Geomorphological Study of Bandar Lampung City and Landslide Hazard Assessment

Rahmi Mulyasari[1, a)] Aminudin Syah[2], Azhari[3], Rahmat Catur Wibowo[1] and Nandi Haerudin[1]

Author Affiliations
[1] *Geophysical Engineering, FT Universitas Lampung, Jl. Prof. Dr. Sumantri Brojonegoro No. 1 Bandar Lampung, Lampung, Indonesia*
[2] *Civil Engineering, FT Universitas Lampung, Jl. Prof. Dr. Sumantri Brojonegoro No. 1 Bandar Lampung, Lampung, Indonesia*
[3] *Physics Department, FMIPA Universitas Sumatera Utara, Jl. Dr. T. Mansyur Medan, Sumatera Utara, Indonesia*

Author Email
[a)] Corresponding author: rahmi.mulyasari@eng.unila.ac.id

Abstract. Bandar Lampung is a densely populated urban area consisting of land and water with several plateaus and mountains that stretch across this region. To support sustainable development in a city area, it is necessary to have a spatial planning concept that considers all aspects, one of which is the potential disaster aspect. One of the potential disasters in the city of Bandar Lampung is a landslide. In this research, a geomorphological study was conducted to produce a landslide susceptibility map. The purpose of this research is to produce a map of the hazards and vulnerability of landslide with a geomorphological approach as one of disaster mitigation efforts to support sustainable spatial planning and development. In this study, DEMNAS image was used for the interpretation of landforms in the city of Bandar Lampung. Landform is used as one of the parameters for assessing landslide hazards. By utilizing the geographic information system and the method of weighting and scoring against the parameters and variables used, the landslide hazard class can be assessed. The results showed that the research area was dominated by volcanic forms and coastal sediments. Based on this geomorphological condition, the landslide hazard level is obtained in the study area.

Keywords: geomorphology, landslide, Bandar Lampung.

INTRODUCTION

Background

Landslide or mass movement is a geological event, its occurrence of mass transfer of soil to rock caused by the earth's gravity (Varnes, 1978 in [1]). BNPB noted that landslides were one of the disasters that claimed the most victims with the frequency of events increasing every year [2]. Based on data from the Landslide Hazard Index, around 179 districts are prone to landslides in Indonesia, including Bandar Lampung City which has a high risk class and ranks 18th in Indonesia [3].

Bandar Lampung City is a densely populated urban area consisting of land and water with several highlands and mountains that lie in Bandar Lampung City [4]. Based on the Geological Map of the Tanjungkarang Sheet [5], it is shown that the geological conditions in Bandar Lampung City are under the influence of faults/faults. The map clearly shows several faults that cross the city of Bandar Lampung. The existence of the fault is reflected in its morphological condition in the form of hills with steep slopes. The lithology that dominates this area is former coastal and river sediments scattered around Lampung Bay and around Tanjung Karang, dominated by weathered soil resulting from young volcanic activity from the Lampung Formation, which is generally tuff rock. Such geological conditions with high levels of rainfall make the area prone to landslides.

Based on data collected by PVMBG in 2018, sub-districts in Bandar Lampung City have medium to high potential for landslides [6]. Kemiling, Sukabumi, Sukarame, West Tanjungkarang, Tanjung Bahagia, West Telukbetung, South Telukbetung, East Telukbetung and North Telukbetung sub-districts have medium-high potential for ground motion, while Panjang District has medium-high potential for landslide.

Preliminary research related to landslides in Bandar Lampung City, especially in Panjang District, has been carried out by the authors both with geological, geomorphological and geophysical approaches [7-9]. The results of the study produced a zoning map of the potential landslide, lithological indications and slip planes at several landslide points. Agustina et al. conducted research related to the identification of landslide-prone areas based on the characteristics of the constituent rocks in Bandar Lampung City, identified several landslide-prone areas influenced by volcanic sedimentary rocks [10]. The research data provide basic information related to landslides in Bandar Lampung City. Geomorphological studies on landslides are an interesting thing to study further for landslide prevention in the future.

Study geomorphological condition of an area is necessary for development of that area. Geomorphological studies have an important role to provide information and overview on the existing landscape of an area on a map [11]. Geomorphological map can be considered as graphical inventories of a landscape depicting landforms and surface as well as subsurface materials. This map can act as a preliminary tool for land management, geomorphological and geological risk management [12-14], as well as providing baseline data for other applied sectors of environmental research [15] [11] [16].

Therefore, this study was conducted to combine geomorphological and landslide studies in Bandar Lampung City. The purpose of this study is to update the map of the landslide susceptibility of Bandar Lampung City with a geomorphological approach to support spatial planning and sustainable development.

Geological Setting

Physiography

The physiography of Sumatra Island is divided into several physiographic zones, including the Bukit Barisan Zone, the Semangko Fault Zone (Sumatra), the Plains and Hills Zone, the Bukit Tiga Puluh Zone, the Outer Arc Zone, and the Sunda Exposure Zone [17]. Most of the Bandar Lampung City area is the Bukit Barisan Physiographic Zone.

The Bukit Barisan Zone is a hilly zone with a southeast-northwest orientation and has an elongated pattern of about 1,650 km with a width of 100 km. In terms of morphology, in general this area can be divided into three morphological units: undulating plains in the east and northeast, rugged mountains in the middle and southwest, and hilly to flat coastal areas. The slopes are generally steep with a height of up to 500-1,680 m above sea level.

