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MECHANISM AND CHARACTERISTICS OF THE LANDSLIDES IN BONE BOLANGO REGENCY, GORONTALO PROVINCE, INDONESIA

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ABSTRACT: One of the regencies in Gorontalo Province, Indonesia, Bone Bolango is an area in which landslides occur frequently. This study was at identifying the mechanism and characteristics of landslides in Bone Bolango Regency. This study is important to minimize hazards caused by this disaster. Data were obtained from the results of site survey, surface geological survey and geotechnical investigation. Cohesion during the dry season ranged between 0-15kPa, and the angle of internal friction ranged between 30º-44º. The topography of this area indicates a steep slope (>40°), with weathered rock and discontinuity. These internal factors made the slopes prone to landslide. Meanwhile, external factors that trigger landslides are high precipitation (>100mm), the absence of vegetation covering the slopes, as well as land use on the slopes. In general, the types of the landslide in the study area were debris flows, rotational slides, and rock falls. At the period of high precipitation, the rate of infiltration of rainwater into the soil was slower than the rate of the increase in the volume of rainwater deposited and flowing into the slope surface, resulting in the debris flow. Slope-forming material became soft due to the rise of groundwater levels. This caused a decrease in shear strength and pore water pressure that turned into positive. In the rock slope, rainwater filled the crack of slope discontinuity area so that rock got loose and fell freely. Therefore, a further research is necessary to conduct in order to determine the most accurate and efficient method for slope stability.

Keywords: Landslide, Debris Flow, Rock Fall, Rotational Slide

1. INTRODUCTION

Bone Bolango is one of the regencies in Gorontalo Province located on Sulawesi Island, Indonesia in which 43% of the land is generally hilly or mountainous. Floods and landslides often occur in this area. Such disasters occur almost every year during the rainy season and always affect the economic life of the surrounding community in the form of loss of life, material damage, and damage to the environment and public facilities. Several studies have been conducted by researchers on the mechanisms and characteristics of the slide as conducted by [1], [2], [3], [4], and so on. Reference [5] states that debris flow in Xiaojiagou, Sichuan Province has two (2) types, namely the hill-slope debris flow and channelised debris flow. The characteristics of the landslide are based on geological, geotechnical and geomorphological study as conducted by researchers [6], [7], [8], and [9]. Reference [7] investigates gully erosion. Each location has different characteristics of the landslide. Therefore, it is necessary to conduct a research on the mechanisms and characteristics in Bone Bolango Regency in order to determine a proper method of disaster management.

2. CLASSIFICATION AND DIMENSIONS OF LANDSLIDE

The movement of the slope is divided into six types as shown in Table 1 [10] and the geometry and dimensions of landslides are based on the standards of the International Asociation of Engineering Geologies (IAEG) as shown in Fig. 1 [11].

Table 1 Classification of landslide according to Varnes, 1978

Movement type	Rock	Debris	Earth
Fall	Rock fall	Debris fall	Earthfall
Topple	Rock topple	Debris topple	Earth topple
Slides:			
Rotational sliding	Rock slump	Debris slump	Earth slump
Translational sliding	Block slide	Debris slide	Earth slide
Lateral spreading	Rock spread	-	Earth spread
Flows	Rock creep	Talus flow, debris flow, debris avalanche, solifluction, soil creep	Dry sand flow, wet sand flow, quick clay flow, earth flow, rapid earth flow, loss flow
Complex	Rock slide-debris avalanche	Cambering, valley bulging	Earth slump-earth flow

Based on the numbering in Figure 1, reference [12] shows variables of landslide dimensions based on the proposed standard of IAEG as below:

1. Width of displaced mass *(Wd)*
2. Width of rupture surface *(Wr)*
3. Total length *(L)*
4. Length of displaced mass *(Ld)*
5. Length of the rupture surface *(Lr)*
6. Depth of displaced mass *(Dd)*
7. Depth of the rupture surface *(Dr)*

