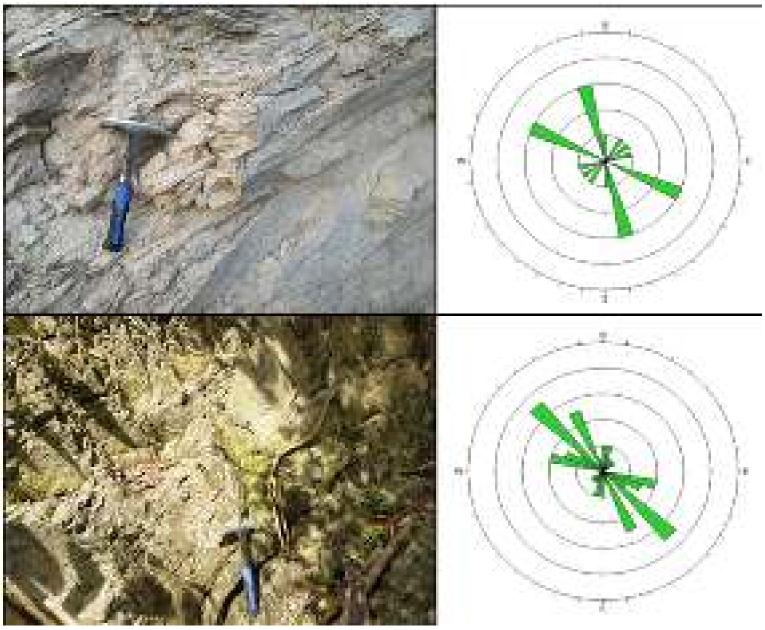

Figure 10. Processing Results of Tension Joints at Stations SP1.13 (Above) and SP2.6 (Bottom)

The fault found at the research site is located at the SP1.6 observation station, precisely at the rock contact between the breccia and limestone. The results of the fault measurement obtained the position of the N320^{o}E/69^{o}NE strike/dip with a line streak of 61^{o}E:N312^{o}E. Observation results show the fault is a type of down fault (Normal Fault).

Figure 11. Normal Fault at Station SP1.6

1.3. Slope

The slope data used is sourced from the DEM data in 2020. The data that has been obtained is then processed into a slope map of the Kabila Bone Sub-district. The slope class that will be made refers to the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The slope map of Kabila Bone Sub-district can be seen in Figure 12. The slope map of Kabila Bone Sub-district shows that Kabila Bone Sub-district is dominated by slopes with a slope above 40%, which is 3855.01 ha which is indicated by red on the map.

The slope class on the slope map of the Kabila Bone District will then be score according to the guidelines to be processed into a landslide-prone zoning map. The determination of the score and the results of the slope is presented in Table 2.

Table 2. Score and Slope of Kabila Bone Sub-district

No.	Slope (%)	Characteristics	Sensitivity	Score
1.	0-35	Slopes with a slope of 0-35%	Low	0,30

2.	35-40	The slope is relatively gentle with a slope between 36% to 40%	Medium	0,60
3.	>40	Relatively convex slope with a slope of more than (above) 40%	High	0,90