Stratigraphy

The research area is composed of Paleozoic metamorphic rocks, Mesozoic intrusive rock overlying to alluvium surficial deposits, Quaternary volcanic product and tertiary sediment mixing to Miocene intrusive rock (Figure 1). Lithology characteristics are divided rocks formation, however distinguishing of formation boundary.

a. Paleozoic Group

This group is compiled of Schist Way Galih and Quartzite Sidodadi. These formation is depend on orogenesis processes product and related to reverse fault. The existence of rocks formation is basement rock of Bandar Lampung and Sumatra region. This group is distributed of eastern and southeastern of Tanjung Karang.

b. Mesozoic Group

Granodiorite is intrusive igneous rock as feature of magmatisme in Bandar Lampung and distributed to eastern of research area. The existence of granodiorite intruded Paleozoic Sidodadi Quartzite.

c. Tertiary Group

Tarahan Formation and Campang Formation are sedimentary rock formation composed of research area. Campang Formation in the southeastern part of research area. This formation associated straight of Lampung-Panjang fault, which segmentation fault similarly to Semangko fault (one of big segment fault in Sumatra), whereas Tarahan Formation have width distribution, which is in the southeastern-northeastern and western-southwestern part of research area.

Tertiary group is also composed of magmatic intrusive igneous rock, which is Miocene Granitoid. This intrusive associated to secondary segment of Lampung-Panjang fault and the existence in the western part of research area.

d. Quaternary Group

This group can be divide two cluster, which are Alluvium as product Recent geological processes and Quaternary volcanic product. This group is focused to volcanic product. Lampung Formation distributed in the part of northern and southern research area, meanwhile Young Volcanic Deposits (Betung Volcano) distributed in the part of central to western research area. Young Volcanic Deposits of Betung Volcano product is occupied more half than research area extensive.

Geological Structure

The research area is traversed by the Panjang-Lampung Fault. The Panjang-Lampung Fault has been identified on the Geological Map of the Tanjungkarang Sheet with a NW-SE direction [5] (Figure 1).

