Bulletin of Scientific Contribution GEOLOGY

Fakultas Teknik Geologi
UNIVERSITAS PADJADJARAN
homepage: http://jurnal.unpad.ac.id/bsc
p-ISSN: 1693-4873; e-ISSN: 2541-514X

Volume 21, No.3
Desember 2023

GIS-BASED LANDSLIDE HAZARD ANALYSIS BASED ON WEIGHTED OVERLAY METHOD IN SAMARINDA, EAST KALIMANTAN

Ni'matul Azizah Raharjanti[1,*], Syamsidar Sutan[1], Wisnu Ismunandar[1], Fajar Alam[1], Muhammad Wira Andhika[1]
[1] Study Progam of Geological Engineering, Faculty of Science and Technology, Universitas Muhammadiyah Kalimantan Timur, Indonesia.
* Corresponding author : nar674@umkt.ac.id

ABSTRACT
Samarinda has experienced a frequent landslide disaster, totaling 30% from the total disaster occurring in 2019. Based on these data, it is necessary to carry out the analysis on the landslide hazard as the mitigation to minimize the damage that may be caused by the landslides. The research was conducted in GIS based processing, by collecting secondary data supported by field observations and quantitative analysis to produce the landslide hazard map. Slope gradient, geology, soil type, and rainfall are the parameters used to determine the landslide susceptibility zonation in the research area. These parameters are then processed using a weighted overlay method. The zoning results show most of Samarinda is included in the intermediate landslide hazard zone, followed by the high landslide hazard zone, and the low landslide hazard zone which has the narrowest distribution. The high landslide hazard zone has a distribution associated with geological structures identified as fold which are included in the Samarinda anticlinorium and thrust fault in north-south direction. The distribution of the landslide hazard zones indicates that the slope gradient, lithology which consists of sedimentary rock, and fold and fault structures, are the main controlling factors for landslides in Samarinda.

Keywords: Landslide Hazard, Geographic Information System (GIS), Controlling Factor of Landslide, Samarinda.

INTRODUCTION

Indonesia is one of the countries which are located on the equator and controlled by tectonic activities. One of the effects are Indonesia is prone to natural disasters. According to the National Disaster Management Authority (BNBP), Indonesia has experienced 5402 disasters in 2021, with landslides being the second of the most frequent disasters, accounting for 1321 incidents (BNPB, 2022).

The disaster also happened in the Capital of the East Kalimantan Province, Samarinda. From the regional disaster management agency (BPBD), Landslides in Samarinda City are ranked third in terms of disaster events after forest and land fires and floods, calculated as 30% of the total disasters that occurred. Based on 2019 BPBD data, out of 41 landslide incidents, there were losses for the community in the form of damage to residents' houses and caused injuries (2 people), fatalities (3 people), and 422 people suffered minor injuries (BPBD, 2019)

Currently, publications related to landslide hazard in Samarinda have only been in the form of disaster data, as well as publication of slope analysis at various locations, such as in the Selili area of Samarinda (Sutan et al., 2017). However, publication of landslide hazard zoning in the entire capital city of East Kalimantan has not occurred. Therefore, research to analyze and create the landslide hazard map needs to be carried out. This research is one of the initial mitigation efforts to minimize the impact of the disaster from the landslide disaster in Samarinda City. In this study, the discussion of landslide hazard factors is focused on geological factors, including slope gradient, lithology, and geological structure. The landslide hazard map is also compared to the actual landslides occurrences as the validation of the analysis that was conducted.

The mass movement or landslide can be categorized according to the type of movement and its material. The materials of the landslide can be composed of rocks, soil, or the combination of both materials (Cruden and Varnes, 1996; Najib et al., 2015). There are two factors that can cause landslides, identified as controlling factors and movement triggering factors. Controlling factors of mass movement are components that can make slopes vulnerable to movement, including morphological conditions, lithological types, relationships between lithology, geological structures, geohydrology, and land use (Karnawati, 2005; Vasudevan and Ramanathan, 2016; Yu et al., 2021). The controlling or conditioning factor of the mass movements can be various depending on the location (Chau and Chan, 2005). Moreover, there are processes which may cause the slope to become critical and mass movement occurred, known as triggering factors, which are rain infiltration, vibration that can be caused by the earthquakes or human activities, and the utilization of land in the slope area (Karnawati, 2005). The National Disaster Management Authority (BNBP) defines that landslide hazard is controlled by several parameters which include morphology, geology, soil, and hydrology. Based on these factors, it is necessary to investigate the landslide hazard in Samarinda as an effort to minimize damage from the disaster.

REGIONAL GEOLOGY

Samarinda is a part of the Kutai Basin. Kutai Basin occupies most of the East Kalimantan area with its sediment supply coming from the central part of Kalimantan Island. This suggests that the central part of Kalimantan experienced uplift and erosion during the Tertiary Period. Kutai Basin is divided into western Inner Kutai Basin and eastern Outer Kutai Basin, and Samarinda area is included in eastern Outer or Lower Kutai Basin. The Lower Kutai Basin is primarily made up of Miocene sedimentary rocks (Chambers et al., 2004; Moss and Chambers, 1999) (Fig. 1). According to the regional geology map by (Supriatna et al., 1995), Samarinda is composed by Tertiary Pulau Balang and Balikpapan Formation, also Quaternary Alluvium. Pulau Balang Formation consists of interbedded greywacke and quartz sandstone with intercalation of limestone, claystone, coal, and dacitic tuff formed in the Middle Miocene – Late Miocene. The Balikpapan formation has interfinger relations with Pulau Balang Formation indicates it formed in the same period. Balikpapan Formation consists of sandstone interbedded with claystone intercalation with silt, shale, limestone, and coal. Quaternary Alluvium is composed of gravel, sand, and mud occupied around Mahakam River. Regionally, Samarinda is controlled by a geological structure mainly known as Samarinda Anticlinorium elongated in the North – South direction. The thrust fault with North – South direction also occurs in the central part of the Samarinda City (Supriatna et al., 1995; Witts et al., 2016). Those mentioned geological structures form the regional morphology of Samarinda which dominantly categorized as structural landform and affect the slope of the geomorphology in the research area (Poedjoprajitno et al., 1998).

