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Landslide Potential Analysis Using Unmanned Aerial Vehicle in South Leato Village, Gorontalo City, Indonesia

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ABSTRACT

Spatial data technology using unmanned aerial vehicle (UAV) is one of the aerial imaging technologies used to produce detailed data. However, its utilization for mapping, especially disaster mapping needs an in-depth study. The research site is located within 00-“00‘29° 51‘31°00” N and 12327‘5°-123“00‘3°” E that covers an area of 2,531 Ha, which consists of 1,745 Ha land and 786 Ha water areas. Administratively, the research site is in South Leato Village of Dumbo Raya sub-district of Gorontalo city with a total area of 41,9 Ha. This study is aimed at assessing the landslide by creating a landslide zonation map and finding out the landslide potential area by using the UAV. This research employs field surveys by using drones and Geographic Information System (GIS) analysis. It is found that the parameters that influence landslides are lithology, rainfall, slope inclination, lineament density, and land use. The landslide vulnerability analysis reveals three levels of vulnerability in this site; low, medium, and high vulnerability, in which, 19 Ha is classified as low vulnerability area, 9.5 Ha is classified as medium vulnerable, and 13.5 Ha is classified as highly vulnerable area.

INTRODUCTION

Gorontalo province is prone to landslides through various types and mechanisms. Several studies were carried out to identify landslides using various methods. These research results serve as a reference to determine landslides’ disaster mitigation steps (Asiki et al. 2019, Eraku & Permana 2020, Naryanto et al. 2019, Usman et al. 2022). Specific to Gorontalo province, there are a few studies on landslides. The latest research on landslides showed that within landslides there are rotation slides, planar slides, flow slides, and stone block slides. Landslide is usually influenced by the slope and shape of the slope surface (Patuti et al. 2017, Lihawa et al. 2021).

Since Gorontalo City has been established as the capital of the province, various issues, including rapid population growth, have become more evident. The population growth for the last five years has been showing an uptrend. This creates a high demand for land and an increase in the fulfillment of services and city facilities, which may have an impact on the decrease in environmental quality, such as environmental degradation and natural disasters. One of the most common problems in this city is natural disasters, especially floods, and landslides (Doda 2013, Wunarlan 2019).

A landslide is a natural disaster that can be predicted due to the high level of rainfall in a region. Other factors like lithology, geological structure, types of soil, slope inclination, and land use also add to the severity of the landslide. Landslides often cause large casualties, both materials and humans. Landslide-prone areas needed to be minimized to minimize their destruction. Efficient and time-effective mapping of landslide-vulnerable areas can employ GIS (Kumoro & Yunarto 2010, Yunianto 2011, Naryanto et al. 2019, Silalahi et al. 2019).

Remote sensing is one of the methods used in various industries. It offers many benefits and can analyze different information. Remote sensing technology for land use rapidly develops with unmanned aerial vehicles (UAV).

THEORETICAL REVIEW

Landslides and mass soil movement are similarly defined as slides, and both need distinction. Soil movement is defined as the process of vertical, horizontal, or oblique displacement of soil or stone masses. Based on this definition, the landslide is part of soil movement. When following the vertical soil metabolism, bending happens due to the collapse of the

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soil foundation during the vertical movement, and then it is classified as a type of soil (Shanmugam 2013, Shanmugam & Wang 2015, Naryanto et al. 2019, Yanrong & Mo 2019). Gorontalo geological structure is influenced by three plates, micro-plates of Banggai-Sula from the south, Sangihe plates from the east, and Sulawesi Sea plates from the north (Hall 2002, 2012, Hall & Spakman 2015, Watkinson et al. 2011, Purmana et al. 2020).

Soil or rock debris materials were first moved to the bottom part, for the slope to be able to penetrate the rock pores through water penetration. Such conditions can increase the load of the material on the surface of the slope and put pressure on the materials like rocks. When this pressure is unstable due to natural phenomena or due to human intervention, it could cause disaster, which further causes casualty of both materials and injuries, destruction of public facilities, and disturbance of people's lives and livelihoods (Bogaard & Greco 2016, Asikin et al. 2019, Naryanto et al. 2019, Lucas et al. 2020).

The Regional Disaster Management Agency (BPBD) of Bone Bolango Regency recorded a soil movement disaster in April 2019 in Suwawa Selatan sub-district. This incident destroyed one house in Bondawuna village. In 2016, the Social Protection Agency of Gorontalo province established the Suwawa Selatan sub-district as a Disaster Prepared Village due to its assessment that revealed this sub-district is prone to land movement disasters due to its geographical condition (Djakun et al. 2020).

On the other hand, drone technology, also called unmanned aerial vehicle (UAV) has become more and more popular among society. It is one of the alternative means for aerial imaging. Researchers and foreign practitioners have been using this technology in various mapping applications. UAV is an affordable remote sensing technology (Rokhmana 2015). Further, the scoring method is a method to determine the score of each parameter. The scoring is adjusted to the assessment criteria. The higher the influence of a parameter on landslides, the higher the score (Rokhmana 2015).