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

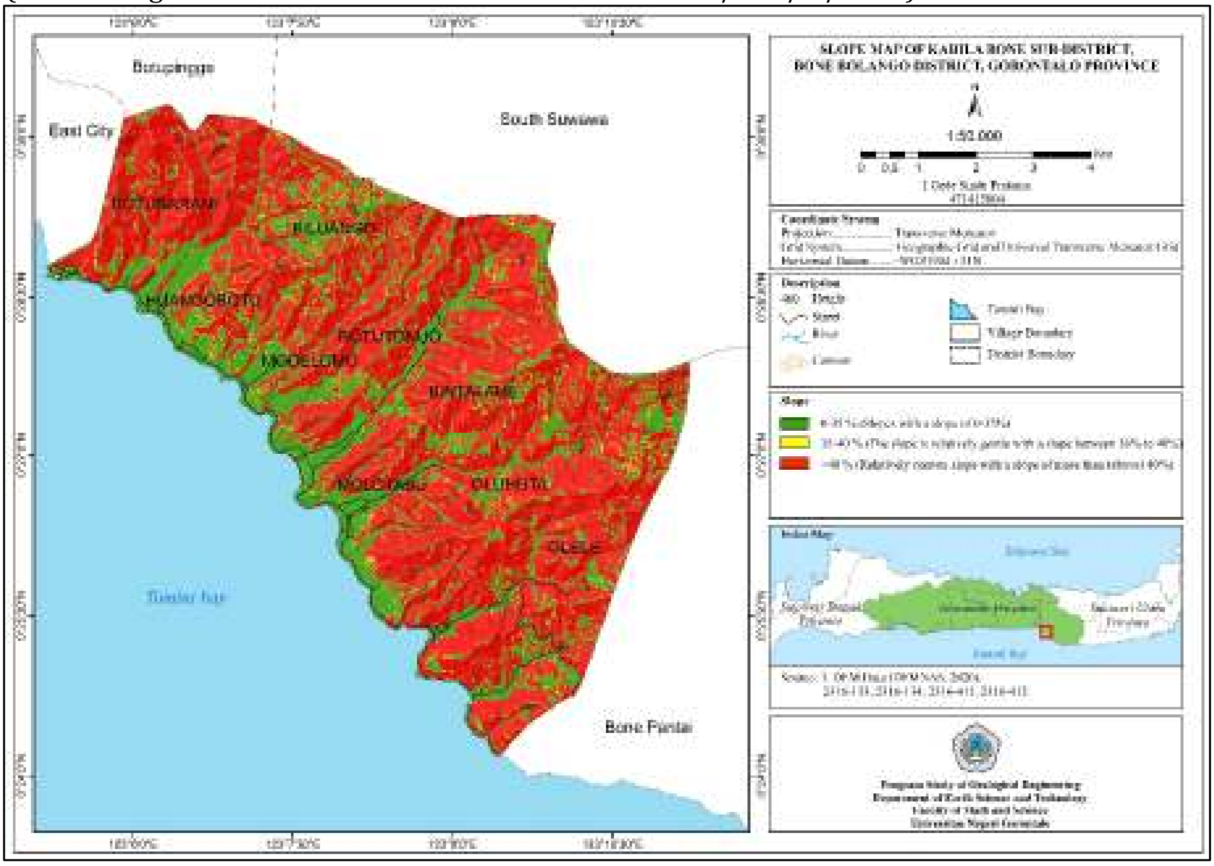

Figure 12. Slope Map of Kabila Bone Sub-district

1.4. Soil Type

The soil condition indicators used are soil type data from the research area. The soil type data used is sourced from the soil type map of Bone Bolango Regency with a scale of 1:50,000 issued by the Ministry of Agriculture in 2019. The data is then processed into a soil type map of Kabila Bone Sub-district which can be seen in Figure 13.

The soil type map of Kabila Bone Sub-district shows that the research area consists of 3 types of soil, namely Latosol, Mediterranean, and Podsolic. The Latosol type of soil has an area of 1458.38 ha which is marked in white on the map. The Mediterranean type soil has an area of 1470.03 ha which is marked with a reddish brown color on the map. Podsolic soil type has an area of 2877.24 ha which is marked with light brown color on the map.

The scoring of the soil type indicators is based on the guidelines of the Regulation of the Minister of Public Work No. 22/PRT/M/2007 and determination of soil characteristics is based on the national soil classification (Ministry of Agriculture, 2016), namely on the level of looseness and soil fertility. The scores and type of soil in the study area are presented in Table 3.

Table 3. Score and Soil Type of Kabila Bone Sub-district

No.	Soil Type	Characteristics	Sensitivity	Score
1.	Latosol	Slopes are composed of thick (>2m) overburden, loose, water-permeable, for example residual soil that sits on the bedrock.	High	0,45
2.	Mediteran	The slope is composed of thick soil cover (>2m), not too loose, water permeable, there is a contrasting area in the lower layer.	Medium	0,30

3.	Podsolik	Overburden (2m), dense, does not pass water, there is a contrasting field in the lower layer.	Low	0,15

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

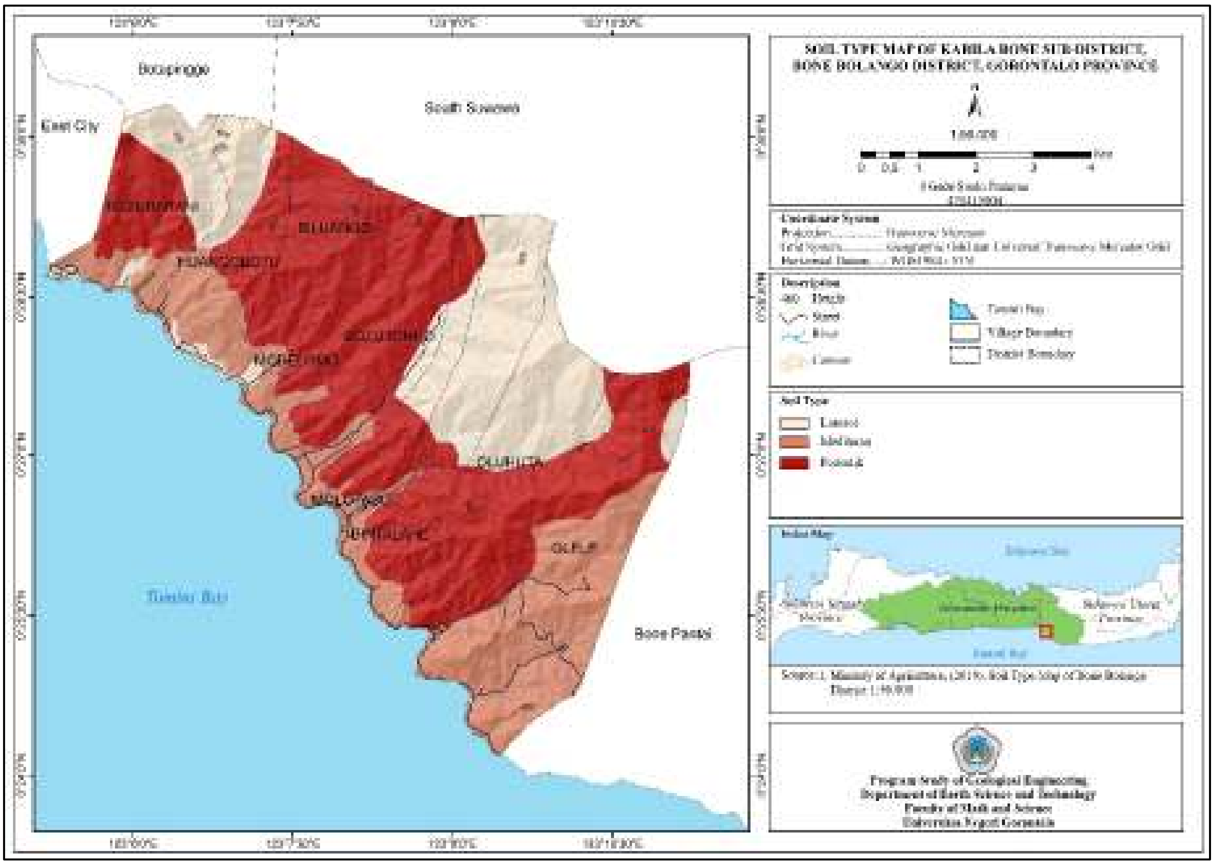

Figure 13. Soil Type Map of Kabila Bone Sub-district

1.5. Slope Composing Rock

Rock type data used directly through rock data collection in the research area. Additional data used is also sourced from a geological map of the Botutonuo area and its surroundings, Bone Bolango Regency (Masulili, 2016), and a geological map of the Olele area and its surroundings, Bone Bolango Regency (Bahutala, 2016). The type of data that has been collected is then processed into a geological map of Kabila Bone Sub-district which can be seen in Figure 14.