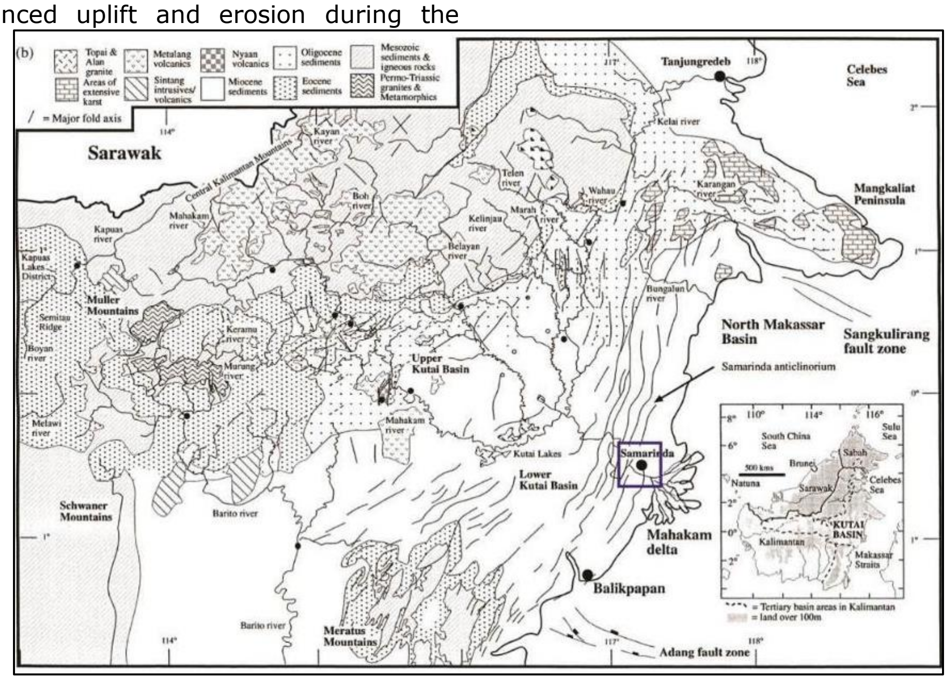

Fig. 1. The regional geology of the Samarinda (blue rectangle) that included in Lower Kutai Basin composed by Miocene sedimentary rocks and controlled by folding known as Samarinda anticlinorium (modified from Moss and Chambers, 1999)

RESEARCH METHOD

The research was located in Samarinda and conducted in various processes, including a literature review, secondary data gathering, field observation, and data analysis to create the landslide hazard map. The secondary data that were used are (1) Digital Elevation Model (DEM) from the DEMNAS (Badan Informasi Geospasial (BIG), 2022; Hell and Jakobsson, 2011) website (https://tanahair.indonesia.go.id/demnas/). DEM was utilized to analyze the morphology and slope of the research area. (2) Geological data which collected from the regional geology map to identify the lithology and geological structure formed in Samarinda. (3) The rainfall data from last ten years (2013 – 2022) is collected from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS, 2022; Funk et al., 2015). (4) Soil types are collected from the Geonetwork website associated with the Food and Agriculture Organization (FAO) of the United Nation. The soil classification used in this paper is also based on the FAO classification system (Nachtergaele, 2017; Subardja et al., 2014). This data is collected as the controlling factors of the mass movement (BNPB, 2016; Karnawati, 2005). (3) The administrative border of the Samarinda which is then processed in a geospatial information system to delineate the border of the research area and produce landslide hazard maps.

The field observation which includes geological and landslide location observation. The analysis of slope from the DEM, geological, rainfall, and geological data are processed in GIS. These Data then delineate with the administrative border of Samarinda. Therefore, the landslide hazard map can be made. The record of the landslide location occurred from 2020 – 2022 also collected to compare the landslide hazard map that produced with the actual events occurred.

The landslide hazard index is obtained from the delineation of the landslide zone with cutoff of minimum slope is 15% or angle of slope 8.51°. The procession of the data using the deterministic method which each of the controlling parameters of the landslide has their score and weight according to (BNPB, 2019, 2016) (Table 1).

Table 1. The score and weight of the parameters for determination of the landslide hazard in Samarinda (modification of (BNPB, 2019, 2016)).

No	Data	Parameters	Classification	Score	Weight
1	DEM	Slope	15 – 30%	0.250	0.40
			30 – 50%	0.500	
			50 – 70%	0.750	
			>70%	1.000	
2	Geology	Lithology	Alluvium	0.333	0.20
			Sedimentary Rocks	0.667	
			Volcanic Rocks	1.000	
		Distances from structures	>400 m	0.200	0.05
			300 – 400 m	0.400	
			200 – 300 m	0.600	
			100 – 200 m	0.800	
			0 – 100 m	1.000	
3.	Soil	Soil type	Sandy	0.333	0.150
			Clayey - sandy	0.667	
			Clay	1.000	
4.	Hydrology	Annual rainfall	<2000 mm	0.333	0.20
			2000 – 3000 mm	0.667	
			>3000 mm	1.000	

Each of the parameters then calculated with weight overlay parameters method based on the dominance of each landslide controlling parameters to the landslide that may occurs (BNPB, 2019, 2012), including slope, geology, soil, and hydrology. Based on BNPB (2019, 2012), each data's weight is determined using the Analytic Hierarchy Process (AHP) method, in which the slope is determined as the dominance factor and distances from structures is the least significant factor (Table 1). The formula of landslide hazard calculation to produce a hazard index map of the research area is written in Eqn.1 (BNPB, 2019; Lanto et al., 2022; Yulianto et al., 2019).