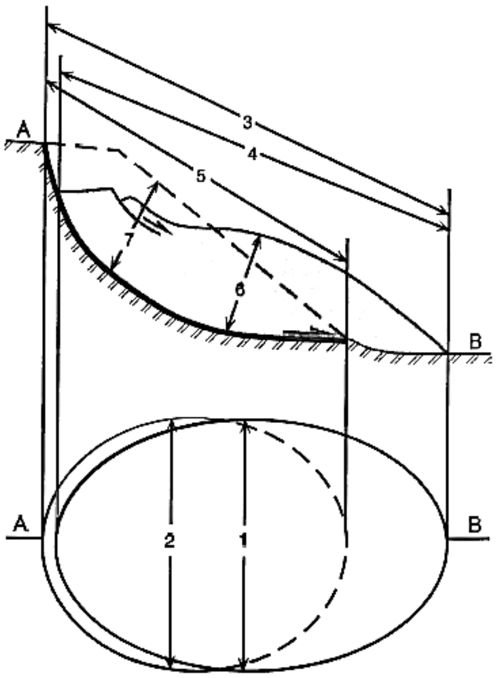

Figure 1 Dimension of landslide [11]

3. RESEARCH METHOD

In this study, primary data were obtained from observation and field survey, surface geological surveys and geotechnical investigation. The surface geological survey was conducted by taking rock samples in 4 (four) locations of the landslide (R1, R2, R3, and R4). The geotechnical investigation was carried out during the dry season in three landslide sites, namely Tupa Village, Bolango Utara Subdistrict (BH 1, BH 2, BH 3), Oluhuta Village, Kabila Bone Subdistrict (BH 4, BH 5, BH 6) and Muara Bone Village, Bone Subdistrict (BH 7). Drilling point was located on foot slope, middle slope and upper slope (Fig.2). Physical and mechanical properties of materials forming the slope were obtained by testing in the laboratory.

4. CHARACTERISTICS OF THE STUDY AREA

The study was conducted in the area of the landslide, namely Bulango Utara Subdistrict and landslide areas located along Trans-Sulawesi Highway, South Coast Line, Bone Bolango Subdistrict (13 landslide points) as shown in Fig. 2.

4.1 Topography Conditions

Bone Bolango Subdistrict is located at an altitude between 7-95 meters above sea level, with the various slope. In general, the topography of Bone Bolango Subdistrict is divided into three groups:

1. Land condition with plateau (mountainous) surface or on the slope of 40% and with rough morphological texture,
2. Land condition with hilly (wavy) relief and with medium morphological texture,
3. Land condition with low surface relief.

The locations of landslide were included in the groups with the mountainous land conditions and the slope between 40º-90º.

4.2 Geological Conditions

Reference [13] states that the geological conditions (Fig. 2) are generally based on the sequence of rock units that compose Bone Bolango and surrounding areas, from oldest to youngest as follows:

1. Tertiary rocks (sedimentary and volcanic). Tertiary rocks occupy the northern part and compose a hilly morphology. These rocks are compacted into good, hard, solid and stable. They mostly have experienced weathering, resulting in the soil movement due to a strong shake.
   a. Tinombo facies sediments Formation (Tets) consists of shale and sandstone inserted with limestone and chert.
   b. Member of Limestone of Tapadaka Formation (Tmtl) consists of solid light-gray limestone, containing green volcanic rock fragments. Limestone forms lenses in Tapadaka Formation and facies partly changes into sandstone.
   c. Bilungala Volcanic rock (Tmbv) consists of breccia, tuff, and lava composed of andesite, dacite, and rhyolite. Zeolite and calcite are often found on pieces of rock making up the breccia. In the Southern coast area near Bilungala, this unit is dominated by lava and breccia.
2. Intrusive rocks, diorite of Bone (Tmb) consist of quartz diorite, diorite, granodiorite, and granite. Diorite is often found in Taludaa River, with a diversity of diorite, granodiorite, and granite. Granite rock is often found in Bone River. This unit intrudes through volcanic rock of Bilungala and formation of Tinombo. This unit was likely formed by the late Miocene.