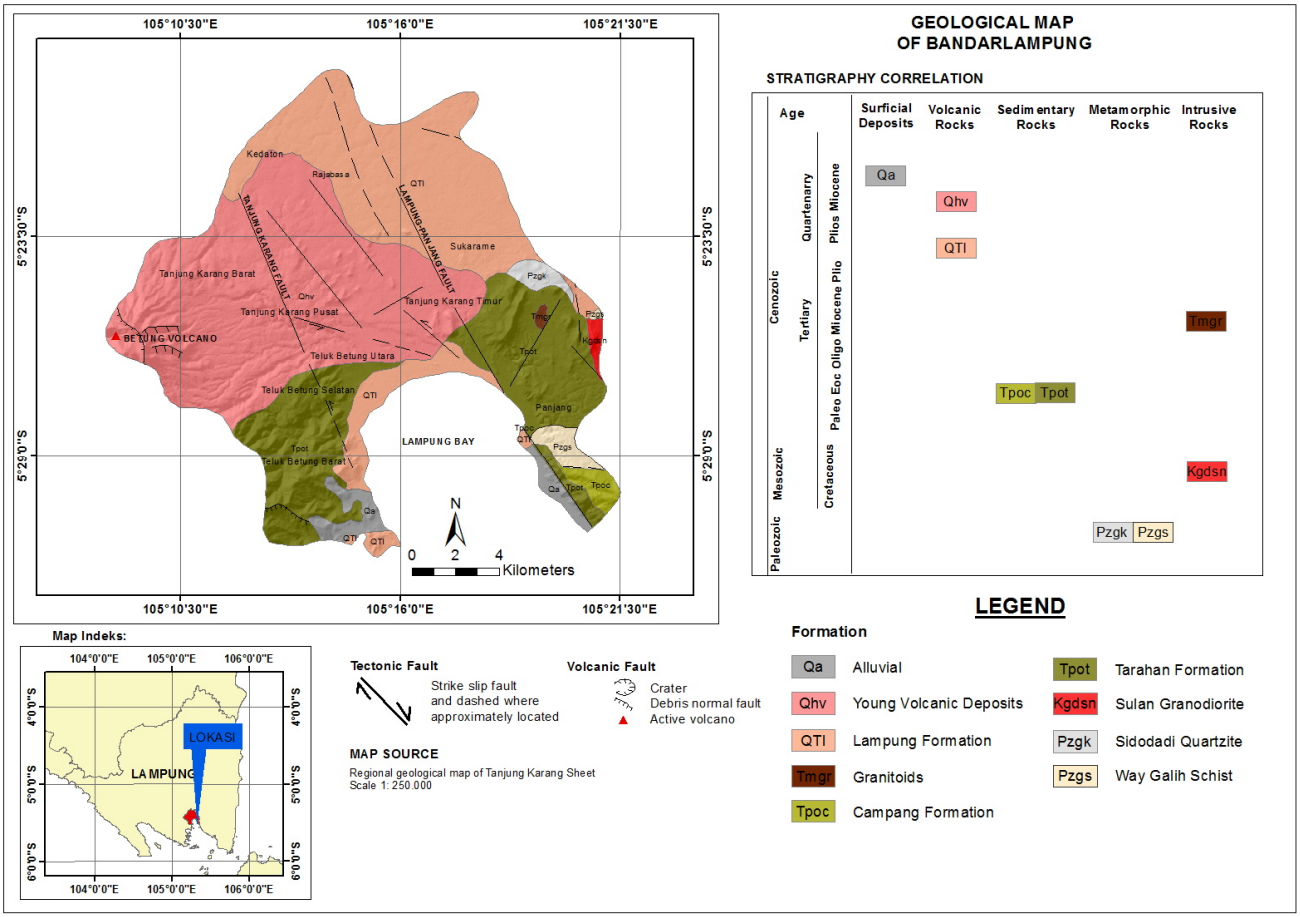

FIGURE 1. Geological map of the research area [5].

MATERIALS AND METHODS

This research was conducted using some data, Digital Elevation Model National (DEMNAS) image, which has 8 m resolution, which are available free of cost from https://tanahair.indonesia.go.id/ website [18], regional geological

map which scale of 1:250.000 on Tanjungkarang sheet of regional geology [5], land use map of Bandar Lampung City, and rainfall data for Bandar Lampung City 2015-2019. All of data were used to analyze and specify geomorphological aspects and their relation with landslide. Digital topography has been used to classify geomorphology [19-21].

The research was presented to find geomorphological aspects, namely morphology, morphogenesis, and morphochronology [22-24]. Data and geomorphological parameters were used to calculate and compute geomorphic aspect using remote sensing method integrated with GIS (Geographic Information System) techniques. The image of DEMNAS was used as the basic data to analyze and interpret geomorphological aspects and their relation with landslide. Several stages of analysis were carried out to achieve objectives of study. From DEMNAS image and regional geological map, interpretation is carried out to identify type of lithology and rock resistance, drainage patterns, structural geologi, weathering and erosion as reflected by the slope and elevation. Based on geological map can be determined geomorphic units, this units used to determine morphological-morphochronological aspects. In addition, this research was supported by checking several location for deciding and ascertaining data.

Furthermore, to create a landslide susceptibility map, the methods used in this study is remote sensing with the Index Overlay Model (IOM) from slope maps, land use maps, geomorphological maps, geological maps, and rainfall maps. The process of making a zoning map of the potential mass movement area is carried out using the IOM weighting method which refers to the Regulation of the Minister of Public Works Number 22/PRT/M/2007.

RESULT AND DISCUSSION

Geomorphology

In the research area is four geomorphic units that could be identified. Classified of geomorphic unit divided become landscape. There is composed of fluviatil unit, structural unit, volcanic unit, and denudational unit. The geomorphic unit is too the determination based on morphochronology of landforms (Figure 2).

Drainage pattern in the research area compiled of radial and subdendritic. Radial is occupy in Betung Volcano geomorphic unit, subdendritic is covered of structural, fluvial and denudational geomorphic units (Figure 3).

a. Structural Geomorphic

This landscape have influenced by structural, which was active fault and approximately fault. There were occupied in the central-north-east-southeastern-west-southwestern part of research area. This landscape associated Lampung-Panjang fault with similarly Sumatra Fault System which Semangko fault segmented. This landscape is composed by Way Galih Structural Hills (WGSH), Way Galih Structural Hill (WSH), Sidodadi Structural Hill (SSH), Tarahan Structural Hills (TSH), Campang Structural Hills (CSH), Lampung Structural Hills (LSH), and Lampung Structural Valley (LSV).the existence of fault segment is primary element to formed of landscape.

b. Volcanic Geomorphic

This landscape controlled by Recent volcanic activity of Betung Volcano and magmatism in Granodiorite Cretaceous and Granitoid Miocene. The existence of active volcano is counted of Barisan Range, meanwhile presence of intrusion magmatism indicated tectonic-magmatism-volcanism the associated with Sumatra Fault Zone. This units geomorphic are composed of Sulan Intrusion (SI) Cretaceous, Panjang Intrusion (PI) Miocene, and active volcano product of Lampung Formation Plio-Plistocene, and Betung Volcano unit (BV) Quaternary.

c. Denudational Geomorphic

This landscape is only occupied of little distribution geomorphic unit. This geomorphic unit is controlled by eroded, which have characterized as lithology or rock formation on the hill morphology different to lithology in surrounding. Padang Isolated Hill (PIH) is half of Lampung Formation. This indicated that volcanic product such as pyroclastic, lava, and volcanic-sediment.

d. Fluvial Geomorphic

This landscape is product of Recent geological processes. This geomorphic have characteristics as unlitification, sedimentary material and distributed in plain/flat relief, such as Alluvial Plain (AP).