H (weight) = (0.40 × *A*) + (0.20 × *B*) + (0.05 × *C*) + (0.15 × *D*) + (0.20 × *E*) (1)

Where: *A* = score of slope parameter
B = score of lithology parameter
C = score of distances from structures parameter
D = score of soil types parameter
E = score of annual rainfall parameter

The result from the hazard calculation then divided in to three categories of landslide hazard index based on the classification of the hazard index in the *Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012* (BNPB, 2019, 2012), namely low, intermediate, and high hazard index. The H index, which maximum value is 1 then divided into three class, class 1 for low hazard, 2 for intermediate, and 3 for high hazard. Then it calculated with the weight of class, accounted for 100% (BNPB, 2019, 2012). The determination of the hazard zone is shown in Table 2.

Table 2. The landslide hazard zone categories determination (modification from (BNPB, 2019, 2012).

Hazard zone	value	Weight	Score
Low	1	100%	0.333
Intermediate	2		0.666
High	3		1.000

Therefore, each hazard index zone has interval value, which are low hazard index ranging from H ≤ 0.333, intermediate hazard index ranging from 0.333< H ≤ 0.666 and high hazard index with H value more than 0.666. The landslide hazard map that was produced then compared with the actual landslide occurrences to validate the data that obtained.

The flow diagram of the landslide hazard map making is presented in Fig. 2. (BNPB, 2019, 2016; Polawan and Raharjanti, 2022).

RESULT AND DISCUSSION

The slope was analyzed using slope classification (BNPB, 2016; Van Zuidam, 1985) and the cut off of the landslide potential according to (BNPB, 2019) which is 15%, therefore the slope in Samarinda is divided into four categories, gentle sloping (< 15%), moderately steep (15% – 30%), steep (25% - 50%), and extremely steep (50 - 70%) (Fig. 3 and Fig. 4).

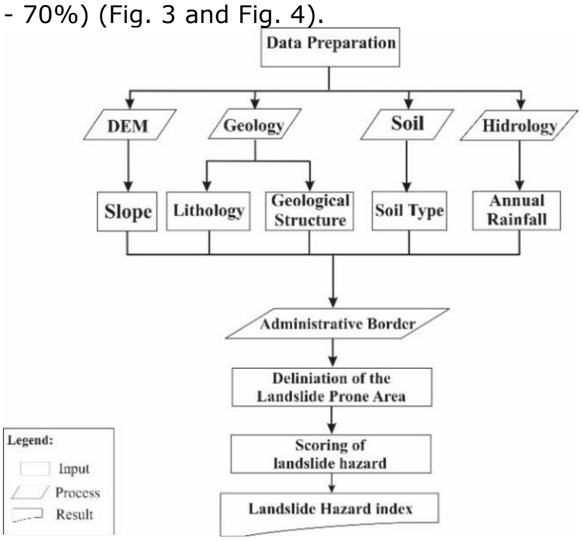

Fig. 2. The flowchart of the landslide hazard map production (modified from (BNPB, 2019, 2016; Polawan and Raharjanti, 2022).

The slope is categorized according to morphometry or quantitative slope evaluation based on the slope percentage by (Van Zuidam, 1985). Meanwhile, the division of slope classes refers to the BNPB landslide hazard classification (BNPB, 2019).

In Fig. 3 shows Samarinda is dominated by the gentle sloping area (<15%) rather than the steep sloping area. The steep slope zone has a lineament in north – south direction. The lineament in Samarinda which has steep slope are associated with regional geological structures known as Samarinda anticlinorium (Supriatna et al., 1995; Witts et al., 2016). The geological characteristics of the research area showcases Samarinda consists of sedimentary rocks and alluvium. Lithology is composed by sandstone, claystone, quartz sandstone, and alluvium deposit (Fig. 5). The sandstone has bedding structures, intercalated with coal. The claystone in the research area also predominantly identified in bedding lithology structure.

