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Lessons learnt from community preparedness for Mount Merapi and Mount Marapi eruption disasters

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Abstract. Mount Merapi, located on the border of Central Java and the Special Region of Yogyakarta, and Mount Marapi in West Sumatra are active volcanoes. Eruption activities will have positive and negative impacts on the surrounding environment. The eruptions of Marapi on December 3, 2023, and Merapi on March 4, 2024, caused severe damage to road infrastructure, buildings, bridges, and settlements and resulted in casualties. This article describes the experiences of communities after the eruption of the two volcanoes. This research uses a combination of literature review and field observation methods to analyze how communities in the Mount Merapi and Mount Marapi areas prepare for disasters. The results of this study show that to increase community resilience to volcanic disasters and flash floods triggered by Mount Merapi and Mount Marapi, collaboration between the government, disaster agencies, and local residents is essential. Measures that can be taken are proactive evacuation protocols, infrastructure development such as sabo dams, and continuous education to increase awareness and preparedness. Recommendations include more intensive cooperation, educational initiatives, and strategic relocation from high-risk zones to effectively protect vulnerable communities.

1 Introduction

Indonesia is one of the countries that annually experience various natural disasters including volcanic eruptions. According to the Disaster Management Law No. 24 of 2007, "A disaster is an event or series of events that threaten and disrupt people's lives and livelihoods caused by both natural and non-natural factors as well as human factors resulting in human casualties, environmental damage, property losses, and psychological impacts". Volcanoes form when liquid magma, gas or other liquids emerge from the earth's crust. Indonesia is home to several active volcanoes, including Mount Agung in Bali, Mount Marapi in West Sumatra, Mount Merapi in Central Java, and Mount Bromo in East Java and others [1, 2].

Volcanic eruptions are one of Indonesia's most dangerous natural disasters, which will significantly impact society and even cost. According to Cassidy et al (2019) [3], a volcanic eruption is the process of releasing hot magma from the inside of the earth to the surface, which is indicated by eruptions that produce loose materials of various sizes or molten rock that forms lava or incandescent flow. Due to the dangers these eruptions various efforts are made to protect the community from these natural disasters. Mount Merapi and Mount Marapi are two of the most active volcanoes and frequently experience eruptions. The eruptions of Marapi and Merapi volcanoes not only produce volcanic ash and hot clouds, but also generate hazardous cold lava flows, severely disrupting the activities of the surrounding communities. Mount Merapi, standing at 2,968 meters above sea level is one of Indonesia most active volcanoes, located on the border of Central Java and the Special Region of Yogyakarta. This mountain is classified as a stratovolcano, distinguished by its conical shape and steep slopes, which are typical characteristic of this type of volcano. From 1906 to 2000, the Merapi experienced numerous eruptions [4]. Its activity has garnered significant public attention due to its scientific and cultural uniqueness. According to Nugraha et al (2019) [5], the current type of eruption of the Merapi is linked to the growth and collapse of the volcanic dome. This phenomenon has intensified since the 1800s. However, it's possible that dome growth-related eruptions occurred even earlier. Historical records indicate that more than 1,369 people died in the 1930 eruption of Mount Merapi. This eruption also destroyed many buildings and agricultural lands, and livestock also. In early 2021, Mount Merapi erupted again, causing cold lava flows and hot clouds, which forced many residents to evacuate in fear [1, 4].

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Mount Marapi has erupted more than 500 times since 1770 and is one of the active volcanoes on the island of Sumatra [6]. According to the Geological Agency, due to limited research, there is insufficient data on this volcano in early December 2023, Mount Marapi erupted with a rumbling sound, and ash was ejected up to 3,000 meters above the crater. The Volcano Observation Post (PGA) in Bukittinggi monitors all volcanic activities, with seismograms recorded at eight seismic stations around the mountain. Monitoring Mount Marapi's seismic activity is critical for disaster warning and mitigation, with an alert status has been in place since August 3, 2011. The potential dangers of Mount Marapi include volcanic ash rain, lava flows and debris flows [7-9].