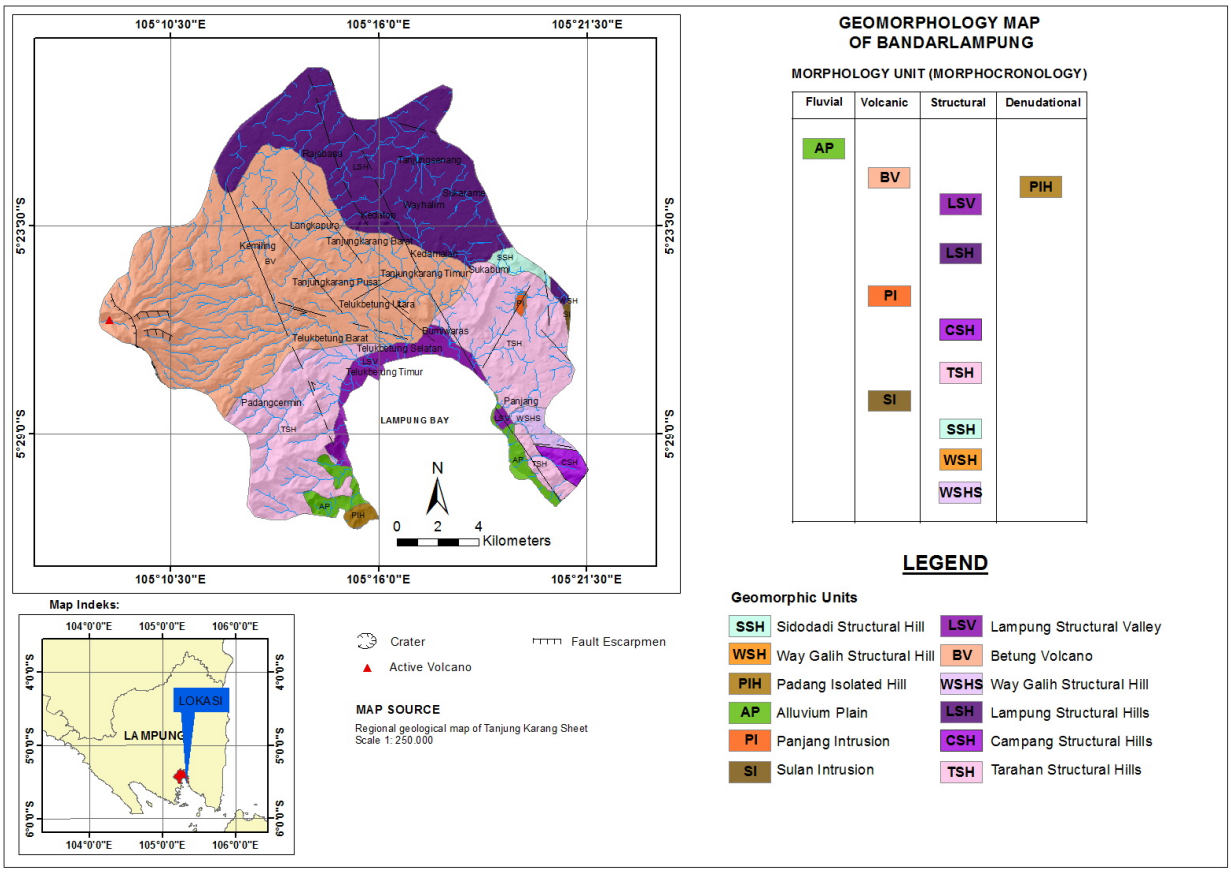

FIGURE 2. Geomorphology map of research area.

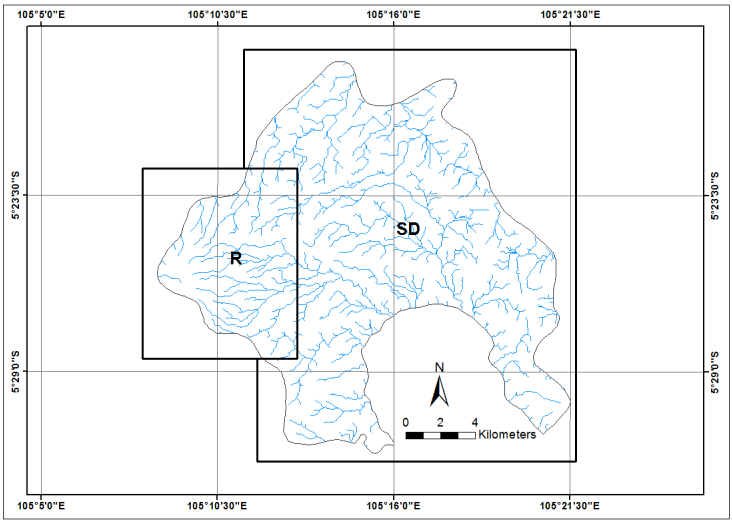

FIGURE 3. Drainage Pattern of research area.

Landslide Hazard Assesment

The process that causes the movement of soil and rock masses on the slopes can be understood mechanically through the approach to the principle of slope stability. This principle explains what forces control the stability of a

slope, under what conditions of force interaction the movement occurs, as well as what natural factors play a role in controlling the interaction of forces on the slope that result in soil and rock mass movements (Karnawati , 2005). The process of moving soil or rock masses on slopes (landslides) can be caused by the influence of factors such as geomorphological factors, lithology, geological structures, hydrogeology and land use. The criteria for the occurrence of landslides are a fairly steep slope, the presence of a slip field under the surface of the soil that is saturated with water and the amount of water content that comes from rainwater that seeps into the ground. The water content in the soil can destabilize the slope, because the soil becomes slippery and the weathered soil above it will move along the slope.

There are several parameters proposed in this research to be the weight of determining landslide-prone areas, namely:

TABLE 1. Landslide hazard parameters and their weight.