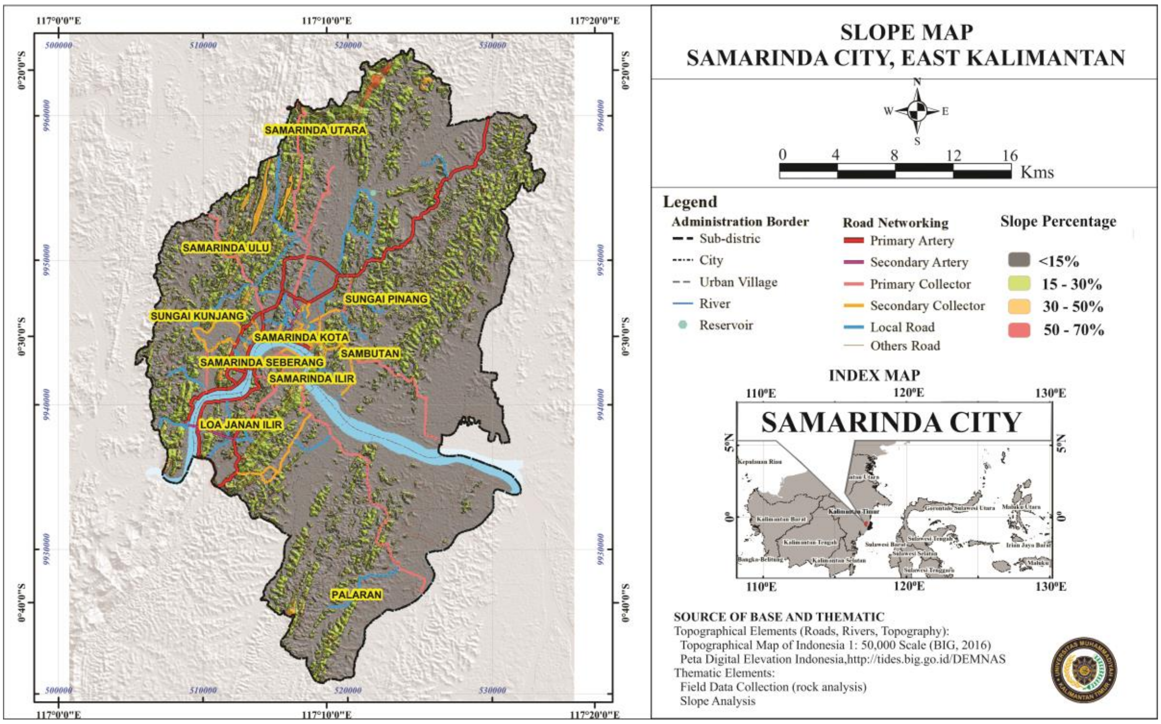

Fig. 3. The Slope Map of Samarinda City, East Kalimantan.

The lithology in Samarinda is strongly controlled by geological structure predominantly folding (Fig. 4). Therefore, the lithology in the research has experienced deformation, the strike is dominated in NNE-SSW direction measured as N354°E dan N20°E and the dipping varies from 36 – 65 °. According to the regional geology data, the lithology in Samarinda is part of the Balikpapan and Pulau Balang Formation, which formed in Middle Miocene to Upper Miocene.

The structural geology that formed in research area is folding identified as Samarinda anticlinorium which extend from north to south with an average slope of 60° (Permana et al., 2022; Supriatna et al., 1995). In addition, the thrust fault was also observed, cutting through the Mahakam River and has a north-south direction (Fig. 5). Sutan et al., (2017) stated that the thrust fault in the research area is identified by the abrupt diversion of the river channel from relatively west – east direction (130°E) to relatively north - south (195°E) (Sutan et al., 2017).

Samarinda is composed by three types of soil according to the FAO classification, namely Orthic Acrisols (Ao), Cambic Arenosols (Qc), and Dystric Fluvisols (Jd) (Nachtergaele, 2017). The Orthic Acrisols soil is characterized by low accumulation of clays and low base saturation.

The Cambic arenosols have coarse texture characteristics, often composed of sandy and clayey - sandy grain. Hence, both of soils type is classified as clayey – sandy soil for landslide hazard analysis based on BNPB (2019) classification (Fig. 6).

Fig. 4. (Left) the morphological features show the steep slope morphology and (right) the appearance of sandstone with coal intercalation and has been influenced by folds resulting in inclination of the rock bedding. The photos were taken facing the south direction.

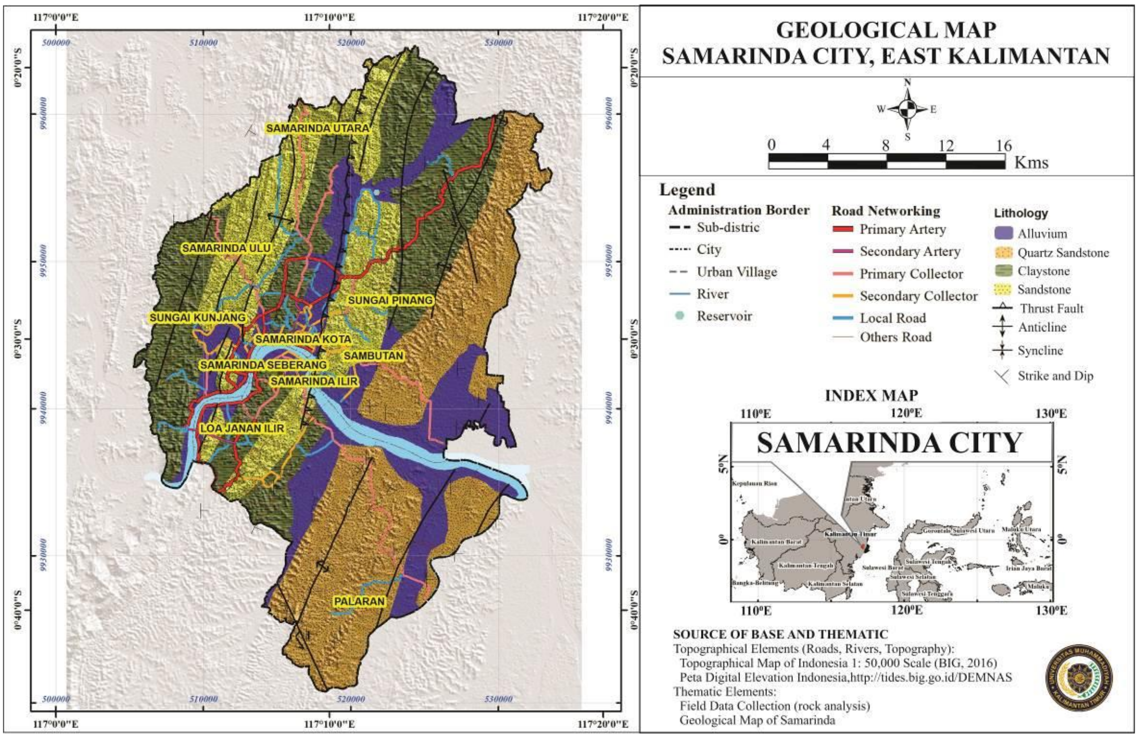

Fig. 5. The geological map of Samarinda, displaying the lithology and structural geology in the research area.