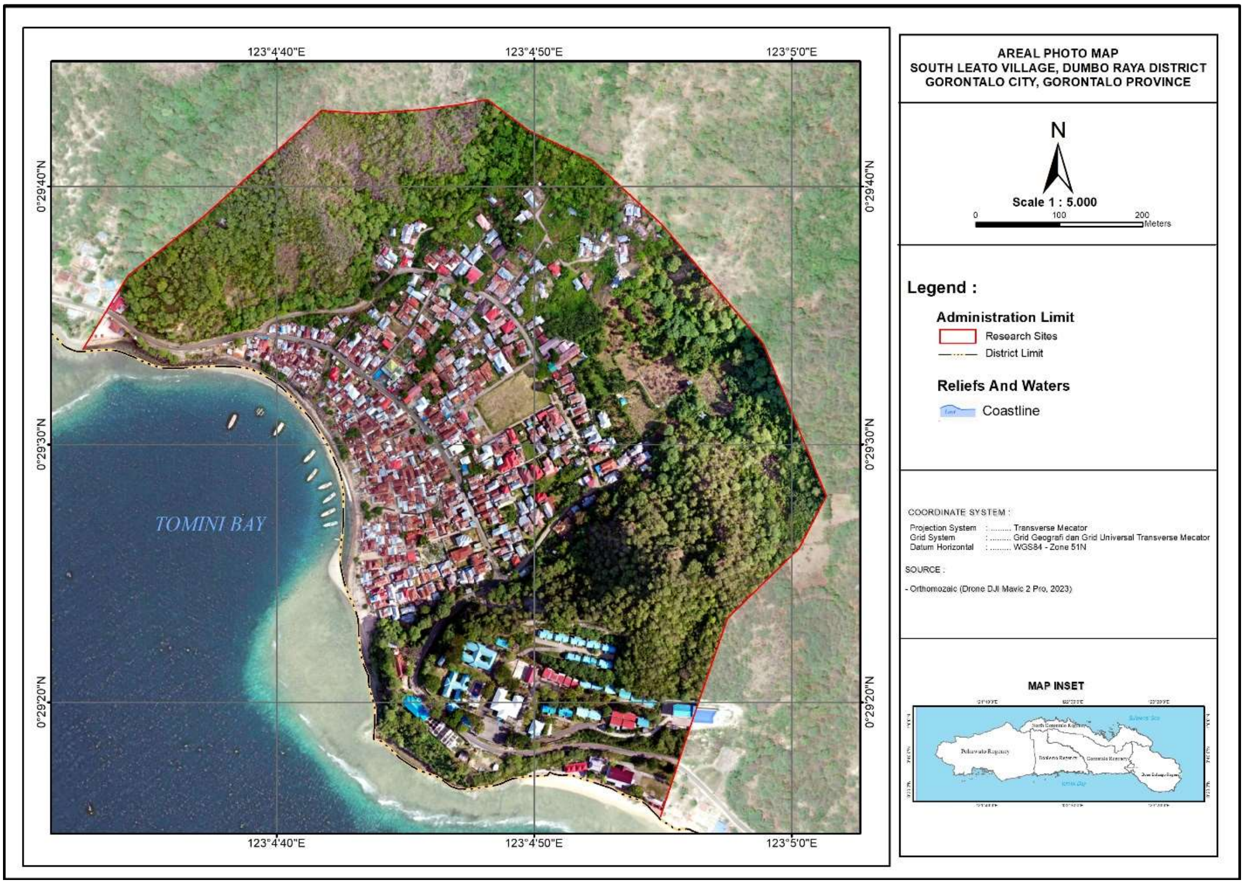

Fig. 1: Research site in South Leato Village of Gorontalo City.

MATERIALS AND METHODS

The research site is located between 0051‘31°-00“00‘29°” N and 12327‘5°-123“00‘3°” E, which covers an area of 2,531 ha that comprises 1,745 ha of land and 786 ha of water area. Administratively, the research site is located in South Leato village of Dumbo Raya sub-district, Gorontalo city. The research focus in this village covers an area of 41.9 ha. The research site can be reached in about ± 17 minutes by motored vehicle from the capital city, and the total distance from the capital city is ± 8.9 km (Fig. 1).

The research started with planning the aerial imaging using the DJI Mavic 2 Pro UAV, remote sensing for mapping. Once the flying track map was planned, aerial photos were taken at the research site. The photos were then processed into orthophotos data and Digital Elevation Model as the basis for mapping. Following this, a field survey and GIS analysis were performed. The field survey was implemented to collect field data such as geological data, geomorphology, structure, region’s stratigraphy and field validation on the level of landslide vulnerability of the research site. Landslide vulnerability analysis utilized scoring and valuation on the factors that influenced landslide namely: lithology, rainfall, slope inclination, soil type, land use and the lineament density. Further, these parameters are overlayed to obtain the level of landslide vulnerability. This process produced a zonation map of the landslide vulnerability level of the research site. The level of vulnerability analysis is performed using the landslide predictability model (BBSDLP 2009, Dewi et al. 2017, Asikin et al. 2019).

Table 1: Landslide vulnerability classification.

Vulnerability class	Score
low	Minimum value – (class interval + minimum value)
medium	>low vulnerability score – (low vulnerability score + class interval)
high	> medium vulnerability score – maximum value

Total score = (20% * slope inclination) + (20% * lineament density) + (10% * rainfall) + (25% * Lithology) + (25% * land use) ….(1)

Further, a calculation is made to obtain class intervals for each level of landslide vulnerability by using the equation (BBSDLP 2009, Dewi et al. 2017, Asikin et al. 2019).

$$I=\frac{R}{K} \quad ....(2)$$

In which:

I = class interval;

R = *range* (largest data – smallest data) from the total score; and

K = number of landslide classes.

Table 2: Characteristics of parameters of landslide-prone determination.

No.	Variable	Criteria	Weights	Score
1.	Lithology	Alluvial and Coastal Deposits	25%	1
		Limestone		3
		Pyroclastic Breccia		5
2.	Rainfall	< 1000	10%	1
		1000-1200		2
		1200-1500		3
		> 1500		4
3.	Slope	< 13	20%	1
		14-20		2
		21-55		3
		>55		4
4.	Land Use	Sea water	25%	1
		Plantation/Garden		3
		Settlements and Places of Activity		3
		Shrubs/Reeds		5
5.	Lineament Density	Low	20%	1
		Currently		3
		Tall		5

Next, vulnerability levels are created based on the obtained interval. Thus, the landslide vulnerability classification is obtained as shown in Table 1 (Yunianto 2011).

The determination of landslide-prone areas used GIS tools with the Storie Index method to obtain a total score. This scoring range was converted at several levels according to requirement, landslide-prone levels were classified into five classes or levels, which were: High, Medium and Low, using the natural break method in Table 2 (Thoha et al. 2020).

RESULTS AND DISCUSSION

Aerial Photo Imaging

Small-format aerial photos are the initial data used as spatial basic data for mapping. Before aerial photo imaging using the UAV with DJI Mavic 2 Pro drone, aerial photo acquisition planning is needed. A photo shooting plan is made to describe the flight pathway in as much detail as possible using Pix4Dcapture software with two missions.