3. Pinogu Volcanic Rock (TQpv) consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccia in Bone Mountains is composed of pyroxene-andesite and dacite. Tuff and lapilli tuff around Bone River are composed of dacite. This unit was likely formed at the Pliocene-Pleistocene.

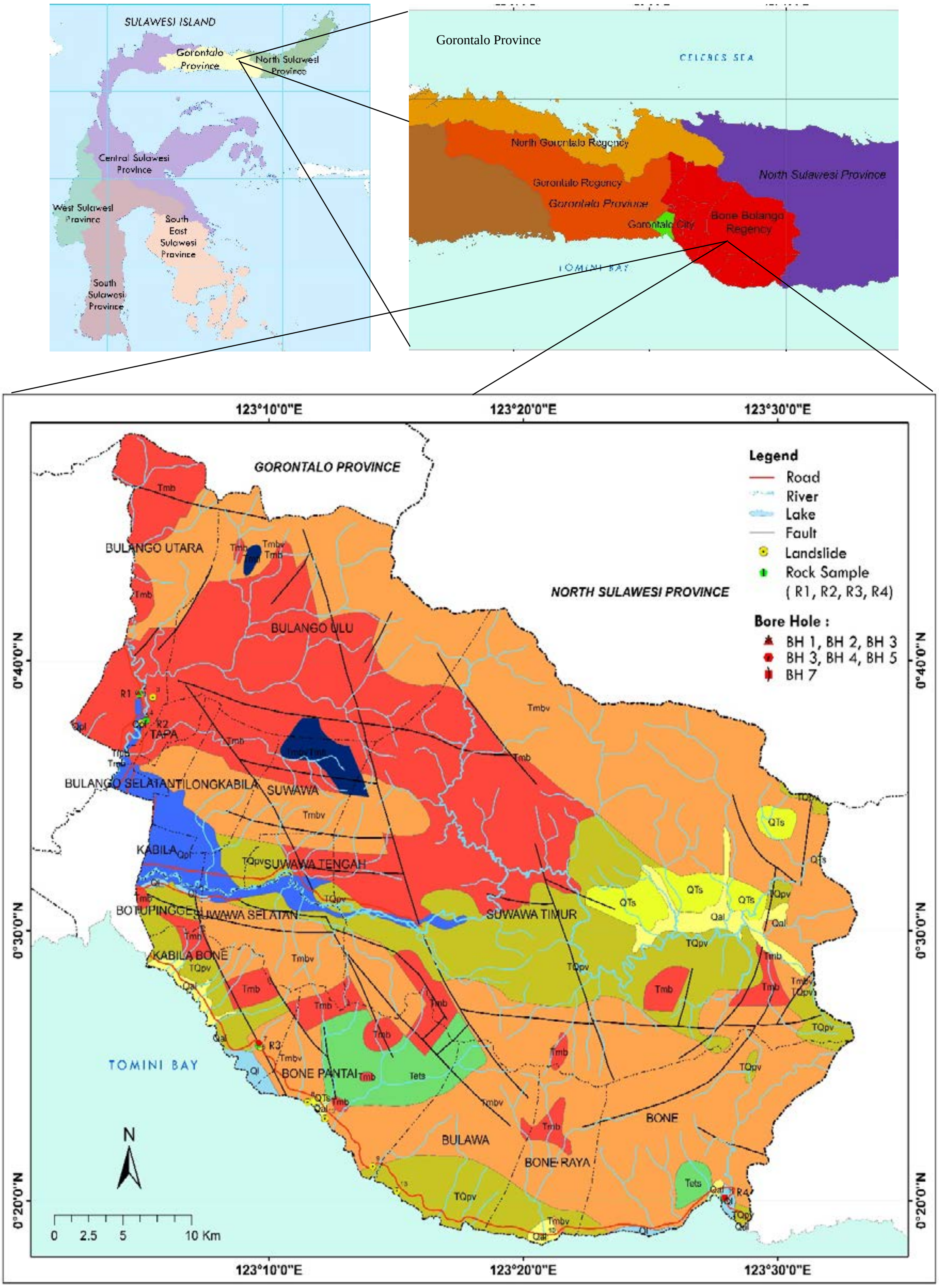

Figure 2 Map of the study area [13]

