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Simulation Model for Rainfall Intensity to Landslide Susceptibility (Case Study in Kota Wisata Batu, East Java)

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Abstract

Landslides are one of the most hazardous natural disasters because their occurrences are often destructive to natural and artificial structures on earth and reduce, the quality of the surrounding environment. Predicting the susceptibility of an area to landslides is essential for reducing losses in terms of property, human lives, and environmental damages. Kota Wisata Batu (KWB) is one of areas which having a highest landslide potential in East Java, Indonesia, recording data mentioned that there are 109 landslides in 2022 caused by highest rainfall intensity of 502 mm with a number of intensities of 2977mm per year. Study purposed to identify the factors contributing to landslide occurrences using a geodetic measurement method. The study uses geographic information system (GIS) and PRISMA software analyses to examine and/ or evaluate the relationship between rainfall intensity and landslide susceptibility. The study results the generation of rainfall patterns and maps highlighting sensitivity areas to landslides. These visual representations the classification area as a high-risk and susceptibility zone to landslides at Kota Wisata Batu, East Java. January to April, and August to November should have pay attention since these months is reflection of monsoonal climate with the hard rain in a few days without the raining pause. Some places which are required to pay attention, such as: Gunungsari, Tulungrejo, and Songgokerto.

Keywords: *Landslide, Geographic Information System, Rainfall Simulation Patterns, Sensitivity Maps, Susceptibility Zone*.

Abstrak

Tanah longsor merupakan salah satu bencana alam yang paling berbahaya karena kejadiannya seringkali merusak struktur alam dan buatan di muka bumi, serta menurunkan kualitas lingkungan sekitar. Prediksi kerentanan suatu daerah terhadap tanah longsor sangat penting untuk mengurangi kerugian baik harta benda, nyawa manusia, dan kerusakan lingkungan. Kota Wisata Batu (KWB) merupakan salah satu daerah yang memiliki potensi longsor tertinggi di Jawa Timur, Indonesia, data rekaman menyebutkan terdapat 109 kejadian longsor pada tahun 2022 yang disebabkan oleh intensitas curah hujan tertinggi sebesar 502 mm dengan jumlah intensitas curah hujan sebesar 2977 mm per tahun. Penelitian ini bertujuan untuk mengidentifikasi faktor-faktor curah hujan yang berkontribusi terhadap kejadian tanah longsor dengan menggunakan suatu metode pengukuran geodesi. Kajian ini menggunakan analisis-analisis dengan sistem informasi geografis (GIS) dan *software* PRISMA untuk mengkaji dan mengevaluasi hubungan antara intensitas curah hujan dan/ atau kerentanan tanah longsor. Studi ini menghasilkan pola curah hujan dan peta yang menyoroti daerah sensitif terhadap tanah longsor. Visual tersebut menggambarkan wilayah klasifikasi sebagai zona risiko tinggi dan kerentanan terhadap bencana tanah longsor Kota Wisata Batu, Jawa Timur. Bulan Januari hingga April, dan Agustus hingga November patut mendapat perhatian karena bulan-bulan ini merupakan cerminan iklim muson dengan curah hujan yang deras dalam beberapa hari tanpa jeda. Beberapa tempat yang wajib diwaspadai seperti: Gunungsari, Tulungrejo, dan Songgokerto.

Kata kunci: Tanah Longsor, Sistem Informasi Geografis, Pola Simulasi Curah Hujan, Peta Sensitivitas, Zona Kerentanan.

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1. Introduction

Landslides pose a significant risk worldwide, causing numerous fatalities and substantial damage each year [1]. It is often triggered by natural disasters such as heavy storms, earthquakes, and volcanic eruptions [2,3]. Different types of landslides, including rockfalls, slope failures, mudflows, and debris flows, can occur due to various factors, including weather conditions, human activities, and other considerations. Landslides are significantly associated with the slope gradient, the moisture content of the subsoil, and climatic conditions caused by the increasing of soil water content, the heavy rain is a triggered to change of soil volume which causes the lateral soil movement to the toe of slope.

In past few years, Kota Wisata Batu (KWB) or Tourism Batu City has been recorded as an exclusion zones for landslides in East Java, Indonesia classified from small to large scale. In accordance with Batu City Regional Disaster Management Agency (or Badan Penanggulangan Bencana Daerah, BPBD) Kota Batu, the number of landslide disaster has rapidly increased in every year [4,5] approximately 77 landslides occurred between January and early April 2023. One of the biggest disasters in KWB is the landslides with 27 incidents especially during 2018 which indicates that KWB is one of susceptible areaa for landslide in East Java Province [6] after Pacitan region, etc.

All incidents of landslide have affected the geomorphology changes, damage to the infrastructure and loss of life in the surrounding areas. Therefore, it is essential to accurately identify the potential areas and magnitude of slope failures to effectively understand and mitigate future landslide events [7,8]. A comprehensive interpretation is required to assess some factors and size of landslide. Therefore, implementation of landslide monitoring is importantly conducted in prediction some efforts and in stabilizing of soil layers leading to landslides problem. Landslide investigation requires high-resolution spatial information on top of soil layer types, terrain contour, hydrological conditions, and geotechnical parameter for mapping activity, detection performance, monitoring intervention, analyses processing, and anticipation of landslides [9,10]. Besides that, the systematic literature review of landslide study is necessary to identify the specific factors and monitoring system in anticipation of landslides. This study focuses a data processing in monitoring currently and for the past years based on the literature review in determining the potential of landslide phenomena at some certain locations of KWB.

2. Material and method

In order to identify the factors of landslide occurrence and to analyze the landslide monitoring solution, the materials and methods were discussed in this section.

2.1 Study area

Batu City is a city in East Java Province, Indonesia that has a land area of 202,800 km². Batu City is situated within the geographic coordinates of 122° 17'-122° 57' East Longitude and 7° 44'-8° 26' South Latitude [11]. The city is divided into three districts and twenty-three villages or sub-districts, namely Bumiaji, Batu and Junrejo. Batu City is located in a hilly zone, surrounded by the several mountains, such as: Gunung Panderman (2010 m), Gunung Welirang (3156 m), and Gunung Arjuno (3339 m) [12]. Recently, KWB has emerged as a well-place for tourism activities. This city has been famous for domestic and international tourists. The areas have been selected as a study area for landslide potential frequently which hit to these regions [13].

2.2 Previous study

Several guidance such as: proceeding and journal articles, reports from the KWB government has completed this study. The technical review uses the publishing 2012 to 2023 [14 to 17], and Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guideline is followed to identify all the reasons for landslide occurrence in KWB. A GIS-based landslide hazard mapping system in Batu City has been proposed. The method used is the SMART (Simple Multi Attribute Rating Technique) method to determine the status level of susceptibility areas. However, this research [18] is far from sufficient, it only maps the locations of the slides, without considering technical aspects, only for Information Technology (IT) needs. This research will use the geomatic or geospatial data which help map in all conditions of the local area under study, including: contour conditions; land use conditions; etc.

2.3 Analysis of geographic information system (GIS)

GIS is a powerful tool that enables the integration of diverse data sets at specific geographic locations, facilitating their analysis and visualization through mapping [19, 20]. The analytical method used by QGIS one of software from GIS method is in the mapping system. QGIS software is used to map utilizing scoring and overlay techniques. Process involved collecting, integrating, preprocessing, and visualizing actual data to the study [21]. Rainfall and landslide occurrence data is employed and developed in this study. Collection data is used to carry out the scoring process and overlap to result a total score representing the landslide susceptibility.