The photos were taken between 08.00-10.00 am, where each flight took 12-19 minutes in ideal conditions. The cruising height was 300 meters above the ground level expected to produce ± 11.9 cm pixel photos. This pixel photo is theoretically expected to produce maps with the scale of 1:5.000 and 1:10.000. End lap and side lap setting of the drone is planned using the small drone which can safely move, as such a small UAV can easily deviate and be disturbed by the wind. An aerial photo shoot using UAV was carried out on the 18th of February 2023. The shooting site was a coastal area with a high tendency for high-speed wind that influences the durability of the UAV battery. This was due to the faster moving rotation of the UAV motor to be able to penetrate wind obstacles. The observation of the battery condition and vehicle is carried out through Pix4Dcapture software on Ground Sampling Distance (GSD).

Aerial Photo Processing into DSM data, Orthophoto Mosaic and DTM

Aerial photo processing is the selection of photos obtained from the first phase through the unification of contras of each

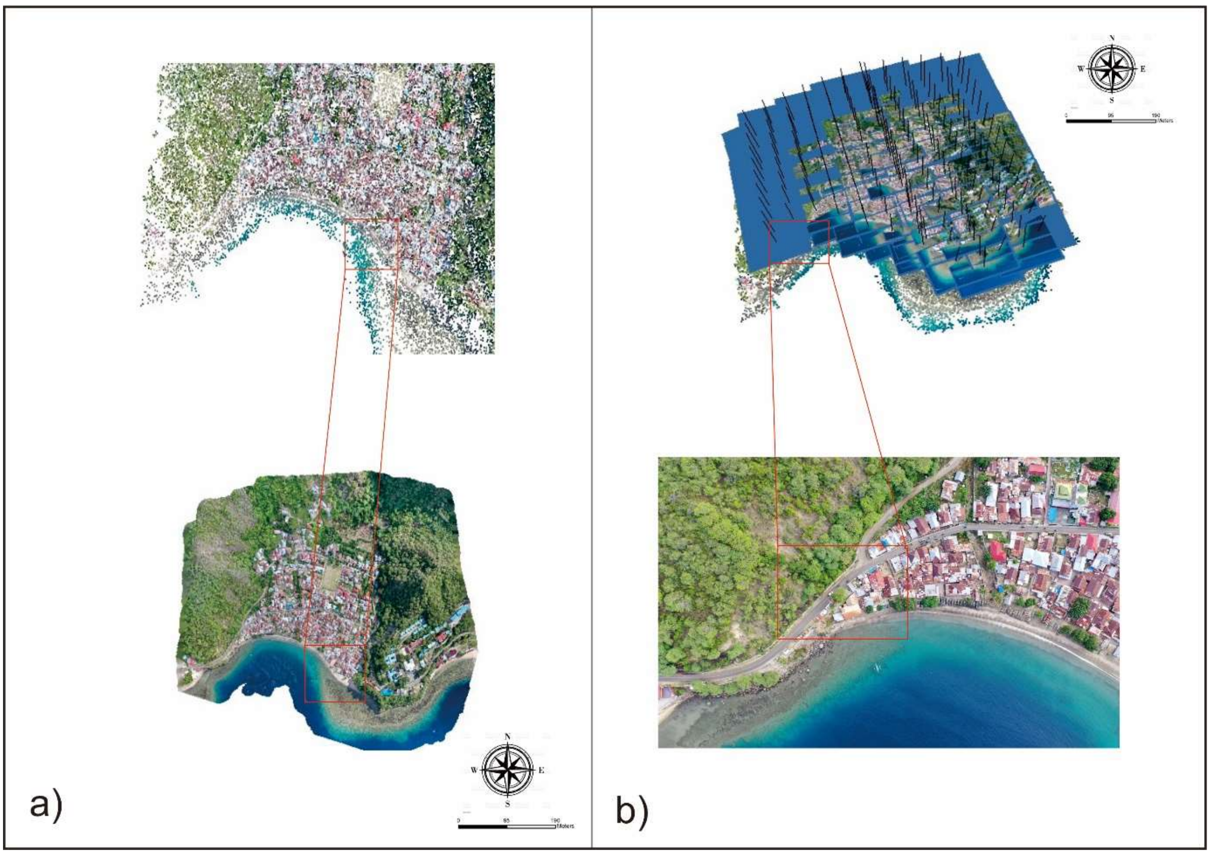

Fig. 2: Photo aligning process at agisoft photo scan, a) Collection of point clouds, b) camera position during exposure.

photo. This unification of contras (enhancement) is needed to detect point clouds on the software. This point cloud is used in recognizing the sequence and photo angle. Photos with high contrast and high levels of brightness that are different from other photos would not be able to be identified and would make it difficult to be converted into orthophoto mosaic and further processing into DSM would similarly be difficult. The total photos obtained from 15 flight photo shooting missions that could be used for processing were 2001/2005 aligned photos.

The processing using Agisoft software was started with photo aligning. Photo aligning consisted of the process to detect similar objects between photos as a point cloud using workflow for all photos. The result is that these pinto clouds, which formerly had pixel coordinates (model) were turned into actual coordinates at the field. Reconstruction of a photo sequence and camera position during the shooting was also performed in this stage. The collection of point clouds and camera position detected during the photo aligning is presented in Fig. 2.

Digital Surface Model (DSM) and Digital Terrain Model (DTM) Development

The initial function of DSM was to create a DSM orthophoto mosaic to eliminate relief errors from the produced aerial photos, thus, they had orthogonal projections and had similar scales in all areas of photos. DSM was created using the Agisoft photo scan software during the densification of point clouds. This point cloud densification was followed by an interpolation process to convert DSM into raster data.

Digital Terrain Model (DTM) is a DSM derivative data, where DTM is the earth surface level without any vegetation object or manmade features like buildings. Converting DSM data to DTM data was initiated by determining the earth level height points, selecting them, and removing other height objects that were not earth-level height. The removed area is then interpolated with earth's surface height data around it (Meiarti et al. 2019). When there was a point above the earth's surface that is hard to recognize, DTM data extraction will be difficult.