4. Molasa Celebes (QTS) is post-orogenic deposit located in small hollows consisting conglomerate, breccia, and sandstone. Conglomerate and breccia are composed of various components materials such as andesite chip, basalt, granite, granodiorite, limestone, sandstone, and quartz. This unit has a mild slope to about 30^o, tens of meters thick, predicted to be formed at the Pliocene-Pleistocene
5. Quarter rock (sedimentary rock). The quarter rock consists of hilly morphology, especially in the southern part. This rock is less dense and prone to landslides.
   a. Alluvium and coastal sediment (Qal) occupy the southern coast area consisting of sand, clay, silt, gravel and cobble.
   b. Lake Deposit (QPL), this unit is mostly gray claystone, containing the remains of plants and lignite. This rock is less dense.
   c. Reef limestone (Ql) consists of uplifted coral limestone, clastic limestone with the main component of coral, locally layered, often found on the southern coast.

The geological structure of the study site is primarily faulted and fold. The direction of normal fault is less uniform, but in the West tends to be directed to approximately east-west. The biggest strike-slip fault is Gorontalo fault and based on the concomitant joint analysis is a strike-slip fault with the shift direction towards right. Several trust fault zone approximately have an angel of 30^o can be found in some places, especially in the volcanic rock of Bilungala. The mapping area has experienced more than one period of tectonic compression that produced fold. Chunks of boulder measuring up to 5 meters are found in several places in the upstream of Dutuna Iya (left branch of Taludaa River), and are thought to originate from the formation of Tinombo by forming the folding twice at least. Old folding produces isoclinal folds which then undergo tight-open folding by younger folds. Based on measurements of the strike and dip on the intercalation of volcanic and sedimentary rocks in the area of Sogitia Kiki River, Tombulilato River, and Bilungala River, it was obtained open folding with the dip of wings of approximately 30° and the axis heading in almost east-west. Pillow lava found in Sogitia Kiki River also has open folding.

Petrological description of rock samples in the study site is as shown in Table 2. In general, the rock samples at the observation site are weathered and destroyed rocks. This is affected by the fault that passes through the rock as described in the samples R1, R2, and R3. The rock type of R4 sample is volcanic rock (pyroclastic deposit).

Table 2 Petrology description of sample rock in study area

No. of Sample	R1	R2	R3	R4
Location	Tupa, Bulango Utara	Lomaya, Bulango Utara	Oluhuta, Kabila Bone	Muara Bone, Bone
Coordinate	00^{o}38’47” N 123^{o}04’54” E	00^{o}37’47”N 123^{o}05’11”E	00° 25’ 46”N 123° 9’ 34E	00^{o}20’05”N 123^{o}27’54”E
Rock Name	Quartz Diorite	Granodiorite	Andesite	Rocks at the observation point are pyroclastic deposits. Pyroclastic deposits are composed of fragments of mafic volcanic rock to ultramafic volcanic rock, the size ranged between 2-60 mm. The geological structure is fold
Color	Grayish white	Pink reddish brown	Brown yellowish	
Texture: The degree of crystallization / Granularity / Fabric	Holocrystalline, Fanerik, in equigranular porfiroafanitik type	Holocrystalline, Phanerocrystalline, Equigranular	Holocrystalline, Aphanitic, Equigranular	
Structure	Massive	Massive	Massive	
Mineral	Plagioclase, quartz, hornblende. There is a green mineral alteration.	Plagioclase K-feldspar, quartz, biotite and hornblende.	Plagioclase, quartz, hornblende and biotite. There is accessory mineral (quartz)	
Description	The rock had experienced landslides and destroyed or decayed (destruction zone). This destruction zone indicates an active fault that passes through these rocks.	Outcrop in this avalanche point had experienced a lot of joint. The rock outcrop was affected by the fault.	Outcrop in this point had been weathered and destroyed. This is affected by active faults that pass trough the rock. Moreover, around outcrops found any alteration mineral, (kaolinite mineral). At this point, the rock had experienced landslides and destroyed or decayed destruction zone.	