2.4 Collection data

There are two types of data used in this study, such as: rainfall data obtained from the Badan Meteorologi, Klimatologi dan Geofisika (BMKG) of KWB, as shown as Table 1, and landslide potential data obtained from the Badan Penanggulangan Bencana Daerah (BPBD) of KWB as shown as Table 2 during 2022.

3. Results and discussion

Firstly, this section focuses on the discussion of data analysis and the result in the research study. The result is presented through descriptive analysis, which is a statistical method used to summarize and describe the main feature, and the findings from this analysis are then collected in the form of tables. Secondly, the result for

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GIS analysis is visually displayed through Quantum GIS (QGIS) maps, bar charts and graphs. It operates on multiple platforms and offers a wide range of capabilities, including the visualization, editing, printing, and analysis of geospatial data, as well as the previous data of geospatial information [22]. Both analyses were used to establish correlations and proposed solutions [23].

3.1 Some factors of landslide potential

Previous literature reviews have identified five articles that discuss the factors contributing to landslides in KWB. A summary of these studies can be found in Table 3, which provides an overview of the factors associated with landslide occurrences in KWB. The result shows that within the array of factors, rainfall stands out as the predominant contributor to landslides in the region. Therefore, the focus of this study is to examine the important main role of rainfall data specifically as the primary factors to landslide potential. Rainfall has been playing in important role for some parts area of KWB.

Table 1. Rainfall data 2022

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall Intensity (mm)	304	349	394	416	34	229	0	55	84	291	501	320

Table 2. Landslide potential data in 2022

Location	Number of landslides
Pandanrejo	2
Bumiaji	2
Bulukert	2
Gunungsari	20
Punten	8
Tulungrejo	16
Sumbergondo	3
Giripurno	3
Sumber Brantas	7
Oro-oro Ombo	1
Temas	9
Sisir	4
Ngaglik	0
Pesanggrahan	0
Songgokerto	15
Sumberejo	0
Sidomulyo	1
Tlekung	0
Junrejo	1
Mojorejo	1
Torongrejo	6
Beji	1
Pendem	0
Dadaprejo	7

3.2 Landslide monitoring solution

The study focused on analysing analyzing a landslide monitoring solution application using Quantum Geographic Information System (QGIS). To address the ongoing monitoring the landslide issues susceptibility in the area study, the study utilizes the software QGIS) as a monitoring tool to analyze and to recognize the rainfall patterns. The study aimed to visualize this information on a geographic map, providing a clear representation of the high-risk or susceptibility areas at some areas focussed in Kota Wisata Batu zone.

3.3 Rainfall intensity analysis using QGIS

The rainfall intensity map generated by QGIS in the Batu City area is plotted in Figure 1. The map classifies the rainfall intensity based on a scale ranging from 0 mm to

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501mm representing the lowest and highest values, respectively. An analysis of the data reveals the rainfall intensity for each month in 2022. Figure 2 shows a graph illustrating the monthly variation in rainfall intensity during the year 2022. The graph reveals interesting trends and patterns in the rainfall data. The graph demonstrates that the rainfall intensity changes during 2022 in every month over the course of the year. Furthermore, the slope of hilly zone is more stable during dry season than rainy season. This software can simulate on a geographic map the rainfall patterns entire of the study area.

Figure 2 shows a graph illustrating the monthly variation in rainfall intensity during the year 2022. The graph reveals interesting trends and patterns in the rainfall data. The graph demonstrates that the rainfall intensity changes during 2022 in every month year. From January to April, rainfall tends to increase until 416 mm, but the rainfall become minimum reaching 34 mm in May. After May, the rainfall fluctuates during June and July, 229 m and 0.0 mm, respectively. Then, during 4 months or between August to November, the rainfall raises again until 501 mm, tends to decrease until 320 mm in December of every year without the raining pause. This pattern would increase the sliding potential at this area.

Table 3. Summary of new previous study of landslide potential factors in KWB in the last 2 years

No.	Author	Year	Article	Factor	Summary
1.	Firdaus & Sukojo	2015	Pemetaan Daerah Rawan Longsor Metode	rainfall, geological condition, soil condition human activities	The findings of their research were visualized in a map which illustrates a rainfall map generated from the data from the year 2012-2023. The study revealed that the average annual rainfall in Batu City during that period varied between 1500-2343 mm. These rainfall values indicate a moderate climate type for Batu City, with the highest amount of rainfall observed in the northern region, particularly in Bumiaji District. There are three types of soil in the Batu City area namely andosol, grumosol, and mediterranean. The majority of Batu City has grumosol soil (form from limestone and volcanic tuffa).
3.	Agung et al.	2023	Compilation of Parameter Control for Mapping the Potential Landslide Areas.	rainfall, geological condition	Over a 20-year observation period, Sumberbrantas and Tulungrejo Village experienced annual rainfall intensities ranging from 875 to 3000 mm and wet days from 110 to 134 days. Rainfall runoff is linked to land slope, which can lead to landslip zones and dangers on access roads. The two formations, Old anjasmara Volvanics (Qpat) and Upper Quarter Volcanic formation are in at Trunojoyo and Songgokerto village. Songgokerto had a 7.7% land slope area in Batu City, with over 40% of the area having an access road.

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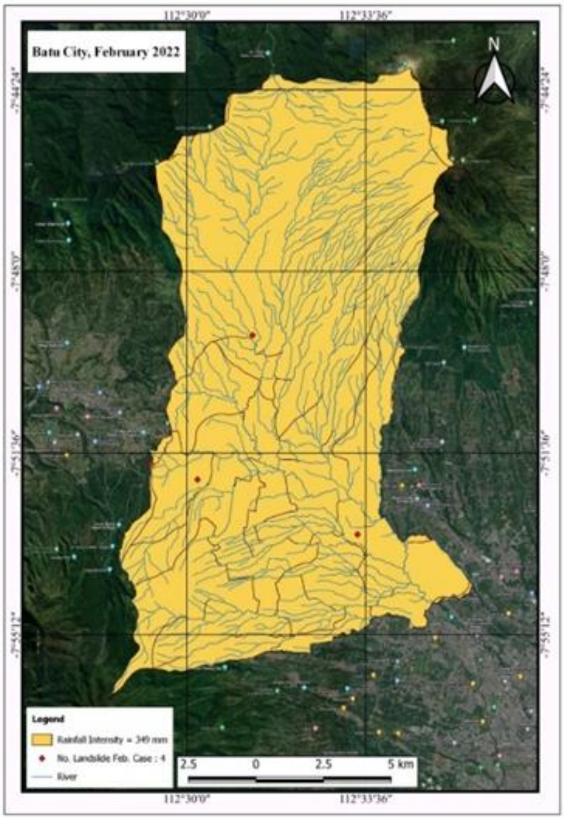