On the other hand, this research site is composed of pyroclastic hills geomorphology. Pyroclastic hills with dense vegetation will not produce optimum DTM data. This supports (Meiarti et al. 2019) who noted that mountain objects with dense forest canopy would be hard to be extracted into DTM data. To overcome this, a semi-automatic

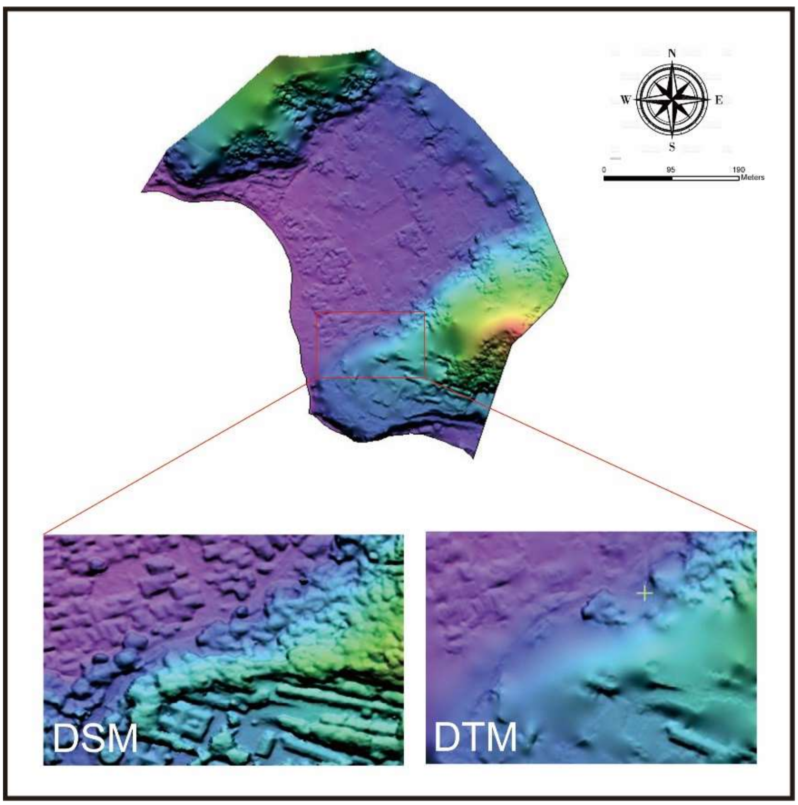

Fig. 3: (a) DTM from DSM processing using PCI Geomatica and after manual editing, (b) example of snippet comparison between DSM and DTM.

method using PCI Geomatica 2016 is employed. Manmade feature objects or vegetation trees are manually eliminated. This resulted in the elimination of most non-earth surface objects. DTM from PCI Geomatica software was manually edited to produce the best result (Fig. 3).

Development of Orthophoto Mosaic

The final stage in this aerial photo processing is combining each orthophoto into an orthophoto mosaic. This process uses DSM input (in TIN form) and aerial photos. TIN is used in correcting object displacement relief of the aerial photo. Thus, the photo has an orthogonal projection and a more accurate coordinate position. When all photos within the blocks have been orthorectified, the next process is the blending process among photos. Thus, photos are connected seamlessly. Photos' brightness and contrast are even in all areas. The produced orthophoto mosaic size is ± 11.6 cm (GSD). This backs up (Rohmana 2015), who noted that GSD produced from UAV technology would be within the range of 5-30 cm/pixel on photos taken from 300 meters above the earth's surface. This GSD size is considered more detailed compared to other remote sensing such as satellite images available to date. Orthophoto mosaic is used as the spatial primary data for disaster mapping. The result of the orthophoto mosaic is presented in Fig. 4 below.