4.3 Climatic Conditions

There are two seasons in this area, namely dry and rainy seasons. This situation is closely related to the wind currents blowing in Bone Bolango Regency. In October to April the wind comes from the West/Northwest that contains a lot of water vapor, resulting in the rainy season. In June to September, the wind comes from the East that does not contain water vapor. The amount of precipitation varies by month and location of observation station. Precipitation record in 2011-2013 ranged between 79-412 mm [15]. At the time of the landslide, the value of precipitation is greater than 100 mm.

4.4 Hydrological Conditions

Hydrological conditions in Bone regency Bolango include inland waters (river) and sea. Bone Bolango Regency has two big River Basins, Bone River, and Bolango River, both of which run into Tomini Bay/Gorontalo Bay, as well as 25 other small river basins located almost in the entire area of the mountains in the coastal region.

4.5 Geotechnical Properties

The test results of the geotechnical properties in the laboratory are shown in Table 3. Based on the Unified Soil Classification System (USCS), the types of soil in the study are silty sand (SM) and clayey sand (SC). The cohesion value ranges between 0-15 kPa, and the angle of internal friction of 30º – 44º.

Table 3 Geotechnical properties of soil samples

Parameters	Tupa, Bulango Utara				Oluhuta, Kabila Bone				Muara Bone
	BH 1		BH 2	BH 3	BH 4	BH 5		BH 6	BH 7
	1.60-2.00 m	3.20-3.60 m	1.00-1.40 m	0.60-1.00 m	0.60-1.00 m	0.60-1.00 m	1.60-2.00 m	0.60-1.00 m	0.60-1.00 m
Specific gravity	2.69	2.61	2.67	2.60	2.63	2.60	2.64	2.60	2.63
Bulk Unit weight, kN/m^3	19.6	18.2	18.1	18.2	19.6	19.6	18.1	18.6	15.1
Liquid limit (%)	-	-	-	-	38.85	42.22	38.24	-	-
Plastic limit (%)	-	-	-	-	21.48	22.30	22.30	-	-
Plasticity index (%)	-	-	-	-	17.36	19.92	15.94	-	-
Cohesion (kPa)	-	-	5.00	4.00	15.00	13.00	-	-	-
Angle of internal friction (º)	41.52	37.65	36.91	38.01	35.82	30.38	36.05	44.25	37.21
Clay (%)	1.87	2.95	3.95	5.81	13.64	12.50	6.77	9.87	1.99
Silt (%)	15.15	26.32	23.56	17.87	19.66	28.35	23.62	16.38	22.78
Fine sand (%)	20.37	18.54	20.59	16.64	15.38	17.70	16.06	13.58	26.11
Medium to coarse sand (%)	62.61	52.18	51.90	57.11	48.33	40.15	52.34	45.07	46.24
Gravel (%)	-	-	-	2.57	2.98	1.29	1.20	15.11	2.87
Grain size distribution	Well graded	Poorly graded	Poorly graded	Well graded	Well graded	Poorly graded	Poorly graded	Poorly graded	Poorly graded

5. MECHANISM OF LANDSLIDE IN BONE BOLANGO DISTRICT

Based on the study results, landslide in Bone Bolango regency is caused by several factors, namely:

1. Internal factors: the condition of the slope-forming material is weathered and destroyed rock due to strike-slip fault, i.e. Gorontalo fault and folding, and hydrologic conditions, that there are two big river basins and 25 small river basins spreading in the land around the coast, as well as the condition of the steep slopes with an angle of more than 40º.
2. External factors, namely illegal logging in the forests in mountain areas, resulting in the lack of vegetation covering the slopes, cutting the foot of slope for the construction of houses (Fig. 3), construction of roads, and high precipitation.