The eruption intervals of volcanoes range from 2 to 7 years, depending on the location of magma release. Volcanic eruptions such as those of Mount Merapi and Mount Marapi can be divided into several types. Central eruptions occur through the main crater, while the side eruptions occur on the slopes of the mountain. Crack eruptions occur along cracks or faults extending several kilometers, and eccentric eruptions occur in the same way as side eruptions. The process of volcanic eruptions varies but some produce molten lava, ash and solid material. A distinguishing feature of Mount Merapi's eruption is that they do not form a caldera (crater), instead they emit incandescent lava and hot clouds.

Volcanic eruptions are complex events that have a major impact on society and the environment. Adverse effects include casualties, infrastructure damage, and environmental pollution caused by hot clouds, lava flows, pyroclastic falls, toxic gases, and volcanic ash [10, 11]. Additionally, indirect dangers such as cold lava flows after rainfall have been observed following the eruptions of Mount Marapi on December 3, 2023, and Mount Merapi on March 4, 2024. Despite these hazards, eruptions can also yield benefits, such as thermal energy sources, more fertile soil, and mineral springs. Nevertheless, eruptions also produce sources of thermal energy, more fertile soil, and mineral springs [12].

Community preparedness is crucial to mitigate the risks and negative impacts of volcanic eruptions like those of Mount Merapi and Mount Marapi. Effective community preparedness can significantly reduce the impact of natural disasters. Local knowledge of eruption signs, evacuation routes and evacuation sites is essential. Enhancing early warning systems, evacuation procedures, and community response capabilities improves resilience and reduces the overall impact of volcanic disasters.

2 Research methodology

This research was carried out using literature study field observation method to analyze community preparedness for disaster around Mount Merapi and Mount Marapi. The qualitative research emphasizes on the condition of natural objects as critical instruments. Data collection was conducted using a triangulated approach with inductive data analysis. The research findings emphasize understanding and meaning over generalization [13, 14]. The method used to collect data and sources related to the research subject include literature study and field observation.

The literature study involves reviewing journal articles, newspapers and supporting books to understand the dynamics, obstacles and current learning opportunities. This approach helps identify ways to enhance the readiness of the community around the volcano.

The observation method involves making direct observations and recording the state or behavior of the target object to understand and interpret the relevant phenomena [15]. The results of the research are expected to enhance preparedness for volcanic eruptions and serves as a reference for policymakers and practitioners in developing effective interventions. This will help the community mitigate the negative impacts of volcanic disasters, which can be highly damaging and potentially deadly.

3 Results and discussion

Mount Marapi in West Sumatra suddenly erupted on Sunday 3 December 2023 at around 2:53 pm. At the time of eruption, the mountain was under Level II status, indicating an alert. The eruption produced volcanic ash that soared upwards in grey with a thick intensity. When the eruption occurred, dozens of climbers were trapped and as many as 23 people were reported dead [15]. The eruption of Mount Marapi gained widespread attention, because it occurred without any signs or symptoms beforehand. In fact, no volcanic earthquakes detected beforehand, and testimonies of the surviving climbers also stated that there were no signs of eruption at all.

Volcanic eruptions certainly have a negative impact on society as evidenced by the situation in Agam district. Based on data from Regional Disaster Management Agency (BPBD) of West Sumatra, the eruption resulted in 24 deaths, 22 injuries, 2 people being treated, and 709 people displaced. In addition to human casualties, regional infrastructure and livestock were also affected. The high number of affected individuals is partly due to a lack of understanding of how to protect themselves, the areas affected by the eruption of Mount Marapi have a high vulnerability to land movement disasters.

Fig. 1. The collapse of an elementary school and residential area in Nagari Koto Tuo due to flash floods following the eruption of Mount Marapi in West Sumatra.