Geometric Correction of Drone Image

Geometric correction is performed by transforming the

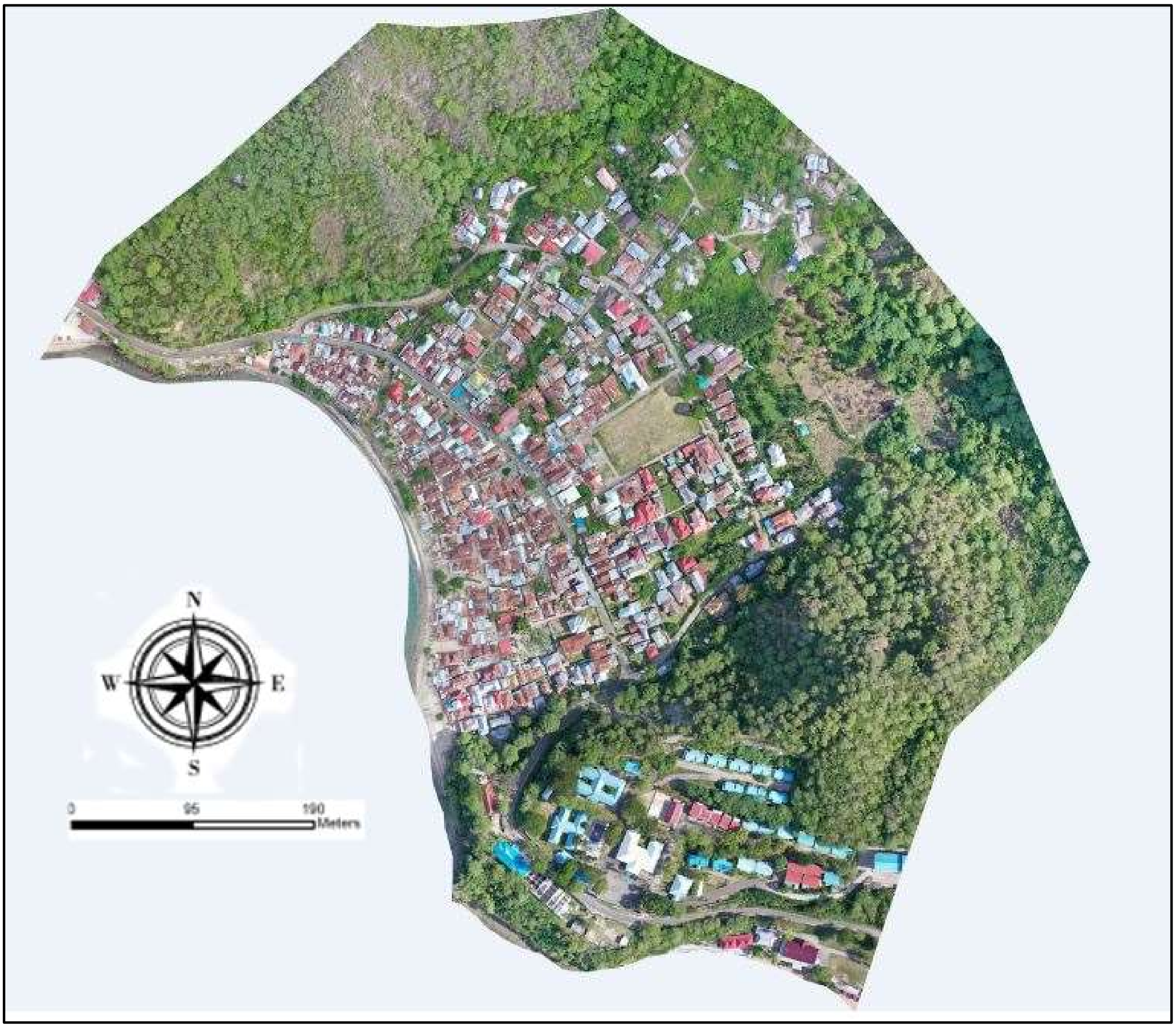

Fig. 4: Orthophoto mosaic of the research site produced from the DJI Mavic 2 Pro drone.

Table 3: Type of lithology (Dewi et al. 2017).

No.	Lithology	Area (ha)	Score
1.	Alluvial and Coastal Deposits	20.24	1
2.	Limestone	7.01	3
3.	Pyroclastic Breccia	14.62	5

position of each pixel within the image toward each similar object position within the earth's surface using the ground control point (GCP). The common location for CGP is an area that usually has the most striking color, road intersection, road corner, railway intersection with road and buildings that can be easily identified or recognized. During the rectification stage, the total RMS error was 0.173795 with five binding points distributed on the drone image points that would be corrected. This value of RMS error on the corrected geometric drone image has met the tolerance level, in which, the RMSE value is below one. Townshend et al. (1992) wrote that the accuracy in binding the coordinate system is usually stated by RMSE with several control points. The range value of 0.5 to 1.0 pixels is sufficient to achieve 10% or less error in the position when the two overlayed images (map) are within the tolerance level.

Lithology

Based on the geological map of the Southern Leato the study area is composed of three lithologies namely breccia, limestone, and alluvial (Table 3). Each rock type is given a score according to its level of sensitivity to landslides. The higher the score given, the higher the influence on the occurrence of landslides. An overview of the distribution of rock types in the study area can be seen in Fig. 5.

Table 4: South Leato Village rainfall rate.

No.	Rainfall	Score
1.	< 1000	1
2.	1000-1200	2
3.	1200-1500	3
4.	> 1500	4

Rainfall

The rainfall data used in the study were taken from only one rainfall observation, namely the BPP Kabila Bone Post Office. Rainfall data is in areas that have an average rainfall of <1000 to >1500 $mm.year^{-1}$. The described rainfall data can be seen in Table 4.

From the rainfall data above, rainfall modeling is then made using interpolation. So that the rainfall data for the South Leato Village area is obtained as shown in Fig. 6.

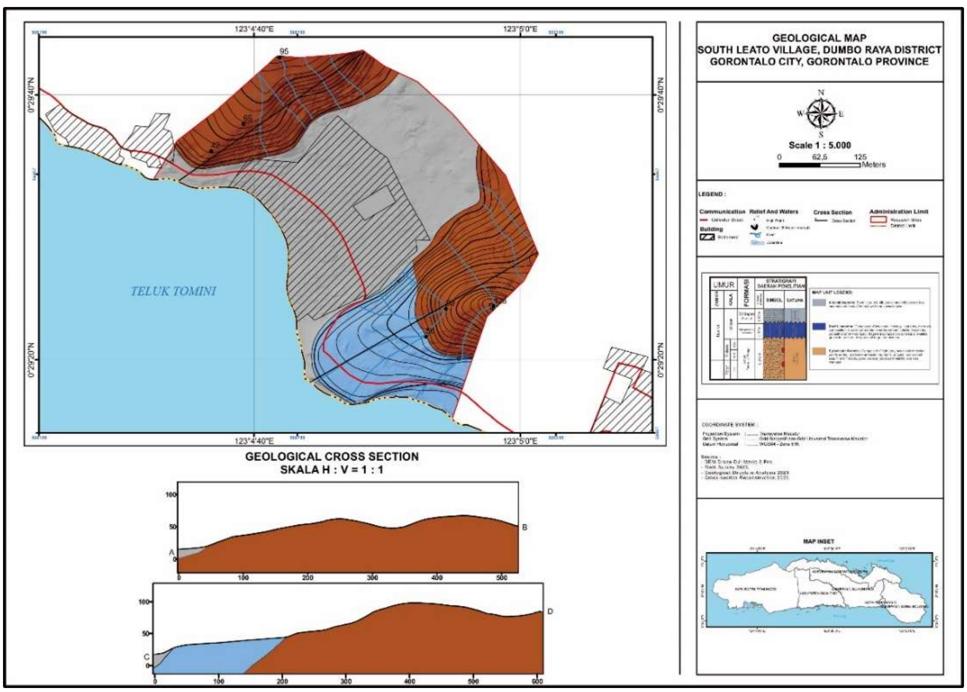

Fig. 5: Geological map of study area.