The geological map of Kabila Bone Sub-district shows that Kabila Bone Sub-district consists of several different rock types. Explanation of the characteristics of some of these rocks can be seen in section 1.1. The Bilungala Andesites are marked in red on the map. This unit occupies the northern part of Biluango Village to the east to Olele Village. Porphyry dacites are marked in yellowish white on the map. Porphyry dacite units are scattered in the east to southeast of the study site.

Granodiorite is marked in pink on the map. The granodiorite units are scattered in the northwest part of the research area, precisely in Huangobotu Village and Botubarani Village. Granodiorite units can also be found in the northeastern part of the study area, precisely in the northern part of Olele Village. The Pinogu Andesites are marked in dark red on the map. The Pinogu andesite unit occupies the western part of Botutonuo Village, spreading west to northwest from Modelomo Village, Biluango Village, and Huangobotu Village.

Basalt is marked in orange on the map. Basalt unit occupies the western part of the study area, precisely in the village of Botubarani. Pyroclastic breccias are marked in brown on the map. The pyroclastic breccia units are scattered in the southern part of the study site and almost occupy the entire southern hills of the study site. Limestones are marked in blue on the map. Limestone units occupy the southern part, especially in the coastal area of the study site. Alluvial deposits are marked in gray on the map. The alluvial deposit unit occupies the southern part of the study site, especially the plains and downstream areas of the river.

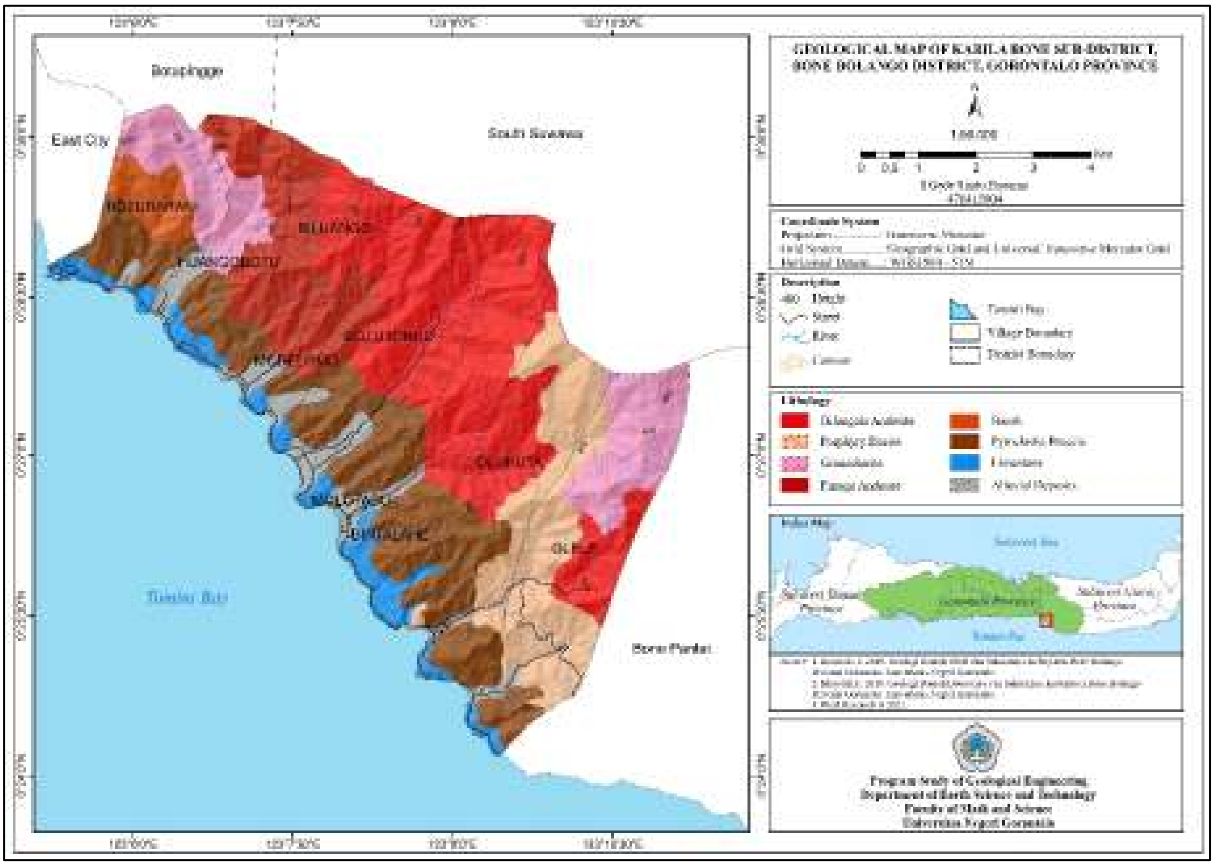

Figure 14. Geological Map of Kabila Bone Sub-district

The scoring of the rock indicators that make up the slopes is based on the rock conditions in the research area, namely the presence of joints in the rocks and the level of weathering in the rocks. If there are joints in the rock and have a high weathering intensity, it will be given a high score, and vice versa. The scores and rock types in the study area are presented in Table 4.

