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# HAZARD LEVEL AND RISK OF MOUNT MARAPI COLD LAVA FLOOD DISASTER BASED ON GEOGRAPHIC INFORMATION SYSTEM (GIS) IN TANAH DATAR REGENCY, WEST SUMATRA, INDONESIA

*Safiah @ Yusmah binti Muhammad Yusoff[1], Rahadhatul Aisy[2], Rosmadi bin Fauzi[1], Daniel Friess[3], Aprizon Putra[4]

[1]Department of Geography, Faculty of Arts and Social Sciences, Universiti Malaya
[2]Master of Geography Education, Faculty of Social Sciences, Universitas Negeri Padang
[3]Earth and Environmental Sciences, Tulane University
[4]National Research and Innovation Agency (BRIN) Indonesia
E-mail: dr.safiah@um.edu.my
rahadhatulaisy02042002@gmail.com

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**ABSTRACT:** Cold lava floods are a significant threat in the area around Mount Marapi, West Sumatra, Indonesia. Flows of volcanic material carried by rain after an eruption can cause major damage to settlements, farmland, and infrastructure. Geographic Information System (GIS) technology is a very effective tool to identify the level of danger and risk of this disaster. This article examines a GIS-based approach in the assessment of the hazards and risks of cold lava floods in Tanah Datar Regency. The mapping shows a flood path in the watershed from the slopes of Mount Marapi, with a high-risk area of 27,480 hectares within 300 meters of the riverbank. Risk analysis shows that low-risk areas include 6,889.28 hectares, medium-risk 8,496.71 hectares, and high-risk 3,999.63 hectares, spread across several sub-districts.

*Keywords: Cold Lava Flood. Mount Marapi. Danger. Risk*

## 1. INTRODUCTION

Mount Marapi in West Sumatra, Indonesia, is one of the most active volcanoes in the region, with a long history of eruptions that have caused various disasters, including cold lava floods [1-5]. Cold lava, which occurs when residual volcanic material such as ash, rocks, and gravel are carried away by rain, is one of the most significant threats to people living around mountain slopes and river valleys. Cold lava flows are often unpredictable, but they can cause major damage to infrastructure, farmland, and threaten life safety [6-11].

Flood lava is among the most severe natural disasters; it causes significant and irreversible damage to property and communication infrastructure, which leads to considerable loss of life [12-13]. Lahars are discrete, rapid, gravity-driven flows of one rated, high- concentration mixtures containing water and solid particles of rock, ice, wood, and other debris that originate from volcanoes [14]. Lahar is an Indonesian term that describes mudflows and debris flows originating from the slopes of volcanoes. Both types of flows contain a high concentration of rock debris, providing the internal strength necessary to transport large rocks, buildings, and bridges, as well as delivering very high impact forces to objects in their path [15]. Tanah Datar Regency, located at the foot of Mount Marapi, has historically been vulnerable to the danger of cold lava flooding due to its position on a river channel that carries the flow of volcanic material. Rainfall on deposits around the summit and slopes of the volcano can cause these deposits to become saturated and prone to landslides or collapse. Landslides of volcanic material, along with rainwater, flow into rivers on the slopes and summit of the volcano in the form of cold lahar flows, which may consist of mud or rock flows [16-20]. Marapi's continued volcanic activity makes it important to continuously monitor and analyze the potential risk of cold lava floods [21]. Cold lava floods occurred in Tanah Datar Regency on Saturday, May 11, 2024. Lahar floods are caused by various factors, including rainfall intensity, meteorological conditions, topography, human activity, and drainage. Lahars are among the most hazardous volcanic processes and are responsible for a large proportion of volcanic fatalities [22-25]. Human interventions, such as deforestation, sediment buildup, settlement in floodplains, dam construction, and poor urbanization, can increase flood risks [26]. Lahar

hazard assessments typically provide this information in the form of hazard maps quantifying the probability and extent of potential lahars to varying degrees [27-30]. This disaster affected five sub-districts in Tanah Datar Regency, namely X Koto District, Batipuah District, Pariangan District, Lima Kaum District, and Sungai Tarab District. As a result of the cold lava flood, there were 32 deaths, 10 missing victims, 7 people seriously injured, 43 severely damaged houses, 26 moderately damaged houses, 80 lightly damaged houses, 43 washed houses, 36 damaged bridges, 18 places of worship, 4 educational facilities, 59 trading facilities, 51 four-wheeled vehicle losses, The loss of two- wheeled vehicles was 119 units, horticultural land was 81.64 hectares, rice fields were 412, 511 hectares, irrigation was 155 units, livestock was 15,038 heads, and Pamsimas was 13 units. The destructive nature of lahars derives from their speed, reach, and composition and our difficulty in pre ducting (in the absence of warning systems) when they may occur [31-32].