Parameters	Weight
Geomorphology	20%
Lithology	20%
Slope	25%
Rainfall	15%
Land use	20%

Geomorphology

Geomorphology is a related science about the shape of the earth's surface and the changes that occur on the earth itself, the geomorphological state of an area greatly affects the level of potential geological hazards of an area. Most of the landslides are in areas with geomorphological conditions in the form of steep slopes.

The research area is included in the terrain and hilly geomorphological conditions. Geomorphology are divided into 3 clasifications, volcano slope in the high category, hills and valley in the moderate category, and alluvium and intrusion in the very low category (Figure 2).

Lithology

Based on Geological Map (Mangga et al., 1993), the research areas included in the Lampung Formation (Qtl), Young Pesawaran Volcano Deposits (Qhvp), Alluvium (Qa), Campang Formation (Tpoc), Tarahan Formation (Tpot) and Inseparable Gunung Kasih Complex (Pzg) which consists of Quarsit Sidodadi (Pzgk). The lithology condition of an area is closely related to the potential of a landslide disaster.

Lithology are divided into 4 classifications, alluvial and volcanic plains are in the very low category, calcareous hills in the low category, hills of sedimentary rocks in the medium category, and volcanic rock hills in the high category. The research area only covers 3 categories, namely the very low, moderate and high categories (Figure 1).

Slope

Slope analysis was analyzed based on 8 m DEMNAS data using Arc GIS 10. Slope is a very important parameter in determining landslide hazard zoning. The research area is divided into 4 categories of slope, <15% with very low categories, 15-24% with low categories, 25-44% with moderate categories and >45% with high categories. The results of the analysis are shown in Figure 4.

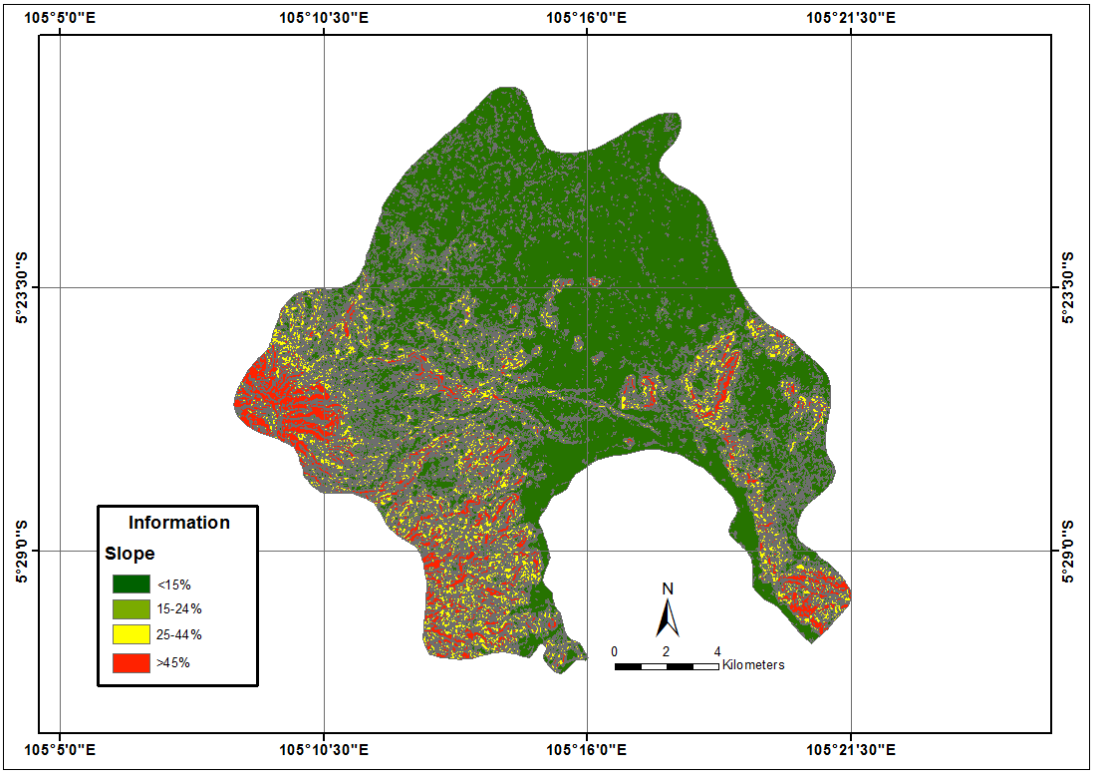

FIGURE 4. Slope analysis of research area.

Rainfall

Rainfall maps are made from rainfall data 2015-2019 sourced from BMKG using the krigging method. The research area is in moderate category with 1500-2500 mm / year rainfall parameters (Figure 5).