Table 4. Score and Type of Rock in Kabila Bone Sub-district

No.	Type of Rock	Characteristics	Sensitivity	Score
1.	Bilungala Andesite	There is a fracture structure, the intensity of weathering is low to moderate.	Medium	0,40
2.	Porphyry Dacite	There is a fracture structure, high weathering intensity.	High	0,60
3.	Granodiorite	There is a fracture structure, the intensity of weathering is low to moderate.	Medium	0,40
4.	Pinogu Andesite	There is a fracture structure, high weathering intensity.	High	0,60
5.	Basalt	There is a fracture structure, high weathering intensity.	High	0,60
6.	Pyroclastic Breccia	No fracture structure, low weathering intensity.	Low	0,20
7.	Limestone	There is a fracture structure, the intensity of weathering is low to moderate.	Medium	0,40
8.	Alluvial Deposits	No structure, high weathering intensity.	Medium	0,40

(Source: Field Research and Previous Research)

1.6. Rainfall

Annual rainfall data used in the study area was obtained at the Bone Bolango Climatology Station. The rainfall data that has been obtained is then processed to obtain a rainfall model in the Kabila Bone Sub-district. The results of the processing are in the form of a map showing rainfall information in Kabila Bone Sub-district. The rainfall class that will be made refers to the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The rainfall map in Kabila Bone Sub-district can be seen in Figure 15.

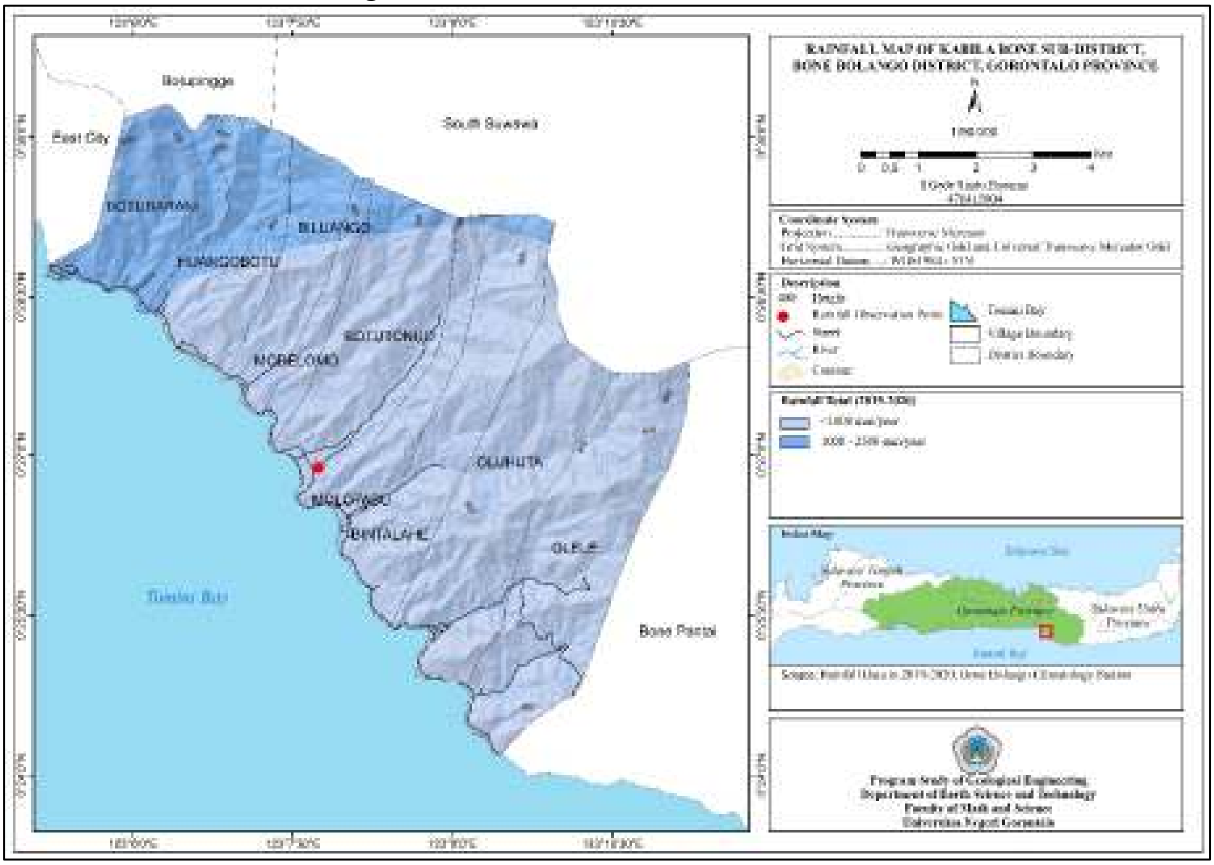

Figure 15. Rainfall Map of Kabila Bone Sub-district

The rainfall map in Kabila Bone Sub-district shows that the study area consists of low intensity (<1000 mm/year) and moderate (1000 – 2500 mm/year) rainfall. Low-intensity rainfall covers the southern part of Huangobotu Village, southern part of Biluango Village, Modelomo Village, Botutonuo Village, Molotabu Village, Bintalahe Village, Oluhuta Village and Olele Village. Moderate rainfall includes Botubarani Village, northern part of Huangobutu Village, northern part of Biluango Village, northern part of Modelomo Village, and northern part of Botutonuo Village.

The scoring of the rainfall indicators is adjusted to the guidelines of the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The score and rainfall in Kabila Bone Sub-district are presented in Table 5.

Table 5. Score and Rainfall in Kabila Bone Sub-district

No.	Rainfall (mm/year)	Sensitivity	Score
1.	< 1000	Low	0,20
2.	1000 - 2500	Medium	0,40

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

1.7. Slope Water System

The slope water system data used is the result of processing from the DEM data (Demnas 2020). The DEM data in the form of raster data is processed into a hillshade model to determine the appearance and relief of the research location. The hillshade model that has been completed is then processed into a slope water system map in Kabila Bone Sub-district. The slope water system map contains information about the level of water seepage on the slopes. The slope water system map of Kabila Bone sub-district can be seen in Figure 16.