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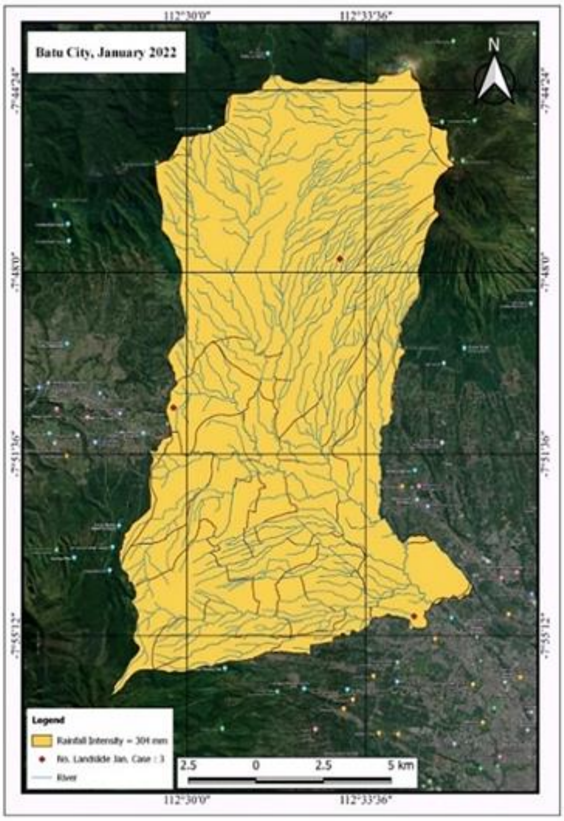

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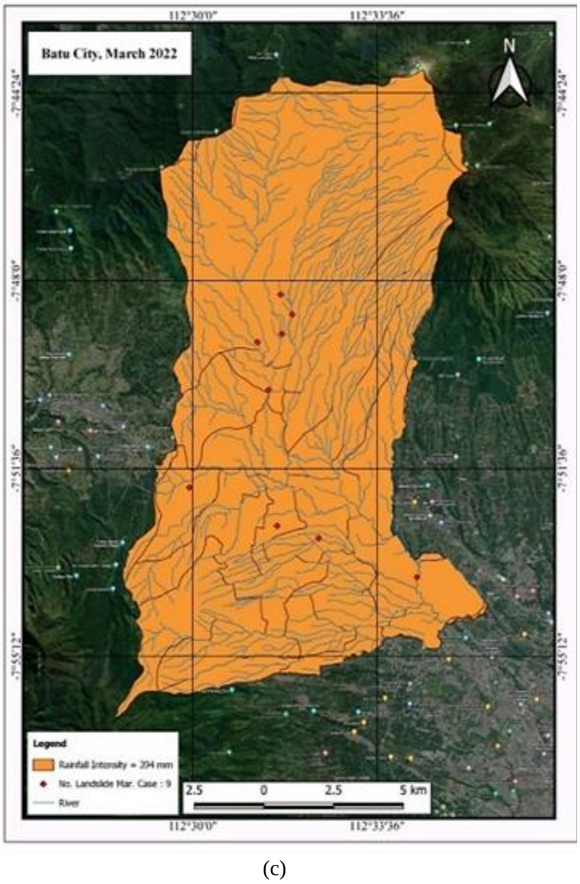

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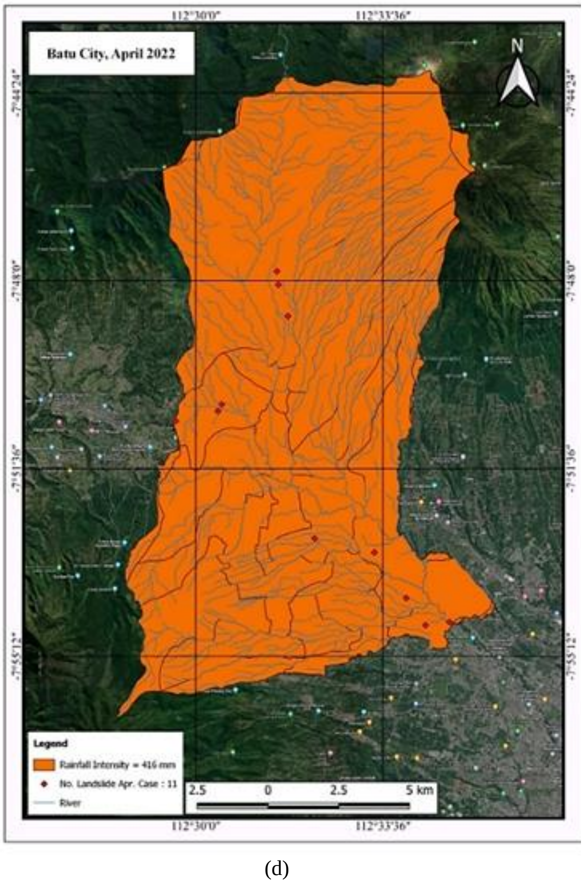

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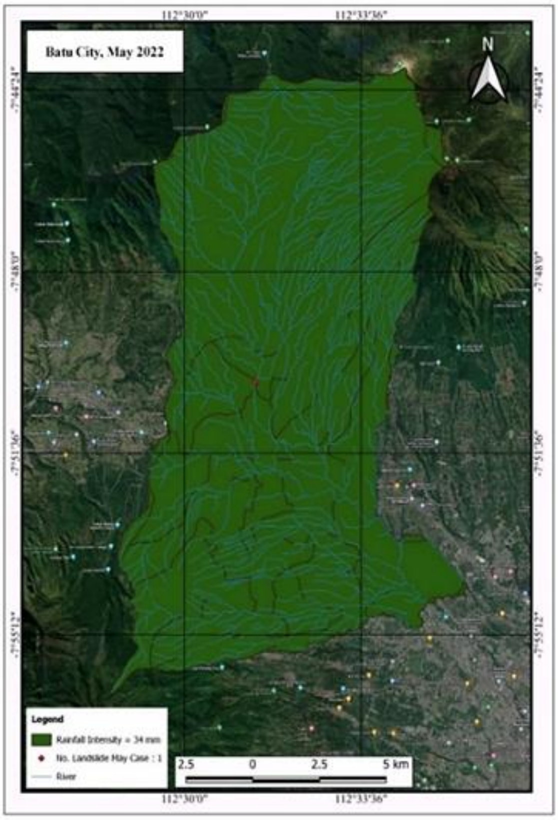

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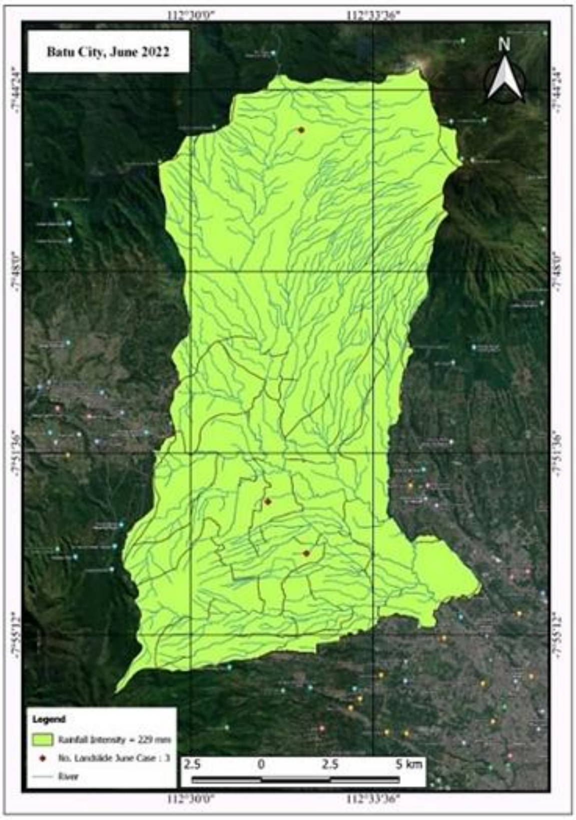