The Dystric Fluvisols are formed by alluvial deposits, which in Samarinda consist of sandy grainsize. Therefore, this soil zone is included as sandy soil zone (BNPB, 2019; Subardja et al., 2014; Supriatna et al., 1995). The analysis of the annual rainfall showing that the rainfall in Samarinda is relatively uniform, classified in 2000 – 3000 mm per year (Fig. 6.) (CHIRPS, 2022).

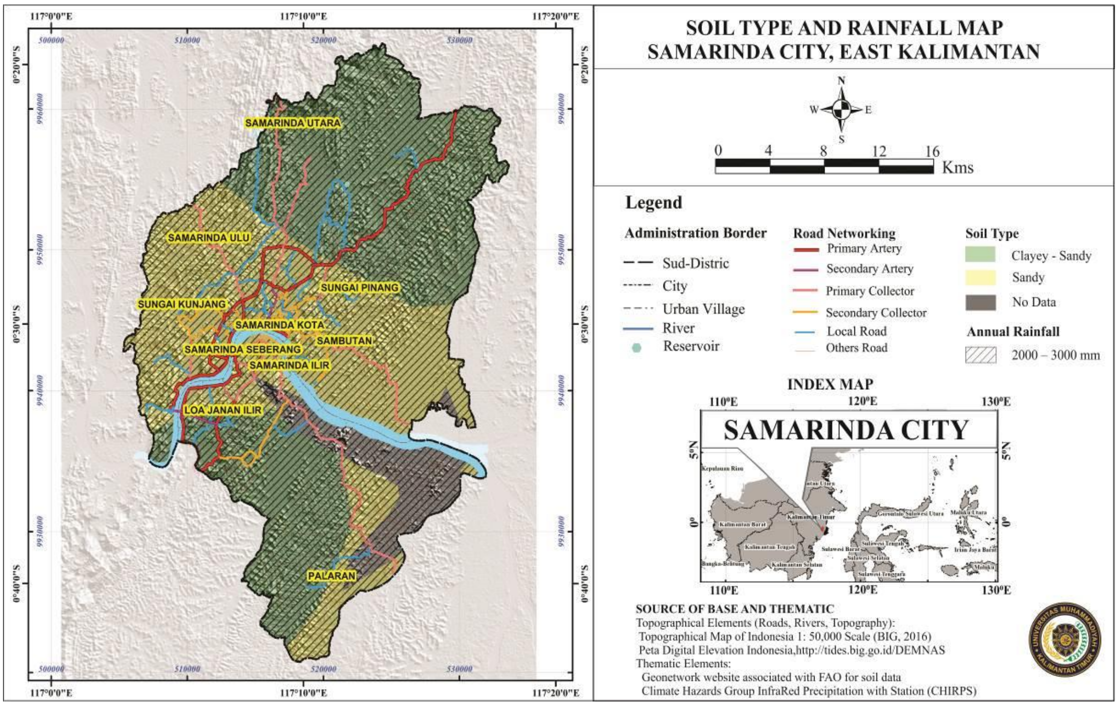

Fig. 6. The distribution soil type and annual rainfall map in Samarinda City, East Kalimantan.

The result of the landslide hazard index of the Samarinda indicates that the research area is mostly covered by intermediate hazard index (Fig 7.). The lowest landslide hazard area has the smallest distribution, concentrated in the flat area on the north side of the Mahakam

River. The high landslide susceptibility zone shows a north – south pattern which interpreted associated with the geological structures occur in the Samarinda. The plotting of landslide occurrences in Samarinda also proves that the landslide is associated with the lineament of the geological structures (Fig. 6).

The landslide is heavily controlled by the gradient of the slope, the steep slope is associated with the higher landslide susceptibility. The measurement in two locations of the landslide occurring in the research area shows that the slope is 34° and 71° respectively (Fig. 7). From field observation, it is identified that joint in the rock bedding which become more vulnerable to the mass movement.

The slope value is one of the main factors in landslide hazard zoning in Samarinda City. The high landslide hazard zone in the study area is associated with areas with high slope percentages (Fig. 3 and Fig. 8 A-C). This is in accordance with Karnawati (2005), the morphology is one of the main factors controlling the occurrence of mass movement with higher slopes having a higher potential for landslide hazard as well.

Karnawati (2005) states that one of the conditioning factors for the occurrence of mass movement is geological structures in which identified as anticlinorium and thrust fault (Fig. 5.) (Supriatna et al., 1995; Witts et al., 2016). The deformation process makes the rocks bedding incline and the slope of the morphology become steep, so that they form movement planes in the rock layers. The geological structure is also a controlling factor for the formation of Samarinda's morphology so that it becomes a hilly area with relatively steep slopes. Furthermore, there are landslide locations that have a slope direction in the same direction as the dipping of the lithology, thereby increasing the landslide susceptibility in the research area (Fig. 8C) (Benzougagh et al., 2020; Yulianto et al., 2019).

Lithological factors, including lithology and stratigraphic relationships between rocks, are also controlling factors for mass movement (Cruden and Varnes, 1996; Mario et al., 2023; Trisnawati et al., 2022). BNPB (2016) classifies lithology into three types, namely volcanic rock, sedimentary rock, and alluvial rock with the highest to lowest landslide hazard class values, volcanic rock, sedimentary rock, and alluvium.