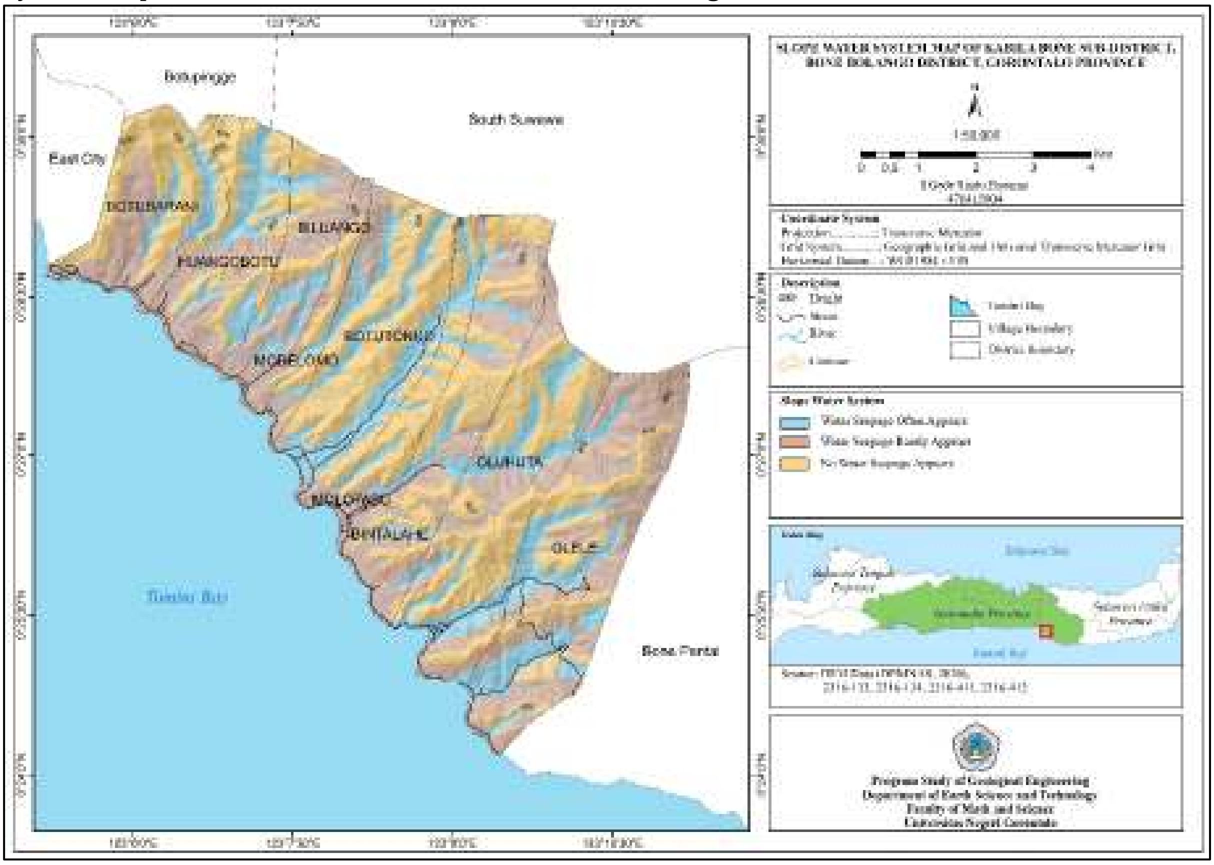

Figure 16. Slope Water System Map of Kabila Bone Sub-district

The slope water system map of Kabila Bone Sub-district shows that Kabila Bone Sub-district consists of high water seepage level (water seepage often appears), moderate water seepage level (water seepage rarely appears), and low water seepage level (no water seepage). The scoring of the slope water system indicators is adjusted to the guidelines of the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The score and level of water seepage in Kabila Bone Sub-district are presented in Table 6.

Table 6. Score and Level of Water Seepage in Kabila Bone Sub-district

No.	Water Seepage Level	Sensitivity	Score
1.	Water Seepage Often Appears	High	0,21
2.	Water Seepage Rarely Appears	Medium	0,14
3.	No Water Seepage Appears	Low	0,07

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

1.8. Seismicity

Seismic data used is earthquake point data obtained from the United States Geological Survey site with a range of 1936-2021. The earthquake point data is then interpolated to obtain a model of the Gorontalo Province seismic map. The seismic map of Gorontalo Province can be seen in Figure 17.

The Gorontalo Province seismic map shows that Gorontalo Province is dominated by an earthquake with a magnitude of 4,0 – 4,9 which is marked with a yellow dot on the map. The map was then simplified into a seismic map of the Kabila Bone Sub-district. The map shows that Kabila Bone Sub-district consists of a low earthquake-prone level and a medium earthquake-prone level. The score given refers to the Regulation of the Minister of Public Work No. 22/PRT/M/2007, which are low (0,03) and medium (0,06).