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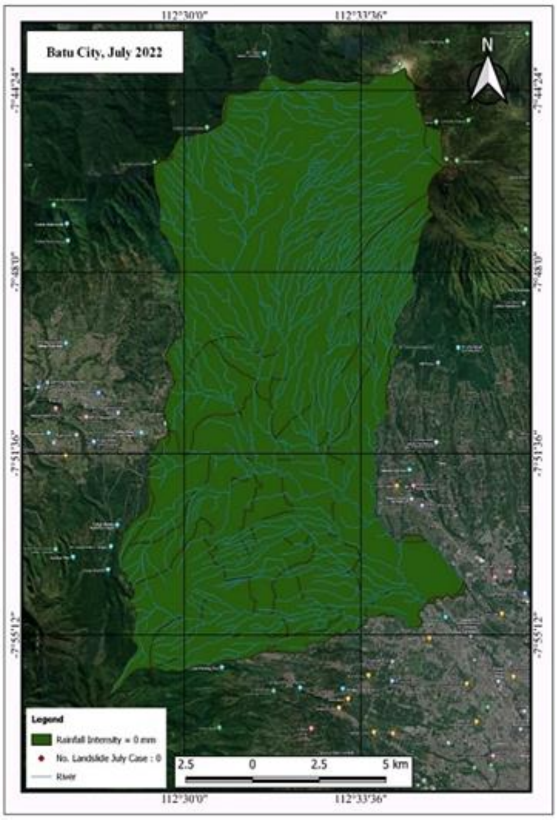

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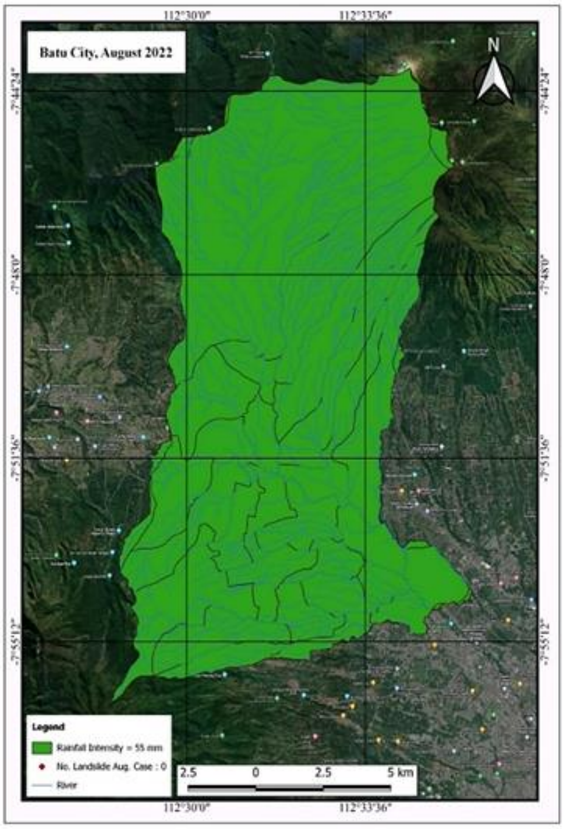

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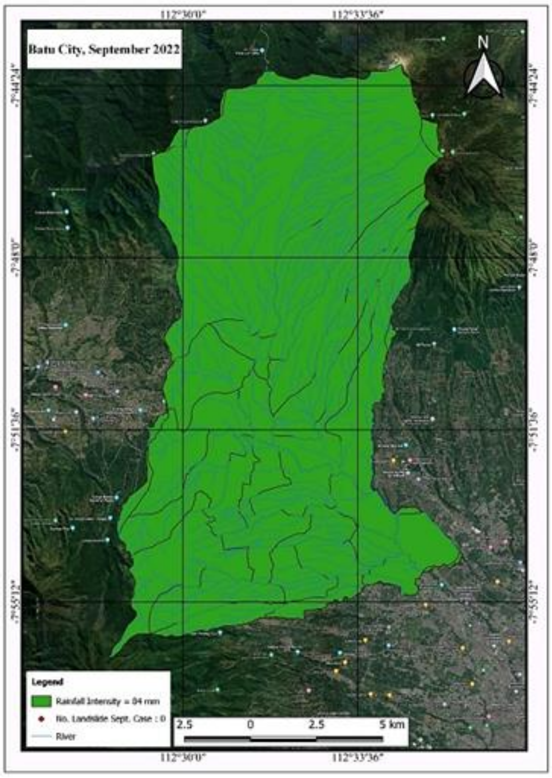

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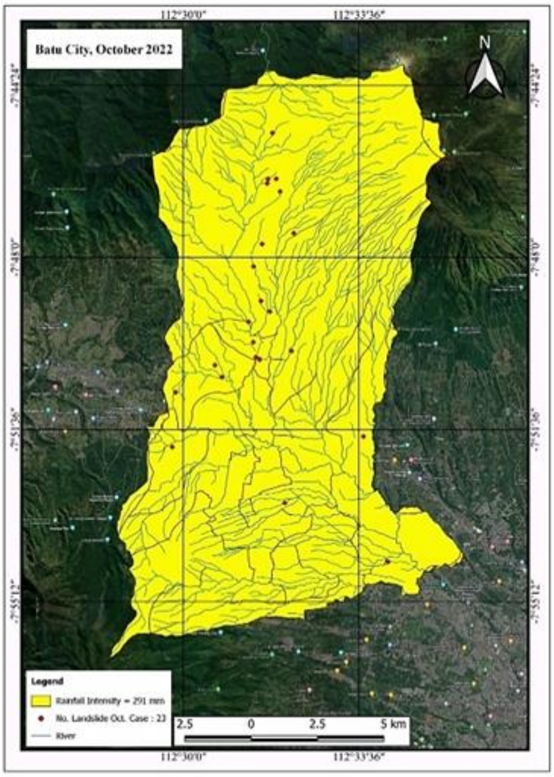

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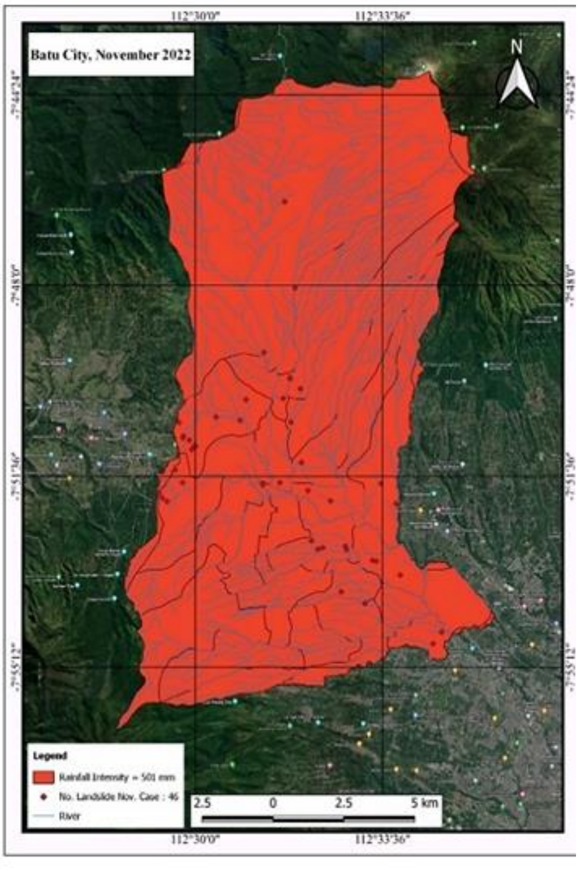