This study refers to a number of international studies that have shown the effectiveness of GIS in handling volcanic disasters. For example, research by [15]. used the Digital Elevation Model (DEM) model to map the potential of lava flows and generate accurate hazard zoning in active volcanic regions. Furthermore, a study by [15-16]. highlighted the importance of hydrometeorological factors in lava formation, which allows GIS to be used in predicting when and where lava flows will occur based on rainfall data. Another study by [25]. examined lava flows in Mount Pinatubo, Philippines, and developed GIS-based hazard zoning that has helped local governments in mitigating the impact of recurring lava disasters.

The risk is calculated by considering not only physical hazards but also socio-economic aspects, such as population density, infrastructure value, and distance from lava flow paths. These risk factors fit into the framework proposed by (Alexander 2002), which emphasizes the importance of combining social and physical aspects in disaster risk analysis. Data analysis was carried out using ArcGIS applications with scoring and overlay methods to produce risk maps classified into high, medium, and low categories [27].

## 2. METHODS

This study uses a quantitative descriptive method to objectively describe the level of danger and risk of cold lava flooding of Mount Marapi. The research location is in seven sub-districts in Tanah Datar Regency, which is located within a radius of 7 km from Mount Marapi. The research was conducted from February to April 2024. The data used in this study includes topographic maps, rainfall data, and historical data of the eruption of Mount Marapi. The Digital Elevation Model (DEM) is used to identify mountain slopes and river flow paths [31-32]. Annual rainfall and distribution of volcanic material were also analyzed to understand the potential for cold lava flooding [30]. This study refers to the study of Iverson et al. 1997), which emphasized the importance of using DEM in lava flow modeling to map the flow path of volcanic materials and associated disaster risks. In this study, a spatial analysis was performed to determine the hazard zone, where cold lava flow paths and potential infrastructure damage were mapped in detail using the GIS technique [32]. In addition, this hazard and risk assessment method is also based on the approach used by [22], in modeling cold lava flows in active volcanic regions. The lava flow modeling algorithm used in this study follows an approach from [27], which combines elevation, land use, and precipitation pattern data to predict the flow path of volcanic material. The risk is calculated by considering not only physical hazards but also socio-economic aspects, such as population density, infrastructure value, and distance from lava flow paths. These risk factors fit into the framework proposed by [21], which emphasizes the importance of combining social and physical aspects in disaster risk analysis. Data analysis was carried out using ArcGIS applications with scoring and overlay methods to produce risk maps classified into high, medium, and low categories [19-24]. The results help illustrate the level of risk of cold lava flooding in each region.

## 3. RESULTS AND DISCUSSION

Tanah Datar Regency is a district in West Sumatra Province, with an area of 1,336 km² and consists of 14 sub-districts, 75 nagari, and 395 jorongs. Geographically, it is located between 00°17' – 00°39' South Latitude and 100°19' – 100°51' East Longitude, bordering Agam Regency, Fifty Cities, Solok, Padang Pariaman, Sijunjung, and Sawahlunto City (Geospatial Information Agency, 2021). The elevation of the area varies between 200 to 1,000 meters above sea level, with higher districts at risk of volcanic disasters. In terms of geology, this area has various types of rocks, including surface deposits, mountain rocks, sedimentary rocks, malihan rocks, and intrusion rocks [15]. The potential for geological disasters, such as earthquakes and volcanic eruptions, is quite high, as seen in the 2007 earthquake that resulted in damage (Mase, L., et al. 2008). There are also eight sub-districts in the Mount Marapi area that are still active, which requires the community to always be vigilant [28].

In terms of population, in 2022, the population will reach 376,276 people, with 188,551 males and 187,725 females, and a sex ratio of 100.44. There are 185,104 people in the labor force, while 75,979 people are non-labor force. In the period from 2000 to 2020, there were 8 types of disasters recorded in

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Tanah Datar Regency, with a total of 61 incidents. Earthquake disasters occurred 4 times (2004, 2007, 2009, and 2014), resulting in 17 deaths**,** 260 injuries, and 69,517 people affected, as well as damage to houses and facilities. One of the significant incidents was the flash flood disaster on October 11, 2018 which killed 6 people and damaged infrastructure. In 2019, there was a landslide that triggered flooding in several sub-districts. Other disaster events include the floods in Nagari Koto Baru in 2018 and the COVID-19 outbreak in 2020, which had an impact on the social and economic activities of the community. In addition, the erosion of the shores of Lake Singkarak is also a potential disaster that must be anticipated in the future.

The creation of a cold lava flood hazard map requires river buffer data, because this disaster occurs in the Watershed (DAS). Cold lava is produced from volcanic material deposits that accumulate on the slopes of Mount Marapi. If there is moderate to heavy rain, the material can extend to rivers upstream from the mountain. Tanah Datar Regency is traversed by several rivers sourced from the slopes of Mount Marapi.