At the time of high precipitation or moderate precipitation in a long duration (> 100 mm), the rate infiltration of rainwater into the soil is slower than the rate of the increase in the volume of rainwater deposited and flowing on the surface of the slope. Due to lack of vegetation covering of the slope, the rainwater directly touches the soil and surface flow occurs in large volumes in a short time. As a result of the steep slope, the rate of water flowing down is so high that soil aggregates are scoured and eroded carrying any material existing around the slopes, either sand, gravel, boulders, or other materials.

On the slopes of rocks in Tamboo Village (Kabila Bone), rainwater filled cracks and joints of rocks on the slope so that the rock would fall freely downwards (Fig. 4).

Water infiltrating into the soil may increase groundwater levels and reduce soil shear strength, as well as change the pore water pressure negative to positive. This increases the burden of the slope.

a. Tupa Village, Bulango Utara

b. Lomaya Village, Bulango Utara

c. Muara Bone Village, Bone

Fig. 3 Landslide in Bone Bolango Regency as a result of cutting the slopes for the construction of houses [16], [17]

Fig. 4 Rock fall in Tamboo Village, Oluhuta Subdistrict, Bone Bolango Regency.

6. CHARACTERISTICS OF LANDSLIDE IN BONE BOLANGO REGENCY

Based on the susceptibility to landslide zone map issued by Center for Volcanology and Geological Hazard Mitigation (PVMBG) of Geological Agency of Gorontalo Province, landslides in Gorontalo is divided into four susceptibility zones, namely very low landslide susceptibility zone, low landslide susceptibility zone, moderate landslide susceptibility zone and high landslide susceptibility zone. A very low landslide susceptibility zone is an area in which landslide rarely or never occurs, both old landslide and new landslide except for small areas on the riverbank. A low landslide susceptibility zone is an area that in general landslide rarely occurs if the soil on the slopes is not disturbed and in the event of a long landslide, the slopes have been stable again. In this area, the small dimension landslide may occur mainly on the riverbank. A moderate landslide susceptibility zone is an area adjacent to the river valley, escarpment, road cliff or if the slope is disturbed. A high landslide susceptibility zone is an area in which landslide often occurs, while the landslide, both the old and the new are still active, due to high precipitation and strong erosion [14]. The study site in Bone Bolango Regency belongs to a moderate landslide susceptibility zone.

Based on the observations in the field, the types and characteristics of the landslide in Bone Bolango Regency are described in Table 4. Debris flow type is most common slide in Bone Bolango Regency. The slide in Kabila Bone Subdistrict is a combination of translational sliding and debris flow, and rock fall occurs on the rock slope in Tamboo Village, Kabila Bone Subdistrict. This type of the landslide is based on the ratio of the depth of landslide to the length of landslide. The dimensions of the landslide (IAEG standard) are based on the results of field measurements as described in Table 5.