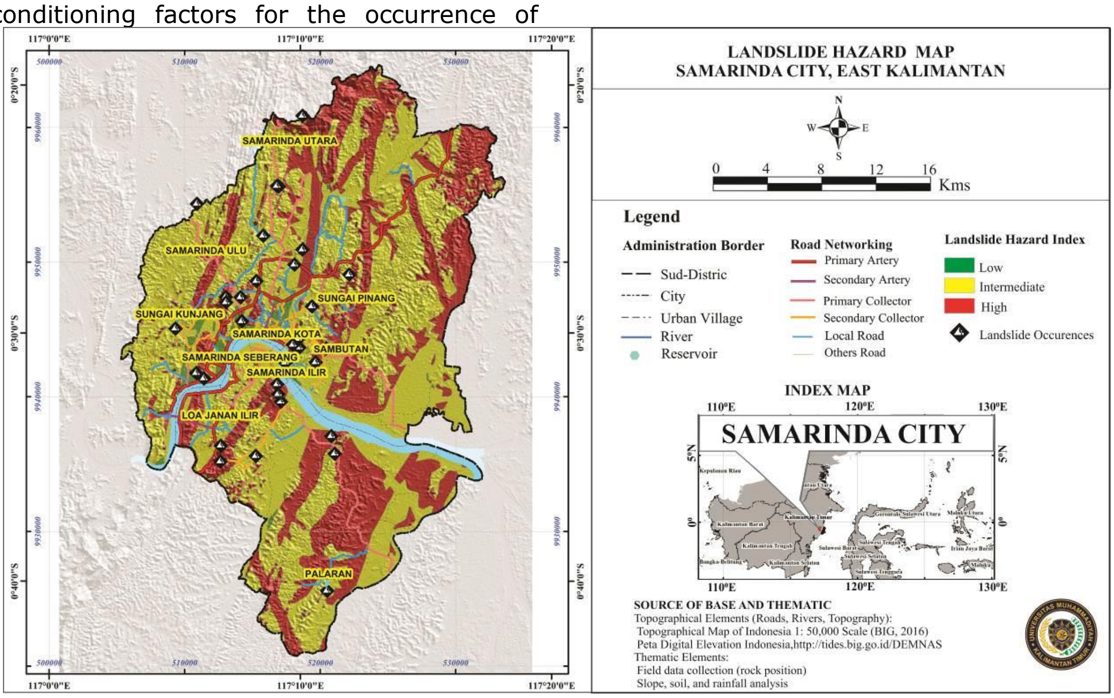

Fig. 7. The landslide hazard map of Samarinda, East Kalimantan.

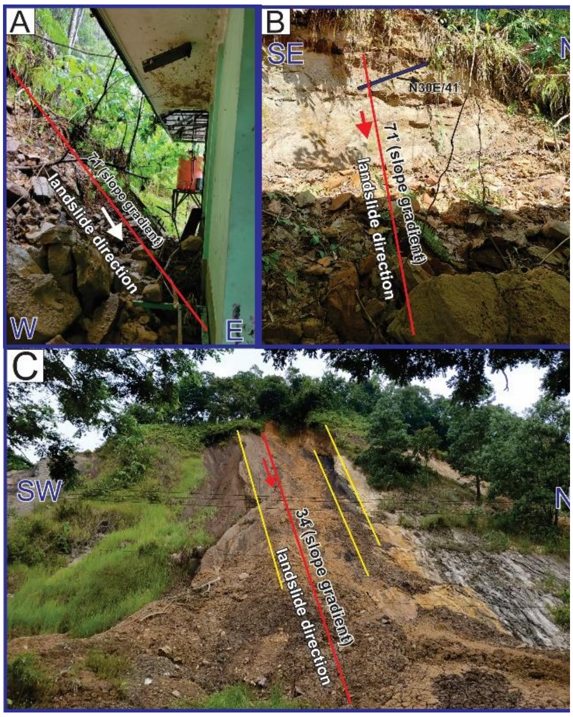

Fig. 8. Landslides occurrences in research area.

Based on BNPB (2016) classification, the study area is composed of two types of lithology, identified as sedimentary rock consisting of sandstone, claystone, and quartz sandstone, which is considered to have a higher landslide hazard value than alluvium. Alluvium is considered to have a low hazard class because alluvial is associated with a zone with low slopes so that it has a low danger of landslides (Sejati et al., 2020). Alluvium deposit is also considered to have a low level of erodibility. This low erodibility also reduces the level of danger of landslides occurring in an area (Purba et al., 2014).

Research that was conducted in Selili Samarinda area shows lithology that composing the area from the bottom layer up is claystone and sandstone, claystone is composed of phyllosilicate minerals, known as clay minerals and have impermeable characteristics. This is interpreted as an avalanche slip plane in the Selili Area. The presence of clay minerals can also reduce rock strength (Regmi et al., 2013; Sutan, 2020). On the other hand, the sandstones in the Selili Area have characteristics brownish yellow color with consits quartz and iron oxide minerals (Sutan 2020). These sedimentary rocks are formed in bedding structures which can be landslide slip planes. Sedimentary rock's particles also do not have high cohesive adhesion and the strength of these rocks is relatively moderate – weak. This causes sedimentary rocks to have a high landslide hazard index (Hunt, 2007; Yamagishi and Iwahashi, 2007).

Another controlling factor of the landslide susceptibility of an area is hydrology and soil aspects. The hydrology represented by the annual rainfall data in Samarinda has uniform intensity, around 2300 to 2500 mm per year which classified in to second class (2000 – 3000 mm) according to BNPB classification (Fig. 6). The intensity of the rainfall affects the water saturation in the soil layer. The higher of the water content in the soil, the value of shear strength will decrease, hence the area is more vulnerable of the landslide (Budianta et al., 2022; Mario et al., 2023). Soil type which in the research area is categorized into two types, sandy and clayey – sandy. The soil containing clay is considered more prone to landslides. The clay in the soil increases the plasticity and lowers the shear strength. Moreover, the clay content in soil has potential for swelling which increase the vulnerability to the landslide (Budianta et al., 2022; Yalcin, 2007).