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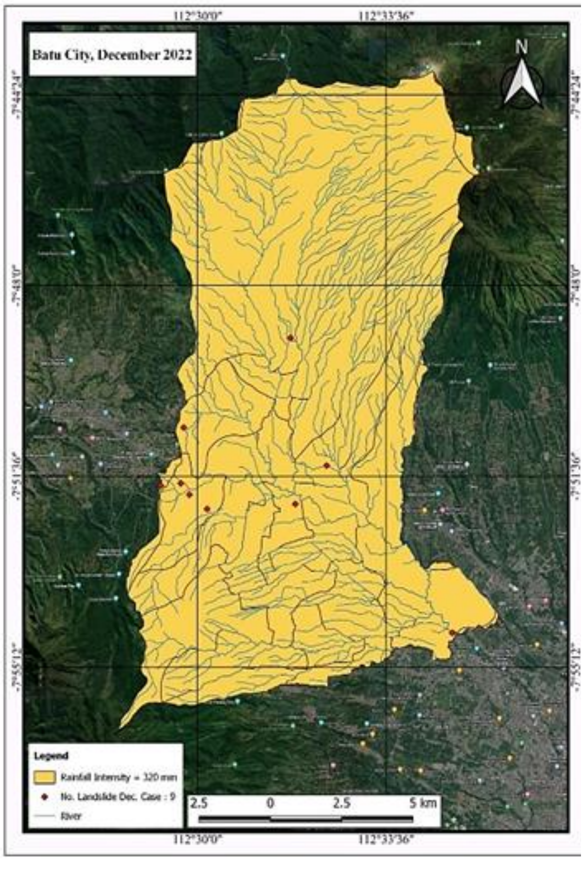

(l)

Figure 1: Rainfall Intensity Map of Batu City for 2022: (a) January, (b) February, (c) March, (d) April, (e) May (f) Jun, (g) July, (h) August, (i) September, (j) October, (k) November, (l) December

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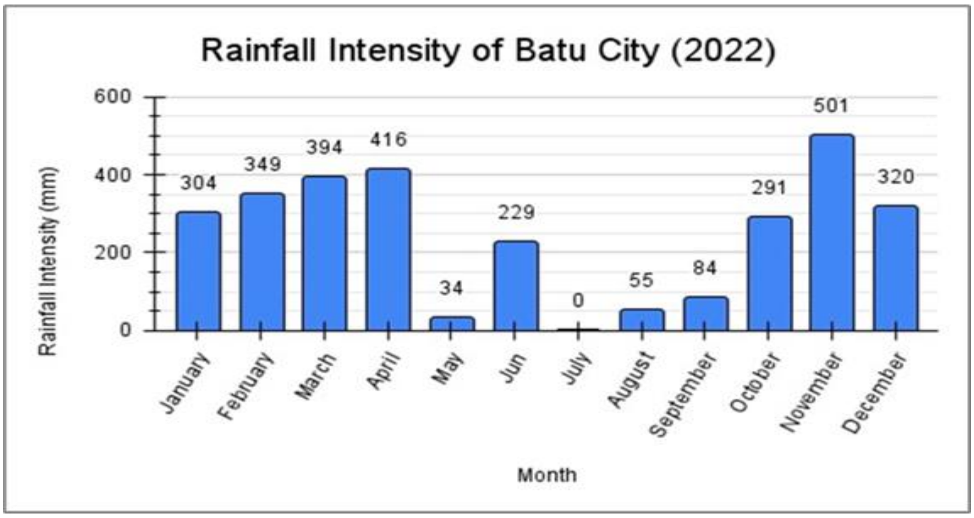

Figure 2. Rainfall Intensity value of Batu City according to each month of 2022

3.4 Landslide susceptibility analysis using QGIS.
The landslide susceptibility map for the Batu City area, generated using QGIS and plotted in Figure 4, the classification of landslide susceptibility illustrates the values on a scale ranging from 0 to 20 landslide cases. This scale represents the lowest and highest values, respectively, indicating the variation of degrees of susceptibility to landslides. An analysis of the data from 2022 provides the frequency and distribution of landslide potential of the region. The result indicates that nearly every village in KWB has susceptibility potential to landslides. A total of 109 landslide cases were reported during 2022 and has a significant impact to the existing area. However, the susceptibility map also shows some variations in landslide potential at the other locations. Gunungsari area could be as the area with the highest landslide potential based on the susceptibility value. The other locations, such as: Tulungrejo and Songgokerto exhibit relatively high landslide potential as well and high susceptibility to this natural disaster using QGIS analysis software.

Figure 3 presents a bar graph plotting results of the number of landslide occurrences potential in each village within Batu City during the year of 2022. The bar graphic model indicates graphically that Gunungsari, Tulungrejo, and Songgokerto had the highest number of landslides incidents with 20, 16, and 15 reported cases from BPBD of KWB, respectively.