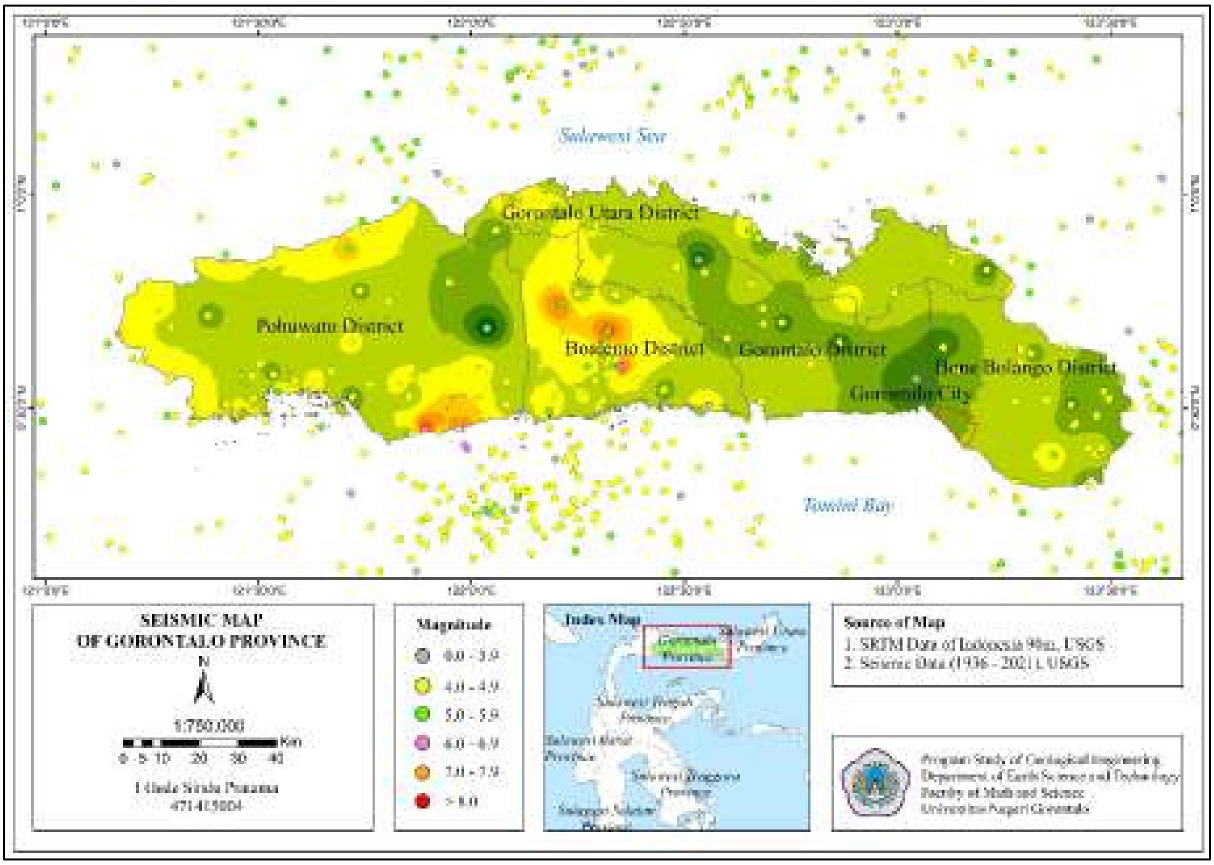

Figure 17. Seismic Map of Gorontalo Province

1.9. Vegetation

The data from the vegetation indicators used are sourced from Landsat 8 data in 2021. Landsat 8 data are then processed using the NDVI (Normalize Difference Vegetation Index) technique to obtain the vegetation density value of the study area. The density value is then included in the vegetation density map of Kabila Bone Sub-district (Figure 18).