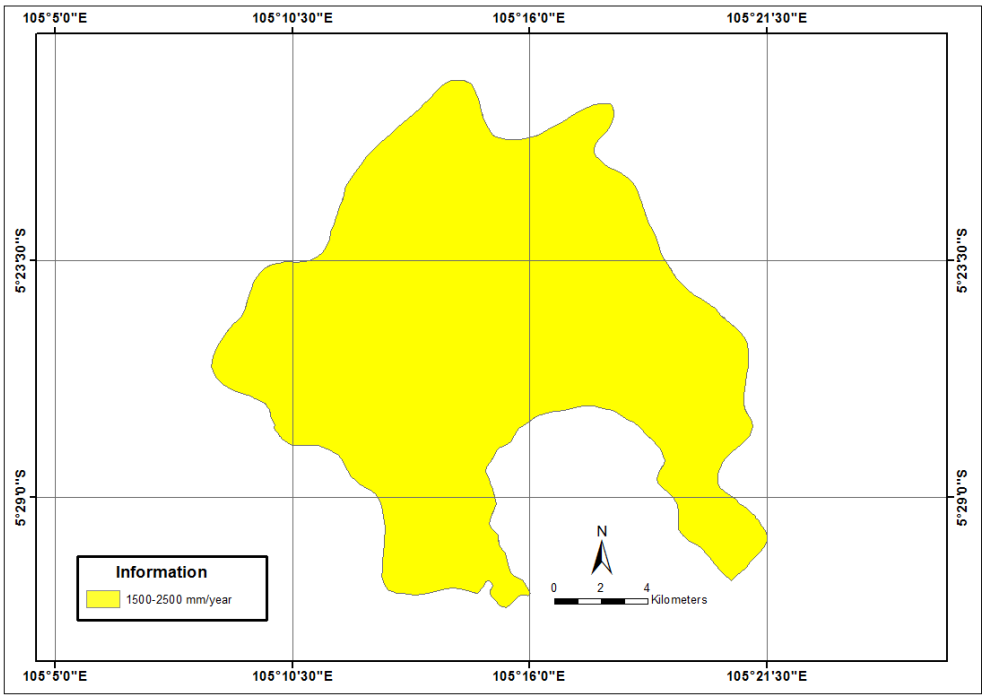

FIGURE 5. Rainfall analysis of research area.

Land use Analysis

Land use analysis was taken from data sourced from INAGEOPORTAL. From these data, the study area consisted of three categories, namely plantations / moorings in the low category, shrubs and grasses in the moderate category, and fields, settlements and buildings with high categories (Figure 6).

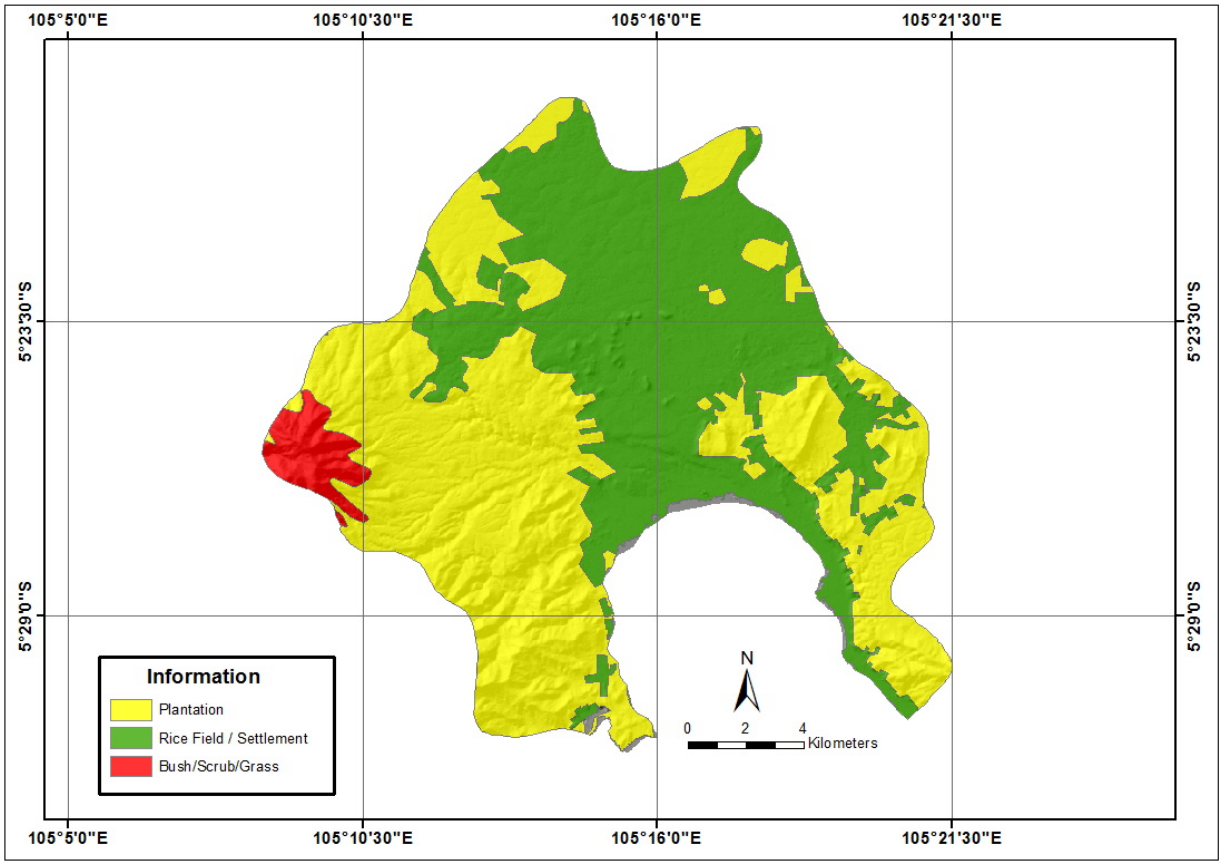

FIGURE 6. Land use analysis of research area.