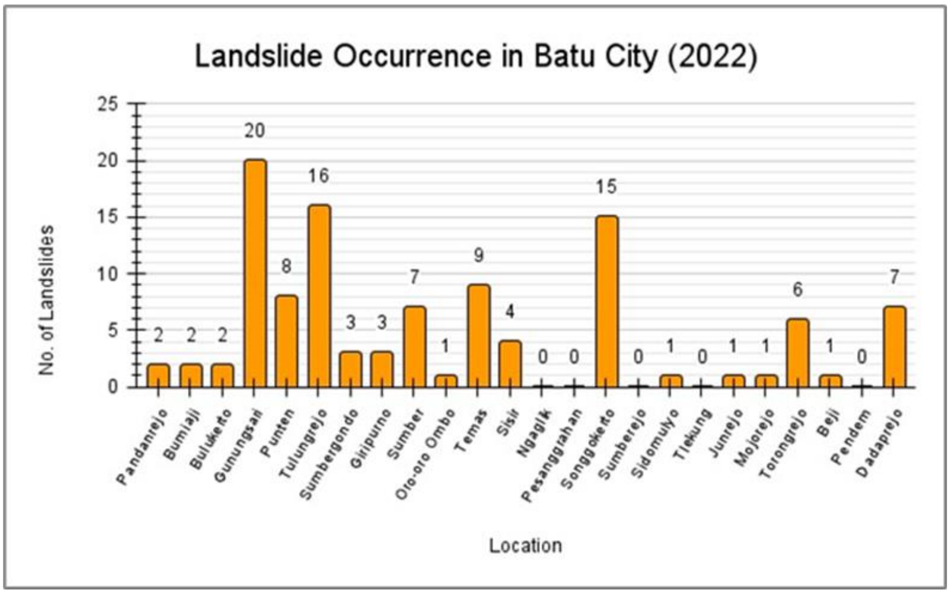

Figure 3. Number of landslide incident in KWB during 2022

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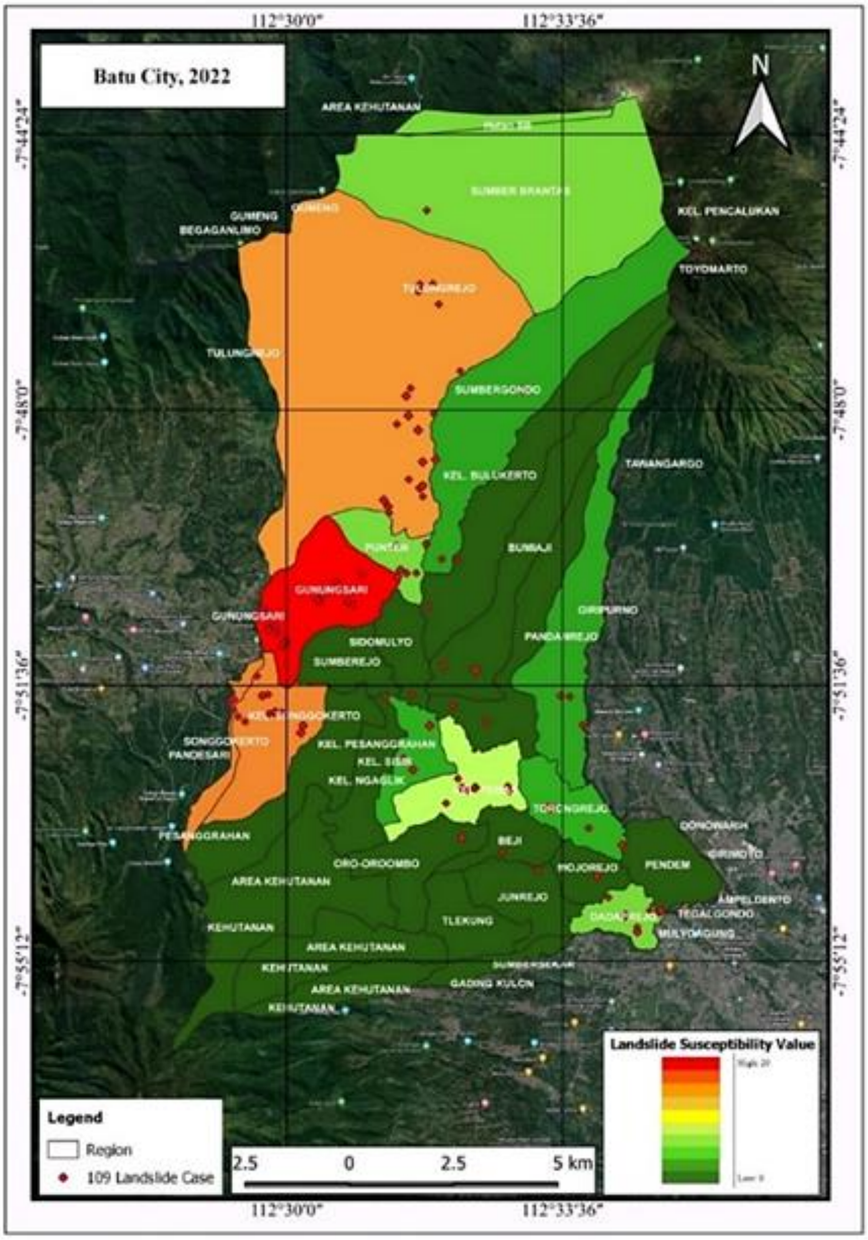

Figure 4. Landslide susceptibility map during 2022 in KWB

3.5 Correlation between rainfall intensity and landslide incidents

The correlation between rainfall intensity and landslide incidents shows in KWB. Figure 5 shows the data indicates that higher rainfall intensities tend to raise landslide occurrences incidents. The highest rainfall intensity of 501mm in November correlates with the highest number of landslide cases of 46 incidents reported by BPBD of KWB and some local multimedia. The relationship between rainfall intensity and landslide occurrence can be explained by the impact of heavy rainfall or precipitation on the stability of slopes and the soil susceptibility condition. Indonesia is not only having tropical climate, but also has the difference significant for rainy and dry seasons including KWB area. During the dry season without rainfall, such as: July, August, and September, the number of landslide incidents become smaller. The rainfall intensity, topographical, geological, geophysical, geotechnical aspect for soil condition, pore water pressure and human activities are some important triggers to the landslide incident in KWB. Some comprehensive studies should be conducted to monitor every ground movement causing the landside.

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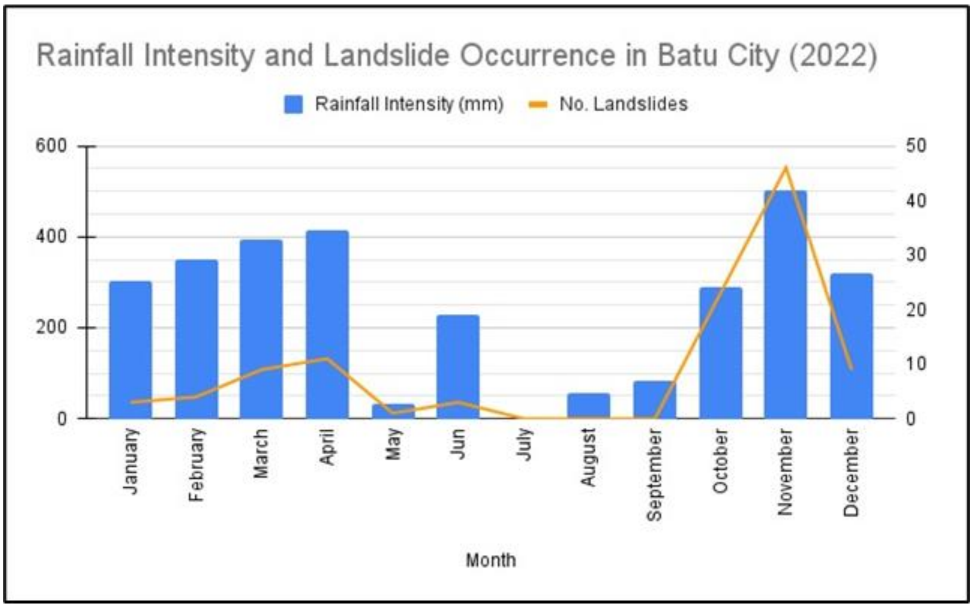

Figure 5. The relationship between rainfall intensity and landslide incidents in Batu city during 2022

Rainfall is one of the triggers for ground movement [24], water surface due to rainfall would enter the soil layers and accumulate along the landslide plane, thereby reducing effective stress and reducing the shear strength of the soil [25]. Most landslide disasters in Indonesia are influenced by climatic conditions with quite high rainfall [26]. Rainfall was also the most common trigger factor for the initiation and reactivation of translational landslides at study area [27]. High rainfall conditions resulted seepage process into the shear plane fractures in landslides, thus increasing pore water pressure and reducing the effective shear resistance of the sliding surface [28], furthermore the seepage due to rain fall would cause acceleration of movement [29]. Depth and surface geometry of soil cracks was very important in determining safety factor of slope stability analysis and estimating the possibility of landslides [30].

Landslide mechanism at study area was also influenced by the soil material in the top layer, the geometry of the bedrock, and the water content below the surface [31]. Steep slope conditions could also trigger the intensity of landslides due to low soil stability [32]. The process of landslides begins with water infiltration into the soil which increases the weight of the soil. If the water penetrates to the impermeable soil layer which functions as a sliding surface, the weathered soil above will move along the slope and leave its initial condition.