The comparison on the landslide occurrences and the hazard map indicates that landslides in Samarinda (Fig. 7.) mainly controlled by the morphology and geological features. The landslide are more often happen in the steep morphology which formed by anticlinorium and thrust fault, this can be interpreted that geological structures also one of the main factor of the landslide (Benzougagh et al., 2020; Supriatna et al., 1995). Lithology type is identified as the controlling factors as the landslide are more likely to occur in the sandstone and claystone lithology, while in quartz sandstone lithology the disaster occurs less intense (Karnawati, 2005; Trisnawati et al., 2022).

Conclusion

Analysis on the landslide hazard in Samarinda shows result that the area is predominantly included in the intermediate landslide hazard zone. Areas which are categorized as high hazard zone are identified associated with the steep slope controlled by the folds and thrust fault, indicating that morphology and geological structures are the controlling factor of the Landslide. The lithology also contributes to the landslides in the research area, proves by more occurrences of the landslide is identified in the sandstone and claystone lithology.

Further research for landslide risk analysis including analysis of landslide vulnerability and capacity in Samarinda City is recommended to be carried out. This can be used as a basis for identifying potential losses and risk management caused by landslides as a method of disaster mitigation.

ACKNOWLEDGEMENTS
We would like to thank LPPM Muhammadiyah University of East Kalimantan for supporting the funding of this research through internal research grants in SK number 282/KEP/SKT/A.2/C/2021.

REFERENCES

Badan Informasi Geospasial (BIG), 2022. DEMNAS [WWW Document]. Seamless Digital Elevation Model (DEM) dan Batimetri Nasional. URL https://tanahair.indonesia.go.id/demnas/#/demnas

Benzougagh, B., Meshram, S.G., Baamar, B., Dridri, A., Boudad, L., Sadkaoui, D., Mimich, K., 2020. Relationship between landslide and morpho-structural analysis: a case study in Northeast of Morocco. Appl Water Sci 10, 175. https://doi.org/10.1007/s13201-020-01258-4

BNPB, 2022. Bencana Indonesia 2021 (Graphic Infor). Badan Nasional Penanggulangan Bencana Indonesia, Jakarta.

BNPB, 2019. Petunjuk Teknis Kawasan Rawan Bencana Tanah Longsor. Badan Nasional Penanggulangan Bencana Indonesia, Jakarta.

BNPB, 2016. Risiko Bencana Indonesia. Badan Nasional Penanggulangan Bencana Indonesia, Jakarta.

BNPB, 2012. Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012 Tentang Pedoman Umum Pengkajian Risiko Bencana.

BPBD, 2019. Dokumen Kajian Risiko Bencana Kota Samarinda, Provinsi Kalimantan Timur, Tahun Anggaran 2019. Badan Penanggulangan Bencana Daerah Kota Samarinda, Samarinda.

Budianta, W., Ohta, H., Takemura, J., 2022. The Effect of Clay-Soil on Landslide: Case Study from Central Java, Indonesia. IOP Conf. Ser.: Earth Environ. Sci. 1091, 012012. https://doi.org/10.1088/1755-1315/1091/1/012012

Chambers, J.L.C., Craig, J., Carter, I., Moss, S.J., Cloke, I.R., Paterson, D.W., 2004. Thin-skinned and Thick-skinned Inversion-Related Thrusting—A Structural Model for the Kutai Basin, Kalimantan, Indonesia, in: McClay, K.R. (Ed.), Thrust Tectonics and Hydrocarbon Systems. American Association of Petroleum Geologists, p. 0. https://doi.org/10.1306/M82813C32

Chau, K.T., Chan, J.E., 2005. Regional bias of landslide data in generating susceptibility maps using logistic regression: Case of Hong Kong Island. Landslides 2, 280–290. https://doi.org/10.1007/s10346-005-0024-x

CHIRPS, 2022. Rainfall Estimates from Rain Gauge and Satellite Observations.

Cruden, D., Varnes, D.J., 1996. Landslide Types and Processes. In: Turner, A.K., Schuster, R.L. (Eds.), Landslides: investigation and mitigation. National Academy Press,Washington, D.C 247, 36–75.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., Michaelsen, J., 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Sci Data 2, 150066. https://doi.org/10.1038/sdata.2015.66

Hell, B., Jakobsson, M., 2011. Gridding heterogeneous bathymetric data sets with stacked continuous curvature splines in tension. Mar Geophys Res 32, 493–501. https://doi.org/10.1007/s11001-011-9141-1

Hunt, R.E., 2007. Geologic Hazards: A Field Guide for Geotechnical Engineers, 0 ed. CRC Press. https://doi.org/10.1201/9781420052510

Karnawati, D., 2005. Bencana Alam Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya. Fakultas Teknik, Universitas Gadjah Mada, Yogyakarta.