Landslide Hazard Map

After analyzing studio and checking mass movements in the field, a zoning map of landslide prone areas in Bandar Lampung City was made. Zoning maps are made by compiling geomorphology, lithology, slope, rainfall, and land use. Weighting is done referring to Table 1 with the Index Overlay Model. From the results of the analysis using ArcGIS obtained 3 classes of zoning Bandar Lampung City, areas with potential for mass movement are very safe, safe, and vulnerable (Figure 7).

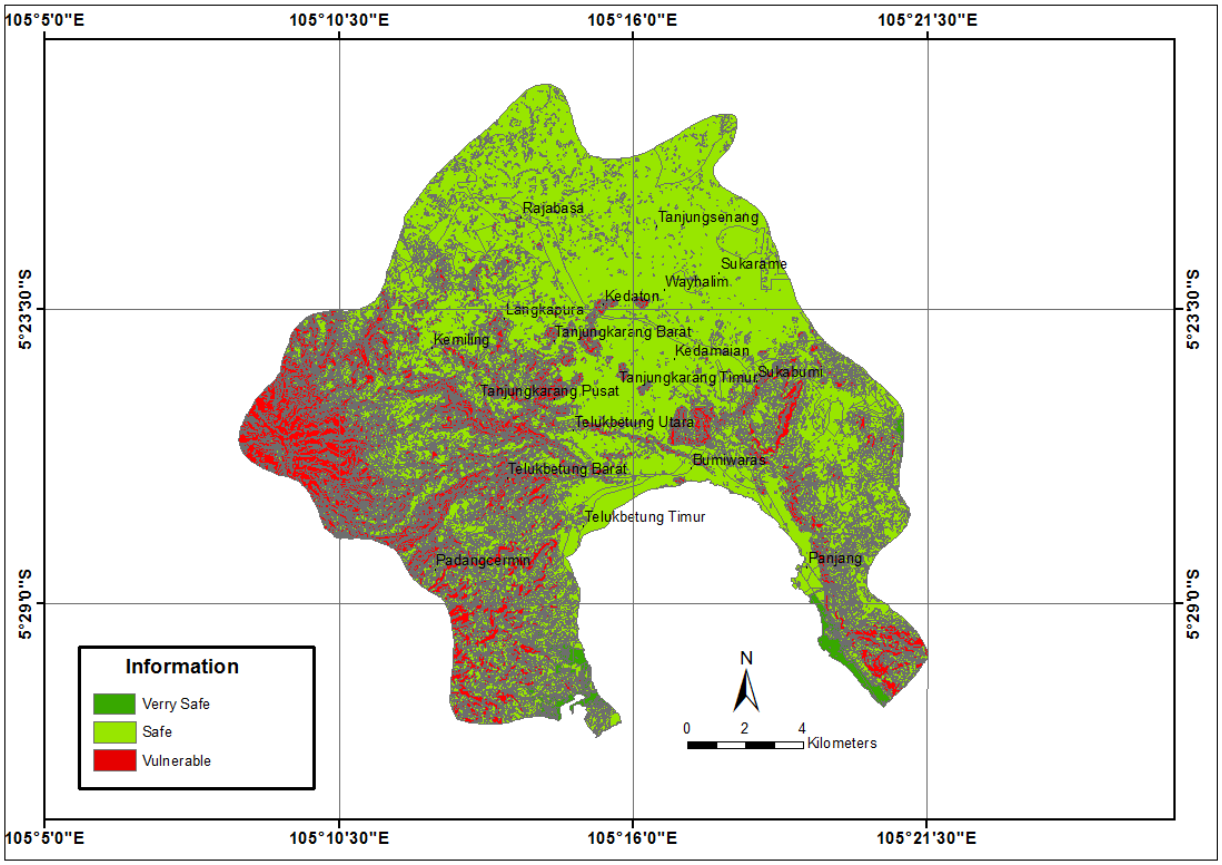

FIGURE 7. Land use analysis of research area.

CONCLUSION

The result found that geomorphologic map is resulted based on analysis morphology aspect. This area could be divided into several geomorphologic units, there are volcanic – denudational, karst, structural, volcanic-structural, structural – denudational, and fluvial morphology. In addition, based on geomorphologic map, landslide hazard assesment could be designed and developed as a recommendation for area development in Bandar Lampung.

Based on results of study it can be concluded that the determination of zoning maps of potential mass movements can be done by remote sensing techniques with the Index Overlay Model. The results of the analysis show that the obtained 3 classes of zoning Bandar Lampung City, areas with potential for mass movement are very safe, safe, and vulnerable. The map produced can be one of the mitigation guidelines and as a recommendation for regional development.

ACKNOWLEDGMENTS

Writers were grateful to research institute and community service, Universitas Lampung with the “Hibah Dosen Pemula” for financial aid to conduct this research.