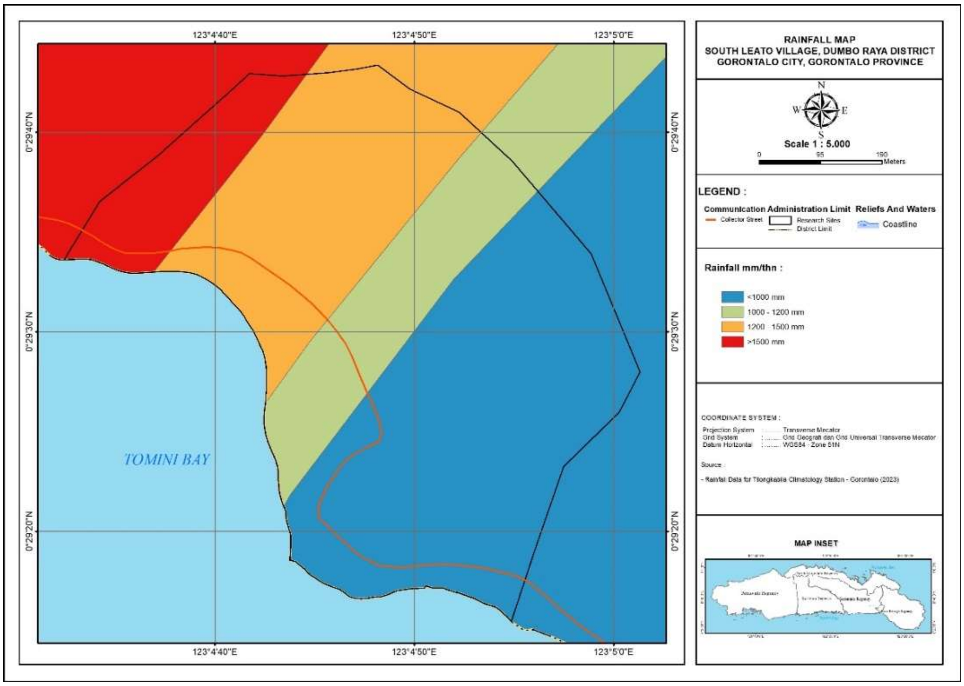

Fig. 6: South Leato Village rainfall map.

Table 5: Slope inclination (Van Zuidam 1983).

No.	Slope	Area (ha)	Score
1.	<13	12.7	1
2.	14-20	7.8	2
3.	21-55	13.5	3
4.	>55	7.9	4

Slope

The slope of the slope is the most influential factor in the occurrence of landslides. South Leato Village is an area that has different slopes. The slope of <13% with an area of 12.7 ha is used as a residential area. While on a slope of 14-20% with an area of 7.8 ha used as plantation land, the area surrounded by hills has a slope of 21-55% with a total

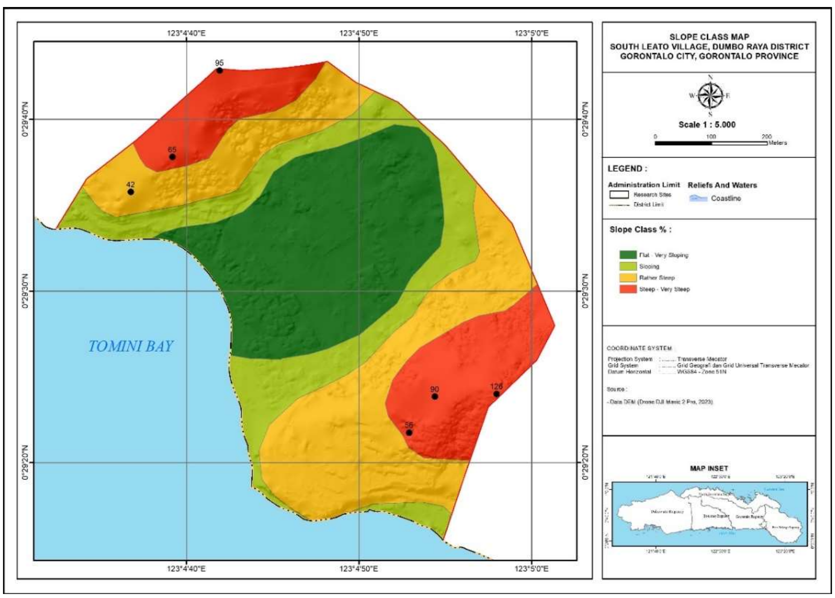

Fig. 7: South Leato Village slope map.

Table 6: Land use.

No.	Land use	Area (ha)	Score
1.	Seawater	1.1	1
2.	Plantation/Garden	1.1	3
3.	Settlements and Places of Activity	18.2	3
4.	Shrubs/Reeds	21.5	5

area of 59.31 ha which is used as a naval base. Complete data can be seen in Table 5 and Fig. 6. In general, areas with higher slopes will have a higher potential for landslides to occur. Sumiyatinah & Yohanes (2020) said that landslides can occur in areas with slopes. The higher the slope of an area, the higher the potential for landslides in that area.

Land Use

Land use is one of the factors causing landslides. Land use affects land stability, control of water saturation, and the strength of soil particle bonds. Land covered by forests or plantations will be more able to maintain land stability because of the deep root system that will maintain the cohesiveness between soil particles and between soil particles and bedrock. In addition, land covered by forests or plantations can regulate runoff and water absorption when it rains so that soil erosion can be avoided. Meanwhile, dry fields, paddy fields, and shrubs have a shallow and inundated root system that is unable to maintain soil stability and compactness of soil particles. Wahyunto (Anwar 2012) said land use such as rice fields, as well as dry fields and shrubs, especially in areas with steep slopes, landslides are common. Based on the results of the DJI Mavic 2 Pro drone orthophoto mosaic analysis, land use in the study area is shown in Table 6 and Fig. 7.

Lineament Density

Alignment is a straight stream and valley, a straight surface, changes in soil tones, alignment of vegetation areas, changes from differences in vegetation types and heights, or striking topographical differences. All of these phenomena may be the result of structural phenomena that occur such as faults (faults), joints, folds, and fractures (Adama & Sukartono 2017). In lineament density analysis, the lineament identified