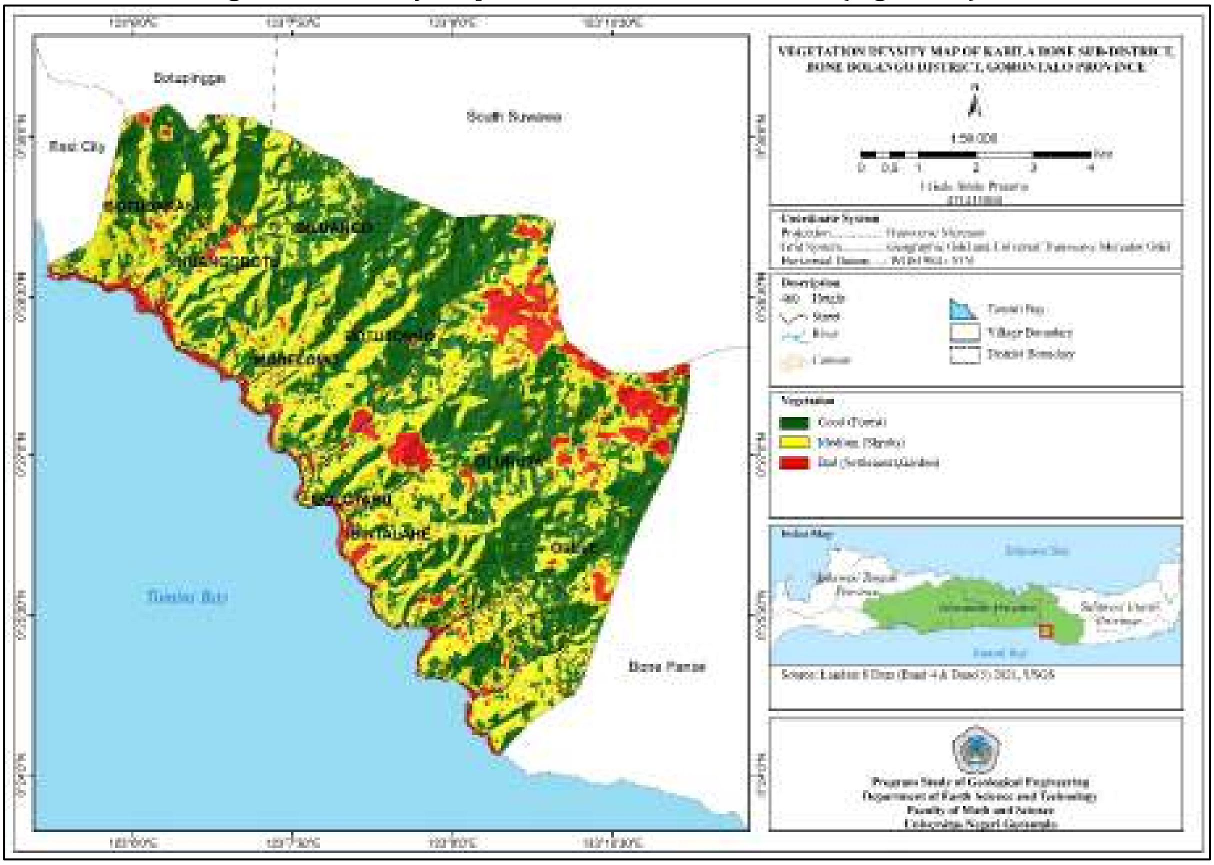

Figure 18. Vegetation Density Map of Kabila Bone Sub-district

The vegetation density map of Kabila Bone Sub-district shows that Kabila Bone Sub-district consists of good vegetation level (consisting of forest), medium vegetation level (consisting of shrubs), and poor vegetation level (consisting of settlements and gardens). The scoring of the vegetation indicators is adjusted to the vegetation density level of the Kabila Bone Sub-district and the guidelines from the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The score and level of vegetation density in Kabila Bone Sub-district are presented in Table 7.

Table 7. Score and Vegetation Level of Kabila Bone Sub-district

No.	Vegetation	Characteristics	Sensitivity	Score
1.	Good	There are many trees rooted in tunjang (Forest), helping the stability of the land or slopes.	Low	0,10
2.	Medium	Consists of shrubs, small wild plants with various types of roots, somewhat strong enough to withstand slope material.	Medium	0,20
3.	Bad	Utilization of residential land, especially near the slopes, as well as the use of garden land which greatly affects the stability of the slopes.	High	0,30

(Source: Regulation of the Minister of Public Work No. 22/PRT/M/2007)

2. Discussion

The level of landslide susceptibility in Kabila Bone Sub-district is known after overlaying all the indicator maps that cause landslides. The results of overlapping are then carried out by the process of summing the score of all indicators causing landslides to get the total weight or total score. The determination of the class or level of landslide susceptibility then refers to the Regulation of the Minister of Public Work No. 22/PRT/M/2007. The level of vulnerability is high if the total value of the score is 2,40-3,00, the level of vulnerability is moderate if the total value of the score is 1,70-2,39, the level of vulnerability is low if the total value of the score is 1,00-1,69. The class or level of landslide susceptibility that has been obtained is then presented in the form of a landslide-prone zoning map. The zoning map of the landslide susceptibility level in Kabila Bone District can be seen in Figure 19.

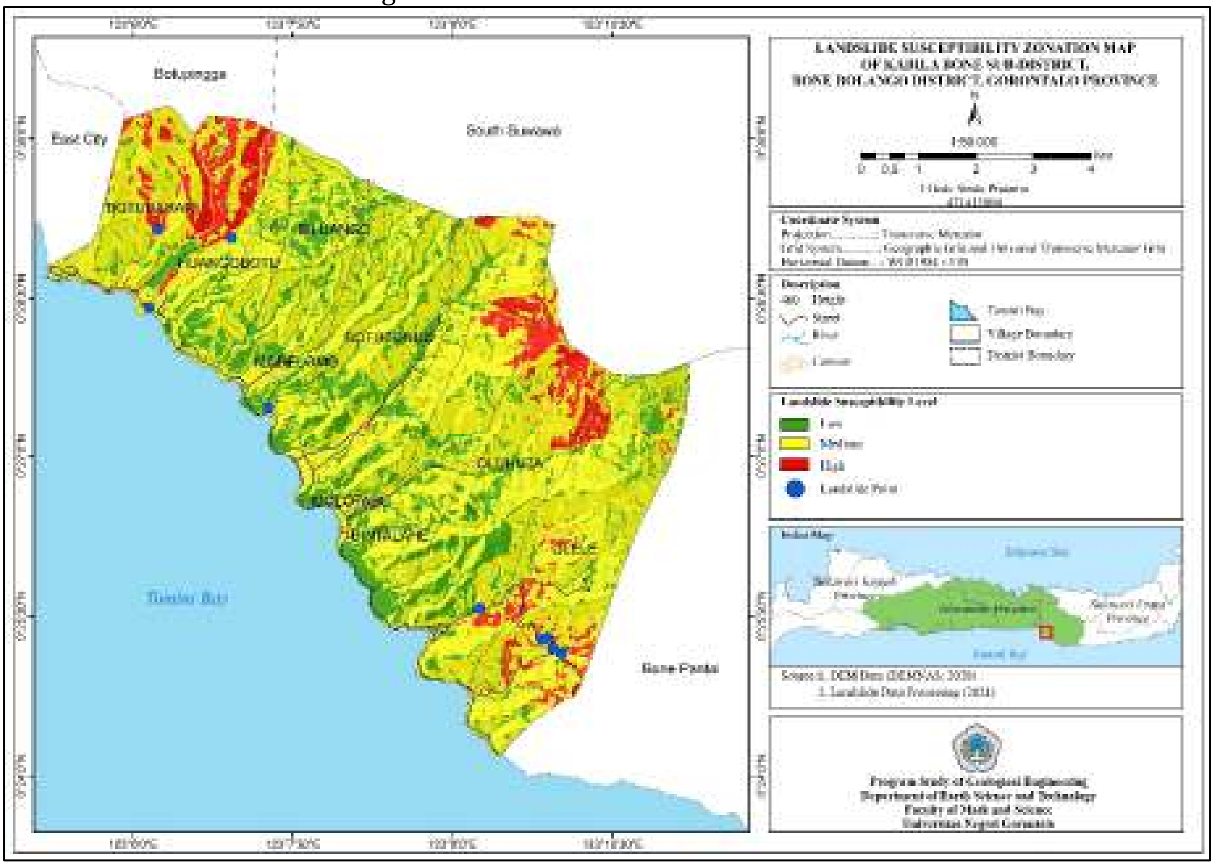

Figure 19. Landslide Susceptibility Zonation Map of Kabila Bone Sub-district

The zoning map of the landslide susceptibility level of Kabila Bone Sub-district shows that Kabila Bone Sub-district is dominated by a moderate level of vulnerability, which based on calculations has an area of 4026,90 ha. The zone with a low level of vulnerability has an area of 1258,76 ha which occupies the lowlands and areas with a relatively sloping surface. The zone with a high level of vulnerability as a whole has an area of 502,03 ha.