Lanto, M.S., Syam, D.N., Wahyuni, A., Kusmiran, A., 2022. Pemetaan Risiko Bencana Tanah Longsor di Kabupaten Barru Menggunakan Metode Pembobotan Parameter dan INARISK BNPB. jurgeo 8, 250. https://doi.org/10.12962/j25023659.v8i3.14758

Mario, B., Giacomo, P., Paola, G., Giuseppe, P., Marco, P., Katia, S., Francesco, C., 2023. Landslides and predisposing factors of the Southern Apennines, Italy. Journal of Maps 19, 2137065. https://doi.org/10.1080/17445647.2022.2137065

Moss, S.J., Chambers, J.L.C., 1999. Tertiary facies architecture in the Kutai Basin, Kalimantan, Indonesia. Journal of Asian Earth Sciences 17, 157–181. https://doi.org/10.1016/S0743-9547(98)00035-X

Nachtergaele, F.O., 2017. Classification Systems: FAO ☆, in: Reference Module in Earth Systems and Environmental Sciences. Elsevier, p. B9780124095489105202. https://doi.org/10.1016/B978-0-12-409548-9.10520-2

Najib, N., Karnawati, D., Sudarno, I., 2015. INFLUENCE OF GEOLOGICAL CONDITION TOWARDS SLOPE STABILITY ON LANDSLIDE: CASE STUDY IN TENGKLIK VILLAGE, TAWANGMANGU DISTRICT,

KARANGANYAR REGENCY, CENTRAL JAVA PROVINCE, INDONESIA. J. Appl. Geol. 2. https://doi.org/10.22146/jag.7265

Permana, A.K., Kusworo, A., Wahyudiono, J., A. Sendjaja, Y., Panggabean, H., Fauziely, L., 2022. Chemostratigraphy and Paleoenvironment of the Miocene Organic Rich Sediments in the East Kutai Sub-Basin, Indonesia. jgsm.geologi 23, 1–15. https://doi.org/10.33332/jgsm.geologi.v23i1.660

Poedjoprajitno, S., Suharsono, Kamawan, 1998. Peta Geomorfologi Lembar Samarinda, Kalimantan 1:100000.

Polawan, S.M., Raharjanti, N.A., 2022. Preliminary Study of Landslide Hazard in Kutai Kartanegara Regency, East Kalimantan using Digital Elevation Model. IOP Conf. Ser.: Earth Environ. Sci. 1071, 012007. https://doi.org/10.1088/1755-1315/1071/1/012007

Purba, J.O., Subiyanto, S., Sasmito, B., 2014. Pembuatan Peta Zona Rawan Tanah Longsor di Kota Semarang dengan Melakukan Pembobotan Parameter. Jurnal Geodesi Undip 3, 40–52. https://doi.org/10.14710/jgundip.2014.5205

Regmi, A.D., Yoshida, K., Dhital, M.R., Devkota, K., 2013. Effect of rock weathering, clay mineralogy, and geological structures in the formation of large landslide, a case study from Dumre Besei landslide, Lesser Himalaya Nepal. Landslides 10, 1–13. https://doi.org/10.1007/s10346-011-0311-7

Sejati, A.E., Karim, A.T.A., Tanjung, A., 2020. The Compatibility of a GIS Map of Landslide-Prone Areas in Kendari City Southeast Sulawesi with Actual Site Conditions. For. Geo. 34. https://doi.org/10.23917/forgeo.v34i1.10582

Subardja, D., Ritung, S., Anda, M., Sukarman, Suryani, E., Subandiono, R.E., 2014. Petunjuk Teknis Klasifikasi Tanah Nasional. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian, Bogor.

Supriatna, S., Sukardi, S., Rustandi, E., 1995. Peta Geologi Lembar Samarinda Kalimantan Skala 1:250000.

Sutan, S., 2020. Pengenalan Daerah Rentan Gerakan Tanah Studi Kasus Kestabilan Lereng Kawasan Selili. Gerbang Etam 14, 44–54.

Sutan, S., Syuhada, E.M., Alam, F., Simon, I., 2017. Longsor Selili sebagai Tolak Ukur Pemerintah Merancang Kawasan Penduduk dan Tata Kota, in: JOINT CONVENTION MALANG 2017, HAGI – IAGI – IAFMI- IATMI (JCM 2017).

Trisnawati, D., Najib, Hidayatillah, A.S., 2022. The Relationship of Lithology with Landslide Occurrences in Banyumanik and Tembalang Districts, Semarang City. IOP Conf. Ser.: Earth Environ. Sci. 1047, 012026. https://doi.org/10.1088/1755-1315/1047/1/012026

Van Zuidam, 1985. Aerial Photo – Interpretation in Terrain Analysis and Geomorphologic Mapping. Smith Publisher, The Hague.

Vasudevan, N., Ramanathan, K., 2016. Geological factors contributing to landslides: case studies of a few landslides in different regions of India. IOP Conf. Ser.: Earth Environ. Sci. 30, 012011. https://doi.org/10.1088/1755-1315/30/1/012011

Witts, D., Davies, L., Morley, R.J., Anderson, L., 2016. Neogene Deformation of East Kalimantan:A Regional Perspective, in: Proc. Indonesian Petrol. Assoc., 39th Ann. Conv. Presented at the Thirty-Ninth Annual Convention, Indonesian Petroleum Association (IPA). https://doi.org/10.29118/IPA.0.15.G.246

Yalcin, A., 2007. The effects of clay on landslides: A case study. Applied Clay Science 38, 77–85. https://doi.org/10.1016/j.clay.2007.01.007

Yamagishi, H., Iwahashi, J., 2007. Comparison between the two triggered landslides in Mid-Niigata, Japan by July 13 heavy rainfall and October 23 intensive earthquakes in 2004. Landslides 4, 389–397. https://doi.org/10.1007/s10346-007-0093-0

Yu, X., Zhang, K., Song, Y., Jiang, W., Zhou, J., 2021. Study on landslide susceptibility mapping based on rock–soil characteristic factors. Sci Rep 11, 15476. https://doi.org/10.1038/s41598-021-94936-5

Yulianto, T., Suripin, S., Purnaweni, H., 2019. Zoning landslide vulnerable area according to geological structure, slopes, and landuse parameters In Trangkil Sukorejo Gunungpati Semarang City's Residental Area. J. Phys.: Conf. Ser. 1217, 012029. https://doi.org/10.1088/1742-6596/1217/1/012029