Table 4 Types and characteristics of landslide in Bone Bolango Regency

Subject	Location							
	Tupa, Bulango Utara	Lomaya, Bulango Utara		Tamboo, Bone Pantai	Oluhuta, Kabila Bone		Tunas Jaya, Bone Pantai	Muara Bone, Bone
Coordinate	00º38'47"N 123º04'54"E	00º37'47"N 123º05'11"E	00º37'42"N 123º05'00"E	00º23'39"N 123º11'31"E	00º25'47"N 123º09'35"E	00º25'42"N 123º09'39"E	00º23'02"N 123º12'12"E	00º20'05"N 123º27'54"E
Slope (º)	45-60	45-60	75-80	85-90	50-75	50-75	50-75	50
Erosion by flow or river	Slope Erosion	Slope Erosion	Slope Erosion	Slope Erosion	Gully Erosion	Slope Erosion	Slope Erosion	Slope Erosion
Old soil movement	Present, cutting the slopes for the construction of houses and cliff roads occurs	Present, disturbance from the cutting foot of the slope for the road cliff occurs	Present, cutting the slopes for the construction of houses and cliff roads occurs	Present, due to the joint and discontinuity (there is a fault zone)	Present, cutting the slopes for the cliff roads occurs	Present, cutting the slopes for the cliff roads occurs	Present, cutting the slopes for the cliff roads occurs	Present, cutting the slopes for the cliff roads occurs
Type of landslide	Debris flows	Debris flows	Debris flows	Rock falls	Debris flows/ slump	Debris flows/ slump	Debris flows/slump	Debris flows
Description	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain	Slopes of steeply weathered rocks and has discontinuity or traversed by Gorontalo fault	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain	Deposit of slopes	A steep slope with a debris movement and flows of a viscous fluid due to erosion or high-speed water scour during heavy rain

Table 5 Dimensions of landslide based on IAEG standard

Description	Location							
	Tupa, Bulango Utara	Lomaya, Bulango Utara		Tamboo, Bone Pantai	Oluhuta, Kabila Bone		Tunas Jaya, Bone Pantai	Muara Bone, Bone
Coordinate N	00º38'47"	00º37'47"	00º37'42"	00º23'39"	00º25'47"	00º25'42"	00º23'02"	00º20'05"
E	123º04'54"	123º05'11"	123º05'00"	123º11'31"	123º09'35"	123º09'39"	123º12'12"	123º27'54"
Slope (º)	45-60	45-60	75-80	85-90	50-75	50-75	50-75	50
Width of displaced mass, *Wd* (m)	45	32	35	120	24	24	34	45
Width of rupture surface, *Wr* (m)	34	30	10	-	18	24	12	50
Total length, *L* (m)	105	40	15	15	37	35	18	35
Length of displaced mass, *Ld* (m)	90	35	11	14	35	32	15	32
Length of rupture surface, *Lr* (m)	60	33	10	-	33	33	9	15
Depth of the displaced, *Dd* (m)	7,5	5	7	1	6	5	4	3
Depth of rupture surface, *Dr* (m)	6	4	5	-	5	4	3	2

7. CONCLUSION

The landslide site in Bone Bolango Regency is a mountainous area with a slope of more than 40º. Geological conditions in which diorite and granodiorite rocks around Bulango Utara Subdistrict and andesite in Kabila Bone Subdistrict have been destroyed and weathered due to the discontinuity. In Bone Subdistrict, the rock is pyroclastic sedimentary rocks with geological structure in the form of folding. The results of geotechnical investigations during the dry season show the density of slope-forming material ranged between 2.60-2.69 kN/m^3, cohesion ranging between 0-15 kPa, and the friction angle ranging between 30-44º. The hydrological conditions illustrate the presence of two big river basins (Bone River and Bolango River) and 25 small river basins. These things were internal factors to the landslide in Bone Bolango Regency. Such incidence is triggered by external factors, namely high precipitation (> 100 mm) as well as human activity around the slopes, which cuts the slopes for building houses and roads, felling trees resulting in the loss of vegetation on the slope surface. When it rains, the water infiltrates into the soil, so that the soil becomes saturated. Along with the increase in water level, shear strength gradually decreases, and the value of pore water pressure becomes positive.

In general, the types of the landslide in the study area is the debris flow, in addition to the type of rotational slide and rock falls found on rock slopes. Debris flow occurred in Bulango Utara and Bone Subdistrict. The combination of debris flow and translational slide occurred in Kabila Bone and Bone Pantai Subdistrict while rock fall occurred on the rock slopes at Tamboo, Kabila Bone Subdistrict.

In order to reduce the danger of the landslide, further research is needed to determine the appropriate method for strengthening the slope by using local materials.

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