The level of landslide susceptibility shown on the map has a different distribution and area for the villages in Kabila Bone Sub-district. The distribution and extent of landslide-prone zones in villages in Kabila Bone Sub-district are presented in Table 8.

Table 8. Landslide Prone Zone Distribution

No.	Villages	Landslide Susceptibility Level		
		Low (ha)	Moderate (ha)	High (ha)
1.	Botubarani	50,09	415,76	117,92
2.	Huangobotu	111,21	373,71	89,35
3.	Biluango	159,16	260,82	0,44
4.	Modelomo	62,80	124,87	0,33
5.	Botutonuo	268,53	584,16	2,91
6.	Molotabu	83,21	237,35	2,83
7.	Bintalahe	185,87	537,36	64,22
8.	Oluhuta	199,10	637,49	119,98
9.	Olele	138,75	855,35	104,01

The distribution table for landslide-prone zones shows that zones or areas that have a high level of vulnerability with a fairly wide distribution are in several villages, namely Botubarani Village, Huangobotu Village, Bintalahe Village, Oluhuta Village, and Olele Village. The indicators that cause landslides that affect the high level of vulnerability in some of these villages are the slope, soil conditions, rocks that composed the slopes, and the level of vegetation. Landslides occurred in several places, especially in Olele Village (Figure 20).

Figure 20. Landslide Incident in Olele Village

D. Conclusion

From the research that has been done, it can be concluded that the results are in the form of a zoning map of the level of landslide susceptibility in Kabila Bone Sub-district. Kabila Bone Sub-district consists of zones with low, medium, and high levels of vulnerability. The zone with a low level of vulnerability has an area of 1258,76 ha which occupies the lowlands and areas with a relatively sloping surface. Zone with a moderate level of vulnerability has an area of 4026,90 ha and is the dominant zone in Kabila Bone Sub-district. The zone with a high level of vulnerability as a whole has an area of 502,03 ha. Zones that have a high level of vulnerability with a fairly wide distribution or spread are in several villages, namely Botubarani Village covering an area of 117,92 ha, Huangobotu Village covering an area of 89,35 ha, Bintalahe Village covering an area of 64,22 ha, Oluhuta Village covering an area of 119,98 ha. , and Olele Village covering an area of 104,01 ha. The dominant factors that affect the high susceptibility zone are steep slopes, loose and water-permeable soil conditions, and very weathered rock conditions making up the slopes.

Based on the results of the research and the occurrence of landslides in Kabila Bone Sub-district, there are several suggestions addressed to the community and local government. Suggestions to the community include not clearing land, not carrying out permanent construction near the slopes, planting with proper cropping patterns on the slopes, for example planting stilt-rooted trees. Suggestions to the local government include making a map of the landslide-prone zone for Kabila Bone Sub-district, as well as socializing and forming a landslide disaster management team in Kabila Bone Sub-district.

E. References

Apandi, T., dan Bachri, S. 1997. *Peta Geologi Lembar Kotamobagu, Sulawesi, skala 1:250.000*. Puslitbang Geologi. Bandung.

Badan pusat Statistik Kabupaten Bone Bolango. 2017. *Kecamatan Kabila Bone Dalam Angka 2017*. Badan Pusat Statistik Kabupaten Bone Bolango.

Bahutala, I. 2016. *Geologi Daerah Olele dan Sekitarnya Kabupaten Bone Bolango Provinsi Gorontalo*. Universitas Negeri Gorontalo.

Badan Informasi Geospasial. 2020. *DEMNAS*. Citra: 2316-133, 2316-134, 2316-411, 2316-412. http://tides.big.go.id/DEMNAS/

Bemmelen, R. W. Van. 1949. *The Geology of Indonesia*, Vol. 1 A, Government Printing Office, The Hague.

Hall, R. & Wilson, M. E. J. 2000. Neogene Sutures in Eastern Indonesia. *Journal of Asian Earth Sciences, 18, 781–808*.

Highland, L. M. & Bobrowsky, P. 2008. *The landslide handbook—A guide to understanding landslides: Reston, Virginia*. U.S. Geological Survey Circular 1325, 129 p.

Manyoe, I. N., Usman, F. C. A., Taslim, I., Mokoginta, M., Napu, S. S. S., Salama, T. H., & Kayambo, M. R. 2020. Geological Structure Analysis For Potential Landslide Disaster And Mitigation At Tanjung Keramat Area, Gorontalo. *Jurnal Sains Informasi Geografi, 3(1), 37-44*.

Masulili, F. 2016. *Geologi Daerah Botutonuo dan Sekitarnya Kabupaten Bone Bolango Provinsi Gorontalo*. Universitas Negeri Gorontalo.

Peraturan Menteri Pekerjaan Umum No. 22/PRT/M/2007. *Pedoman Penataan Ruang Kawasan Rawan Bencana Longsor*. Jakarta.

Simandjuntak, T. O. 1992. An Outline of Tectonics of the Indonesian Region. *Geological News Letter, 252(3)*, 4-6. Geological Research and Development Center, Bandung Indonesia.

Subardja, D. S., Ritung, S., Anda, M., Sukarman, Suryani, E., & Subandiono, R. E. 2016. *Petunjuk Teknis Klasifikasi Tanah Nasional Edisi Ke-2*. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian, Bogor. 60 hal.

United States Geological Survey. 2021. *Search Earthquake Catalog, 1936-2021*. https://earthquake.usgs.gov/earthquakes/search/