REFERENCES

1. Karnawati, D., 2005. Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya, Yogyakarta: Jurusan Teknik Geologi Fakultas Teknik Universitas Gadjah Mada.
2. CNN Indonesia. 2021. BNPB Ungkap Tren Peningkatan Bencana Banjir hingga Longsor, dalam https://www.cnnindonesia.com/nasional/20210202132713-20-601293/bnpb-ungkap-tren-peningkatan-bencana-banjir-hingga-longsor [accessed on 27 of February 2021].
3. Badan Nasional Penanggulangan Bencana 2011. Indeks Rawan Bencana Indonesia, BNPB.
4. Pemerintah Kota Bandar Lampung. 2017. Sekilas Kota, https://bandarlampungkota.go.id/sekilas-kota/ [accesed on 16 May 2018].
5. Mangga S A, Amirudin T, Suwarti S, Gafoer and Sidarto. 1993. Geological Map of Indonesia Quadrangle: Tanjungkarang, Sumatra Scale 1: 250.000 (Bandung: Geological Research and Development Centre).
6. Pusat Vulkanologi dan Mitigasi Bencana Geologi (2018): Wilayah Potensi Gerakan Tanah di Lampung, dalam http://www.vsi.esdm.go.id/ [accessed on 17 May 2018].
7. Mulyasari, R., Haerudin, N., Karyanto, Darmawan, I. G. B. Dan Arifianti, Y. 2018a. Zonasi area potensi gerakan massa di sepanjang Sesar Lampung-Panjang Kota Bandar Lampung, Prosiding Semnas SINTA UNILA, ISBN: 2655-2914, 1, 190-197.
8. Mulyasari, R., Utama, H.W., dan Haerudin, N. 2018b. Geomorphology study on the Bandar Lampung Capital City for recommendation of development area, The 1st International Conference on Geoscience (ICoGes 2018), Makassar, Indonesia on November 1st – 2nd, 2018.
9. Mulyasari, R., Darmawan, I.G.B., Efendi, D.S., Hesti, Hidayatika, A., dan Haerudin, N. 2019. Ilmu-Ilmu Teknik: Kebencanaan 2019, Bandar Lampung: UPT Perpustakaan Universitas Lampung.
10. Agustina, L. K., Harbowo, D. G., and Al Farishi, B. 2020. Identifikasi kawasan rawan longsor berdasarkan karakteristik batuan penyusun di Kota Bandar Lampung. Elipsoida: Jurnal Geodesi dan Geomatika, 3(01). Retrieved from https://ejournal2.undip.ac.id/index.php/elipsoida/article/view/7769
11. Meitzen, K. M. 2017. Applied Geomorphology. International Encyclopedia of Geography: People, the Earth, Environment and Technology, pp. 1–7. doi:10.1002/9781118786352.wbieg0144.
12. Alcántara-Ayala I., 2002. Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries, Geomorphology, 47, pp. 107-124.
13. Bailey, G.N., Reynolds, S.R., and King, G.C.P., 2010. Landscapes of human evolution: models and methods of tectonic geomorphology and the reconstruction of hominin landscapes, Journal of Human Evolution, pp. 1-24.
14. Kale, V.S., Sengupta, S., Achyuthan, H., and Jaiswal, M.K., 2014. Tectonic controls upon Kaveri River drainage, cratonic Peninsular India: Inferences from longitudinal profiles, morphotectonic indices, hanging valleys and fluvial records, Geomorphology, 227, pp. 152-165.
15. Otto, J. C. and Smith, M. J., 2013. Geomorphological mapping Geomorphological Techniques, Chap. 2, Sec. 6.
16. Amine, A., Hassani, I.E.E.A.E., Remmal, T., Kamel, F.E., Van wyk de vries, B., and Boivin, P., 2019. Geomorphological Classification and Landforms Inventory of the Middle-Atlas Volcanic Province (Morocco), Scientific Value and Educational Potential, Quaestiones Geographicae, 38 (1), pp. 107-129.
17. van Bemmelen R. W. 1949. The Geology of Indonesia Volume 1A (The Hague, Netherlands: Government Printing Office) p 732.
18. Geospatial Information Agency. 2018. Digital Elevation Model National (DEMNAS) image http://tides.big.go.id/DEMNAS/.
19. Makowski, C., Finkl, C.W., and Vollmer, H.M. 2017. Geoform and landform classification of continental shelves using geospatially integrated IKONOS satellite imagery. Journal of Coastal Research, 33(1), pp. 1-22.
20. Hunt J. A., Pyle D. M., and Mather T. A. 2019. The geomorphology, structure, and lava flow dynamics of Peralkaline Rift Volcanoes from high resolution digital elevation models. Geochemistry, Geophysics, Geosystems, 20(3).
21. Bell, R., Fort, M., Götz, J., Bernsteiner, H., Andermann, C., Etzlstorfer, J., Posch, E., Gurung, N. And Gurung, S., 2021. Major geomorphic events and natural hazards during monsoonal precipitation 2018 in the

Kali Gandaki Valley, Nepal Himalaya, Geomorphology, 372, https://doi.org/10.1016/j.geomorph.2020.107451.
22. van Zuidam, R. A., 1985. Aerial photo Interpretation in terrain analysis and geomorphologic mapping, Smiths publisher, Netherlands, p. 442.
23. Verstappen, H. Th., 2000. Outline of the Geomorphology of Indonesian, International Institute for Aerosace Survey and Earth Sciences, Hengelosestraat, Netherland, p. 200.
24. Verstappen, H.Th., 2010, Indonesian Landforms and Plate Tectonics, Jurnal Geologi Indonesia, 5 (3), pp. 200.