4. Conclusion and discussion

This research study was to identify the factors contributing to landslide incidents and to analyze the potential of landslide. The factors identified as common contributors to landslides incidents were rainfall, geological conditions, soil conditions, and human activities. Rainfall is the main factor associated with frequency level of landslide incidents in KWB. The results concluded that the heavy rainfall plays the important role in slope sliding in KWB, beside the other factors, such as: the geological, soil condition, and human activity factor. The months to be careful is between January to April, and August to November. These months is reflection of monsoonal climate with the hard rain for some time. Some places which are required to pay attention, such as: Gunungsari, Tulungrejo, and Songgokerto.

It would be also concluded from this study that some risk assessments were required to make landslide susceptibility map, a potential of slope sliding was depended on input and output of physical and mechanical properties of soil layers. In this study was found that collapse or landslide process was caused by two components, such as: increasing and/ or reducing of shear stress. Increasing of shear stress on slopes could be caused by several things, such as:

1. Additional loadings to the slope, such as building infrastructures, reservoir structures from natural or manmade, rock layers compressing the slope zone and additional of soil filling to increase embankments height at top of the slope.
2. Elimination of structural reinforcement or vegetation due to cutting process and material movements of the slope toe, or structure failure behind the slope.
3. Alteration of groundwater table on slopes or sudden drawdown.
4. Lateral force from an earthquake which could push the soil block in a horizontal direction.

Reducing of shear strength could be caused by several factors, such as:

1. Increasing of pore water pressure due to water infiltration into slopes, uncontrolled water discharge in drainage channels, or earthquakes resulting in increasing process of pore water pressure.

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2. A potential of swelling-shrinkage at soil layer of the slope, so the soil layers could be easily to absorb water, but it could remove the soil cohesion.
3. Physical-chemical weathering and degradation due to ion exchange, hydrolysis processes, salting.
4. Gradual failure occurred due to shear strain softening phenomena of soil layers.

Some other conclusions from this study found that some important data required as input for landslide maps including:

i. Transmissivity or seepage potential at the slope (m^2/hr) (is the rate at which groundwater flows horizontally through the aquifer layer or soil).
ii. Void ratio and/ or porosity of soil grains (fraction of voids per unit volume).
iii. Potential of outlet discharge (m^3/s) (the amount of discharge that crosses part of area in unit time).
iv. Catchment area of rainfall potential (m^2).

This study also concluded that the model of susceptibility map requires the following important of soil data parameter:

i. Soil cohesion (in kPa).
ii. Angle of internal friction (in degrees or (^{o})).
iii. Initial of weight volume weight (kN/m^3).
iv. Dry and wet soil volume weight (kN/m^3).
v. Depth of soil elements from ground surface (m).

The final input parameter is vegetation of root cohesion (kPa). Classification of landslide areas were required to susceptibility analysis, such as: slopes at river bends; slope at bay area; slope at fault areas, slope at near earthquake vibration etc. Potential landslide zones were sensitive to landslides according to the terrain conditions and geological conditions due to external disturbances, natural and human activities. Based on hydrogeomorphology, it could be divided into three types of zones based on Indonesia Regulation of PUPR (2007) [33], namely: type A of slope zone where the slope > 40%, with an altitude above 2000 meters above the mean sea level (MSL); type B of slope zone where the slope between 21% - 40%, height 500 - 2000 meters of MSL); type C of slope zone where the slope between 0% - 20%, with a height of 0 - 500 meters of MSL).

Mapping process was carried out using scoring and overlay methods with QGIS software. In this study, the parameters used were rainfall, rock type, gradient of slope, land cover and soil type [34]. The scoring and quality data were then overlaid to produce a total score which was the value of the level of landslide susceptibility. The greater the total score, the higher level of susceptibility. Results of the analysis obtained from this research was a map of the landslide susceptibility level of Batu Tourism City (KWB), which was divided into 4 classes, such as: low, medium, high, and very high based on the total score. Utilizing QGIS applications in mapping landslide susceptibility could simplify analysis work and shorten time and costs. The estimation model used the parameters causing the landslides, such as: rainfall, rock type, slope gradient, land covering and soil type.

The QGIS (quantum geographic informatic system) system could have the ability to connect various data at a certain point on the earth in combining and analyzing and finally, a susceptibility map as the results. The data that would be processed in QGIS is spatial data, namely data that was geographically oriented and was a location that had a certain coordinate system, as a reference basis. The utilization of GIS and/ or QGIS as a monitoring solution facilitated the generation of rainfall patterns and maps indicating areas suscept to landslides [35]. By plotting rainfall patterns and landslide incidents together in one map, the public could identify high-risk areas and avoid the landslides disaster. The QGIS was suitable to make the early warning system at the study area [36].

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References

[1] Abedin, J., Rabby, Y. W., Hasan, I., & Akter, H. An investigation of the characteristics, causes, and consequences of June 13, 2017, landslides in Rangamati District Bangladesh. *Geoenvironmental Disasters, Vol 7, No. 1*, pp. 1-19. 2020.

[2] Skilodimou, H. D., Bathrellos, G. D., Koskeridou, E., Soukis, K., & Rozos, D. Physical and anthropogenic factors related to landslide activity in the northern Peloponnese, Greece. *Land, Vol. 7, No. 85*, pp. 2-18. 2018.

[3] Bozzano, F.; Cipriani, I.; Mazzanti, P.; Prestininzi, A. Displacement patterns of a landslide affected by human activities: Insights from ground-based InSAR monitoring. *Nat. Hazards, Vol. 59,* pp. 1377–1396. 2011.

[4] Kriswibowo, R., Ramdani, F., & Aknuranda, I.. Exploring the role of geospatial technology in disaster management of Batu City: Qualitative analysis using RQDA method. *Journal of Information Technology and Computer Science, Vol. 6, No. 1*, 80–95. 2021.

[5] Muhammad Fathur Rouf Hasan, Putera Agung Maha Agung, Adi Susilo, Eko Andi Suryo, Adnan Bin Zainorabidin, Andrias Rudi Hermawan. Wedge Slope Failure of Natural Sedimentary Rock Formation Based on Weathering Potential. *International Journal of Design & Nature and Ecodynamics Vol. 19, No. 2*, pp. 387-396. 2024.

[6] Siswahyudi, P., Ramdani, F., & Bachtiar, F. A. Evaluating Conceptual Framework for Landslides Natural Disaster Management using Feature Analysis. *Journal of Information Technology and*

Computer Science, Vol. 4, No. 3, pp. 241–252. 2019.

[7] Davies, T. *Landslide Hazards, Risks, and Disasters: Introduction. LandslideHazards, Risks, and Disasters*. Elsevier Inc, 473 p. 2015.

[8] Putera Agung Maha Agung, Mustaffa Anjang Ahmad, Muhammad Fathur Rouf Hasan. Probability Liquefaction on Silty Sand Layer on Central Jakarta. *International Journal of Integrated Engineering, Vol. 14, No. 9*, pp. 48-55. 2022.

[9] Dou, J., Bui, D. T., Yunus, A. P., Jia, K., Song, X., Revhaug, I., Xia, H., & Zhu, Z. Optimization of causative factors for landslide susceptibility evaluation using remote sensing and GIS data in parts of Niigata, Japan. PLoS ONE, Vol. 10, No. 7, pp. 1-29. 2015.