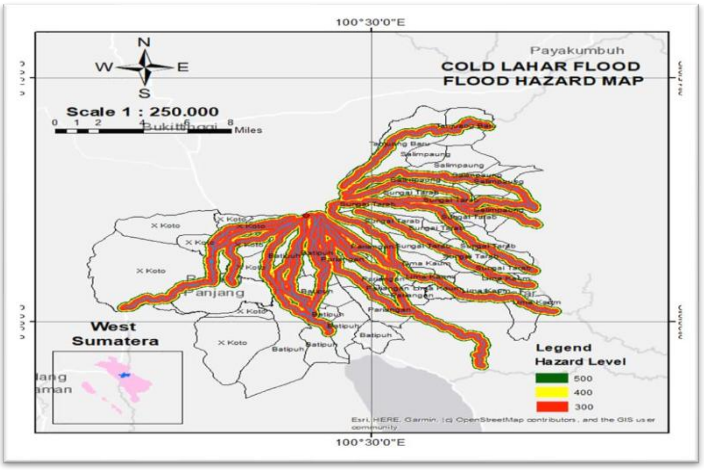


Figure 1. Cold Lava Flood Hazard Map of Tanah Datar Regency

Based on the cold lava flood hazard map of Tanah Datar Regency, the value obtained from the results of river buffering to determine the hazard map has three classifications, namely the riverbank distance of 300 meters with a score of 3 including the high class of the cold lava flood danger zone, the riverbank distance of 400 meters with a score of 2 including moderate from the cold lava flood danger zone, Meanwhile, the distance of the riverbank is 500 meters with a score of 1 is included in the low class of the cold lava flood danger zone.

Disaster risk is obtained from Threat multiplied by Vulnerability and divided by Capacity. The Threat Map is *overlayed* with a vulnerability map and a threat-vulnerability map is generated. The results of the threat-vulnerability map are overlayed with the capacity map and a disaster risk map is obtained. The following are the results of the calculations that produced the risk map of the Mount Marapi Lava Flood disaster in Tanah Datar Regency.

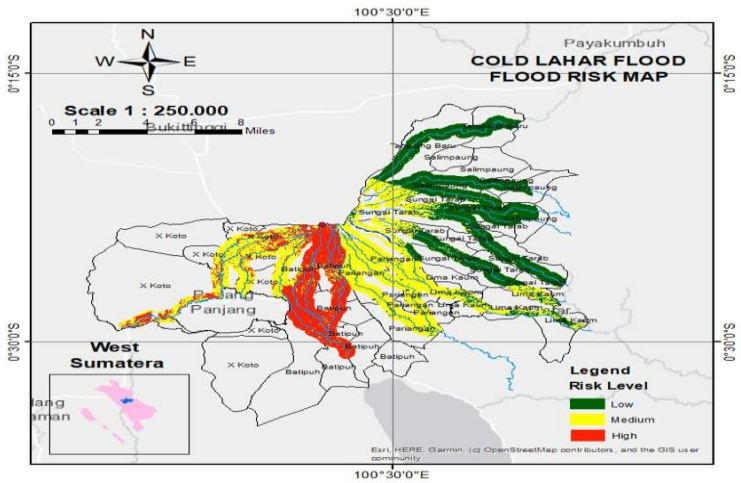


Figure 2. Risk Map of Cold Lava Flood Disaster in Tanah Datar Regency

GIS mapping results show that certain areas in Tanah Datar Regency, such as Batipuh and X Koto Districts, have a high level of danger from cold lava floods. These areas have steep slopes and are traversed by large rivers that have the potential to become cold lava flow paths after eruptions.

Risk assessments show that areas with high population density, especially around river valleys and residential areas at the foot of Mount Marapi, are at greater risk. Vital infrastructure such as highways, bridges, and farmland are also very vulnerable to damage due to cold lava floods.

## 4. ACKNOWLEDGEMENT

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## 5. CONCLUSION

Based on the results of data processing and analysis, the main conclusion obtained from this study is that the cold lava flood hazard map has succeeded in mapping the flood flow path in the watershed (DAS) upstream from the slope of Mount Marapi. High-risk areas were identified at a distance of 300 meters from the riverbank, covering an area of 27,480 hectares. The threat level of cold lava floods is obtained through overlays of several parameters, such as slope, soil type, rainfall, and land cover. Areas with sloping slopes (25%-45%) have an area of 13,413 hectares, andosol soil types with a high level of sensitivity cover 38,625 hectares, and high rainfall of
338,926 mm occurs in an area of 20,628 hectares, while land cover is dominated by jungle forests with an area of 21,666 hectares.

From the vulnerability level analysis, X Koto, Lima Kaum, and Sungai Tarab sub-districts show a high level of vulnerability, while Pariangan, Salimpaung, and Tanjung Baru sub-districts have low vulnerability. Disaster capacity in this region varies, where X Koto, Lima Kaum, and Sungai Tarab Districts are at medium capacity, while Batipuah, Pariangan, Salimpaung, and Tanjung Baru Districts are classified as low capacity. Finally, the risk analysis shows that areas with low disaster risk are located in Pariangan, Lima Kaum, Sungai Tarab, Salimpaung, and Tanjung Baru Districts with a total area of 6,889.28 hectares.

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