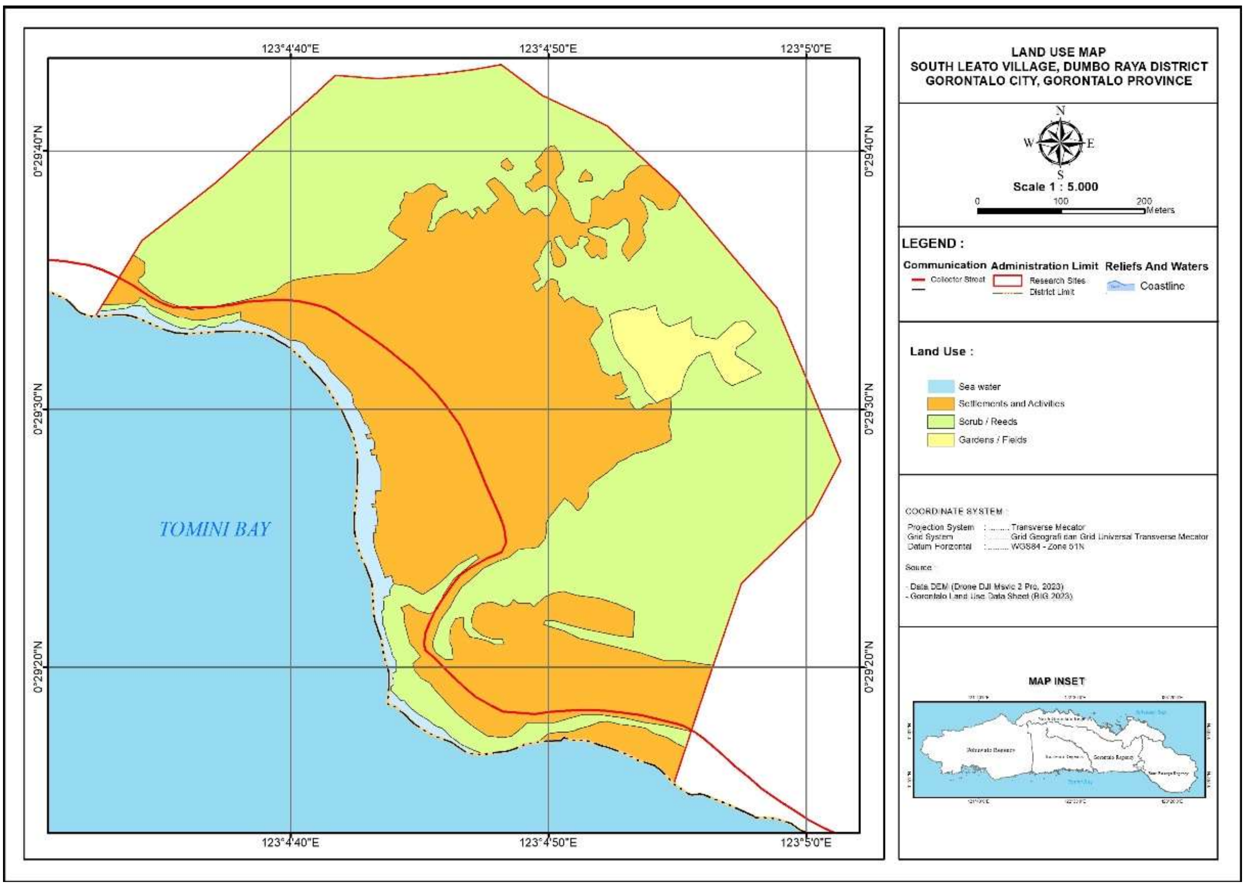

Fig. 8: South Leato village land use map.

Table 7: Lineament density (Adama & Sukartono 2017).

No.	Lineament Density	Density Value m/m^2	Score
1.	Low	1-3.7	1
2.	Currently	3.7-7.4	3
3.	Tall	7.4-11.14	5

is a straight line pattern of a river or escarpment produced by fault activity (Chemong & Chenrai 2013, Saputra 2016).

Linearity studies can help uncover generalizations that can assist in understanding the causes of landslides (Ramli et al. 2010, Bera et al. 2019). The landslides were widely observed to have severe impacts, the lineament density of the study area was analyzed using the line density analyzer extension from ArcView GIS and classified into three density classes (Fig. 8). The alignment pattern of South Leato village shows relatively the same trend as the slope pattern in the area (Table 7).

The results of the analysis are: This study shows that most of the landslides are located in high lineament density classes (1.33–1.67 m.m^{-2}).

Table 8: Classification of landslide vulnerability level.

Vulnerability level	Class interval
Low	1.1-2.3
Medium	>2.3-3.5
High	>3.5-4.7

Landslide Vulnerability Level and Landslide Potential Analysis

The landslide vulnerability prediction model in this study is modeled after (Dewi et al. 2017, Asikin et al. 2019) based on the model developed by Balai Besar Sumberdaya Lahan Pertanian (BBSDLP)/Agricultural Land Resources Agency. This model used lithology, slope inclination, rainfall, lineament density, and land use as its parameters. All these parameters are classified based on their scores and given values based on each of its contribution toward the landslide incidence. Following this, all parameters are overlayed to create a zonation map of the landslide vulnerability level. The landslide vulnerability level is presented in Table 8.