[10] Putera Agung Maha Agung, Ramlan Sultan, Muhammad Idris, Agus Tugas Sudjianto, Mustaffa Anjang Ahmad, Muhammad Fathur Rouf Hasan. Probabilistic of in Situ Seismic Soil Liquefaction Potential Based on CPT-Data in Central Jakarta, Indonesia. *International Journal of Sustainable Construction Engineering and Technology, Vol. 14, No. 1*, pp. 241-248. 2023.

[11] Hartono, R. Landsat 7 Imagery Interpretation for Mapping Potential Hazard of Landslide in Batu City Area of East Java Province, Indonesia. *ICGE Vol. 79*, pp. 24–27. 2017.

[12] Firdaus, H. S., & Sukojo, B. M. Pemetaan Daerah Rawan Longsor dengan Metode Penginderaan Jauh dan Operasi Berbasis Spasial, Studi Kasus Kota Batu Jawa Timur. *Jurnal Geosaintek, Vol. 1, No. 1*, pp. 25-34. 2015.

[13] Suprapto, F. A., Juanda, B., Rustiadi, E., & Munibah, K. Study of Disaster Susceptibility and Economic Vulnerability to Strengthen Disaster Risk Reduction. *Land, Vol 11*, pp. 1-23. 2022.

[14] Zhou, X. P. & Cheng, H. Analysis of stability of three-dimensional slopes using the rigorous limit equilibrium method. *Engineering, Geology Vol. 160*, 21–33. 2013.

[15] Mergili, M., Marchesini, I., Rossi, M., Fausto, G. & Fellin, W. F. Spatially distributed three-dimensional slope stability modelling in a raster GIS. *Geomorphology Vol. 206*, pp. 178–195. 2014.

[16] Liu, S. Y., Shao, L. T. & Li, H. J. Slope stability analysis using the limit equilibrium method and two finite element methods. *Computers and Geotechnics, Vol. 63*, pp. 291–298. 2015.

[17] Mahato R, Bushi D, Nimasow G, Nimasow OD and Joshi RC. AHP and GIS-based delineation of groundwater potential of Papum Pare District of Arunachal Pradesh, India. *Journal of the Geological Society of India 98, Vol. 1*, pp. 102–112. 2022.

[18] Wang G, Zhao B, Wu B, Zhang C and Liu W Intelligent prediction of slope stability based on visual exploratory data analysis of 77 in situ cases. *International Journal of Mining Science and Technology, Vol. 33, No. 1*, pp. 47–59. 2023.

[19] Xianghui Jian. Slope visualisation and stability study using geographic information science. *Geotechnical Research, Emerald Publishing*, pp. 1-11. 2023.

[20] Lü, G., Batty, M., Strobl, J., Lin, H., Zhu, A. X., & Chen, M. Reflections and speculations on the progress in Geographic Information Systems (GIS): a geographic perspective. *International Journal of Geographical Information Science, Vol. 33, No. 2*, pp. 346–367. 2019.

[21] Süzen ML, Doyuran V. Data driven bivariate landslide susceptibility assessment using geographical information systems: a method and application to Asarsuyu catchment, *Turkey. Eng Geol. Vol. 71*, pp. 303–321.

[22] Chang, K. T. *Introduction to geographic information systems*, ninth edition (9th ed.). McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121, 464 p. 2018.

[23] Xie, M., Esaki, T., Zhou, G., & Mitani, Y. Geographic Information Systems-Based Three-Dimensional Critical Slope Stability Analysis and Landslide Hazard Assessment. *Journal of Geotechnical and Geoenvironmental Engineering, Vol. 129, No. 12*, pp. 1109–1118. 2003.

[24] Agung, P. A. M., Hasan, M. F. R., Susilo, A., Ahmad, M. A., Ahmad, M. J. Bin, Abdurrahman, U. A., Sudjianto, A. T., & Suryo, E. A. Compilation of Parameter Control for Mapping the Potential Landslide Areas. *Civil Engineering Journal, Vol. 9, No. 04*, pp. 974–989. 2023.

[25] M. Kamiński, P. Zientara, and M. Krawczyk. Electrical resistivity tomography and digital aerial photogrammetry in the research of the 'Bachledzki Hill' active landslide – in Podhale (Poland). *Eng. Geol., Vol. 285*, p. 106004. 2021.

[26] A. Salimah, M. F. R. Hasan, Suripto, Yelvi, and I. H. Sasongko. Analisis Stabilitas dan Perkuatan Lereng Menggunakan PLAXIS2D di Desa Sukaresmi, Sukabumi, Jawa Barat. *Jukung (Jurnal Tek. Lingkungan), Vol. 5, No. 2*, pp. 29–36. 2019.

[27] C. Ling, Q. Xu, Q. Zhang, J. Ran, and H. Lv, Application of Electrical Resistivity Tomography for Investigating the Internal Structure of A Translational Landslide and Characterizing its Groundwater Circulation (Kualiangzi Landslide, Southwest China). *J. Appl. Geophys., Vol. 131*, pp. 154–162. 2016.

[28] S. S. Uhlemann et al. Integrated time-lapse geoelectrical imaging of wetland hydrological processes. *Water Resour. Res., Vol. 52, No. 3*, pp. 1607–1625. 2016.

[29] A. Ramzani and A. N. Dehghan. A Geo-Electrical Study to Determine the Geometry of Landslide Using a Physically-Based Model. *Indian Geotech. J. 2021 522, Vol. 52, No. 2*, pp. 372–380. 2021.

[30] P. Imani, G. Tian, S. Hadiloo, and A. A. El-Raouf. Application of combined electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) methods to investigate Xiaoshan District landslide site: Hangzhou, China. *J. Appl. Geophys., Vol. 184,* p. 104236. 2021.

[31] S. Rezaei, I. Shooshpasha, and H. Rezaei. *Reconstruction of landslide model from ERT, geotechnical, and field data, Nargeschal landslide, Iran*. Bull. Eng. Geol. Environ, Vol. 78, No. 5, pp. 3223–3237. 2018.

[32] K. D. Priyono, Jumadi, S. Saputra, and V. N. Fikriyah. Risk Analysis of Landslide Impacts on Settlements in Karanganyar, Central Java, Indonesia. *Int. J. GEOMATE, Vol. 19, No. 73*, pp. 100–1007. 2020.

[33] Triutomo, B. M. *Pengenalan Karakteristik Bencana Dan Upaya Mitigasinya Di Indonesia edisi II*. Jakarta: Pelaksana Harian Badan Koordinasi Nasional Penanganan Bencana. 2007.

[34] Karnawati, D. *Mekanisme Gerakan Massa Batuan Akibat Gempabumi; Tinjauan dan Analisis Geologi Teknik*. Yogyakarta: Pascasarjana Universitas Gadjah Mada Jurusan Teknik Sipil dan Jurusn Teknik Geologi. 2007.

[35] Dewi, K. D. Evaluation of Land Use Change in the Upstream of Ciliwung Watershed to Ensure Sustainability of Water Resources. *Asian Journal of Water, Environment and Pollution, Vol 12, No 1*, pp. 11-19. 2015.

[36] Izhom, B. *Kerentanan Wilayah Tanah Longsor Di Daerah Aliran Cicatih, Kabupaten Sukabumi, Jawa Barat. Depok: Skripsi*, Fakultas Matematika dan Ilmu Pengetahuan Alam, Departemen Geografi. Universitas Indonesia. 2012.

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