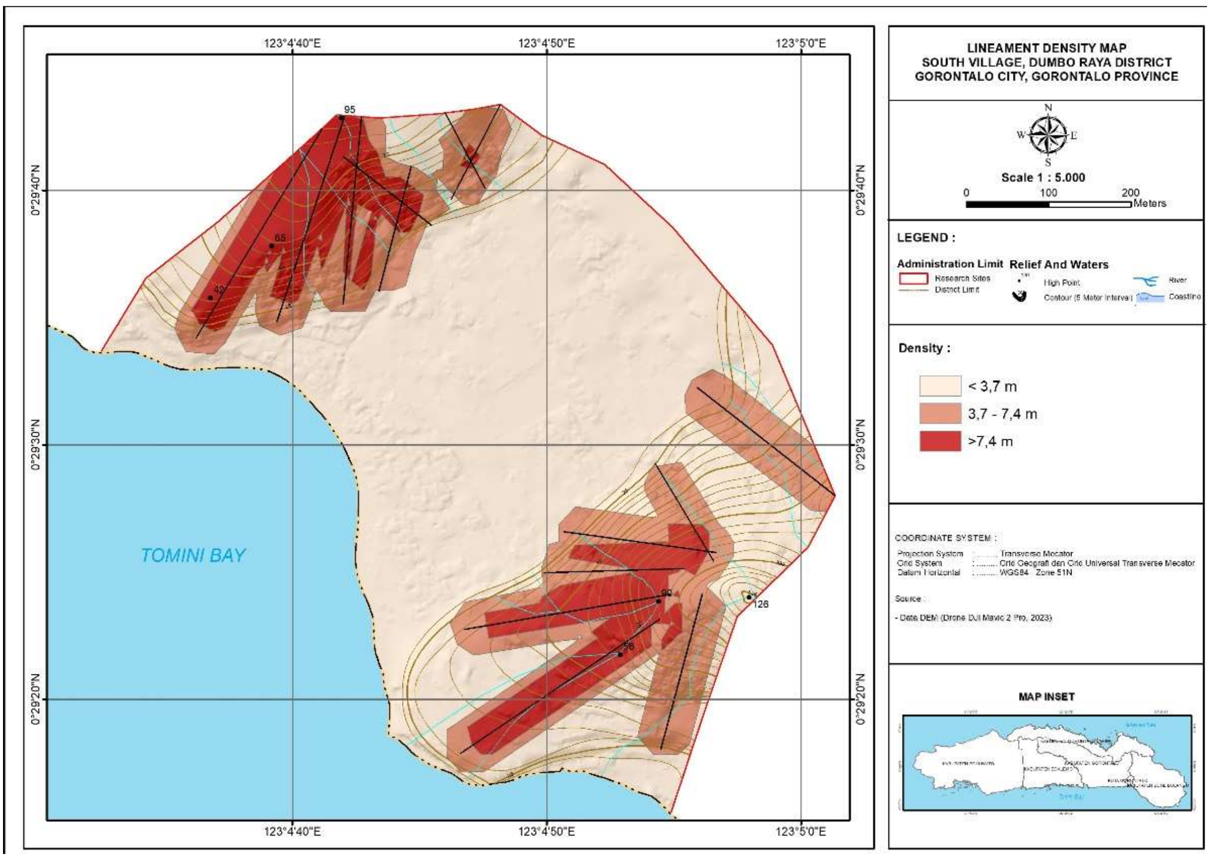

Fig. 9: South Leato village lineament density map.

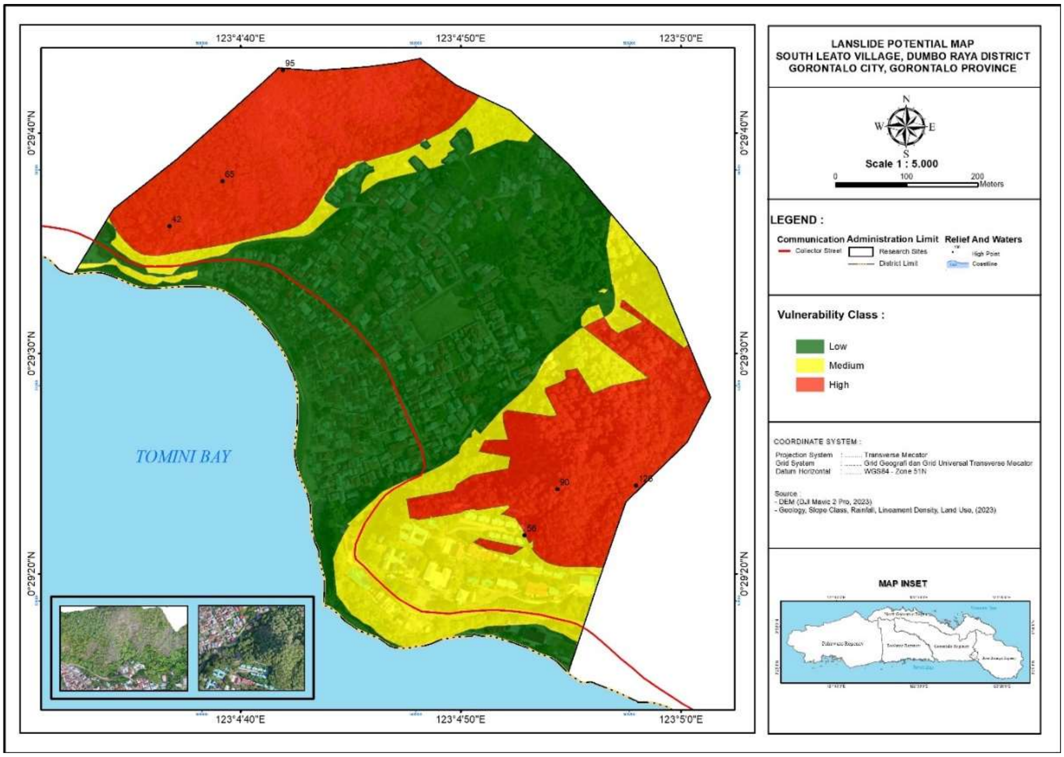

Fig. 10: Landslide potential map for South Leato Village of Gorontalo City.

The analysis revealed that South Leato village has all three levels of vulnerability. Those three levels are described as follows:

a. **Low vulnerability level:** This area is an area that is not prone to landslides. There are 19 ha of land that is considered as area with a low vulnerability level for landslides. This class dominated the residence area in the Leato Selatan village.

b. **Medium vulnerability level:** A medium vulnerability level is an area where a landslide either large or small might happen on this area, especially in areas such as road-cutting cliffs, ridges, and disturbed slopes. This medium-level vulnerability stretches in an area of 19.5 ha. It includes the Marine headquarters that is located within the Tran Sulawesi Road. The landslide has happened once in this area of medium susceptibility level on the part of Trans Sulawesi Road, which has breccia and reef limestone lithology. Thus, the sensitivity of landslides to these lithologies will increase at any time.

c. **High vulnerability level:** A high landslide susceptibility level is an area that is highly prone to landslides. This area often experiences landslides of different magnitudes. There is 13.5 ha of land in this area that is classified as highly susceptible to landslides. It is distributed in the mountainous area of South Leato village and is characterized by breccia lithology that is highly vulnerable to landslides.

In the past, a landslide happened in KM 6 of the Naval base. In an area characterized by breccia and limestone lithology. The landslide destroyed local residences. The landslide happened suddenly due to continuous rain. The locals had to be evacuated and local people together with the Navy troops had to work together to clean the debris of the landslide from the road. This research has revealed some landslide-prone spots; hence, the South Leato village is classified as a disaster prone zone (Fig. 9).

CONCLUSION

The landslide analysis scoring produced three classes of landslide vulnerability. There was 19 ha of areas within the site classified as low-level vulnerability, 9.5 ha was classified as medium-level vulnerability, and 13.5 ha of land classified to have a high vulnerability level. This highly vulnerable area is on a highly inclined slope.

This method could calculate the extent of landslide volume. However, landslide incidents may further escalate. Considering the strategic location of the current research site, which was located along the *Trans Sulawesi* Road, the impact of landslide would be unimaginable for not only the population near the site but also these road users and the economic activities that depend on the existence of this road. Thus, mitigating landslide potentials in this area is required.

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