Fig. 2. Infrastructure damaged by flash floods following the eruption of Mount Marapi in West Sumatera

The type of eruption of Mount Marapi in December 2023 differs significantly to the eruption in March 2024 which was a strombolian eruption. The eruption of Mount Marapi on Saturday 11 May 2024 triggered flash floods accompanied by mud or locally knowns as “galodo” leaving the affected victims traumatized. As felt by hundreds of victims at the Bukit Batabuah refugee post, at SDN 08 Kubang Duo, Koto Panjang, Canduang, Agam district, when the floods swept away their homes and other public facilities as shown in Figs. 1-3. The death toll from the flash floods and landslide in four areas in West Sumatra rose to 37 people [16].

Since the end of 2010, Mount Merapi in Central Java and the Special Region of Yogyakarta has been on an alert status or Level III, as designated by the Geological Agency through PVMBG. On 4 January 2021, lava domes, volcanoes, and hot clouds began to appear. At that time, the two lava domes of Mount Merapi had volumes of 1,598,700 m^3 and 2,267,400 m^3 respectively. This massive lava dome avalanche had the potential to cause hot clouds as far as 7 km to the southwest and 5 km to the south-southeast. The resulting lava dome collapse in the southwest did trigger hot clouds, and the eruption activity was considered very high. Lava flows were observed heading southwest, with the sound of their movement audible from the Kaliurang and Babadan Posts. The monitoring results showed that Mount Merapi’s volcanic activity was still at an alert level. Potential hazards include lava flows, hot clouds in the south-southwest area, and ejections of volcanic material during explosive eruptions.

Table 1. Population data and the impact of the eruption of the Merapi volcano and the Marapi volcano

Impact of eruptions	Mount Merapi	Mount Marapi
Eruption date	October 26, 2010	December 3, 2023
Casualties	353 people	70 people
Number of refugees	350,000 people	3,595 people
Infrastructure damage	High	Medium
Economic impact	Hundreds of million dollars	Local disadvantages

Based on the Table 1 above, it is evident that the eruption of Mount Merapi in 2010 had a more significant impact than the eruption of Mount Marapi in December 2023, both in terms of the number of casualties, the number of refugees, infrastructure damage, and economic impact as shown in Fig. 3.

Fig. 3. Settlements destroyed by the eruption of Mount Merapi in Central Java

The Merapi volcano tends to exhibit higher volcanic activity and is more destructive than the Marapi volcano. In accordance with the Regulation of the Head of National Board for Disaster Management (BNPB) number 2 of 2012 concerning General Guidelines for Disaster Risk Assessment, efforts to reduce disaster risk involve understanding the relationship between threats, vulnerabilities, and capacities. These efforts include minimizing regional threats; reducing the vulnerability of threatened areas; and increasing the capacity of threatened areas. Therefore, to enhance the ability of the community to face and manage volcanic eruption disasters, various strategies and activities are implemented, examples are shown in Table 2 and 3.

Table 2. Availability of disaster management infrastructure

Type	Mount Merapi (unit)	Mount Marapi (unit)
Sabo-dam	272	2
Observation post	5	1
Disaster Management Command post	3	-
Early warning system	5	11
Rivers that have the potential to channel cold lava flows	15	25
Evacuation routes	3	-
Temporary evacuation site	6	-
Livestock evacuation site	3	-

The Klaten and Sleman Regency Governments implemented strategies to manage the threat of a Mount Merapi eruption during the COVID-19 pandemic. Despite the dual challenges, local governments and communities successfully controlled multi-hazard disasters. As a result, during the simultaneous occurrence of these two disasters, the community remained safe in evacuation camps, and no COVID-19 cases were reported among the evacuees.

One of the most effective approaches is the cooperation between the government, disaster management agencies and the community in minimizing the impact of volcanic eruptions. Enhancing preparedness through learning and education improves community knowledge and skills in disaster response, reduces casualties and infrastructure damage, and strengthens early warning and evacuation systems. There significant number of casualties resulting from volcanic eruptions indicates a low level of community preparedness. Therefore, educating communities on preparing for and managing eruption disasters is very crucial; for those living around volcanic areas.

3.1 Development of community knowledge in dealing with mountain eruption disasters

Indonesia is located in an area that is prone to natural disasters, including volcanic eruptions. Land use in these affected areas includes settlements, agriculture (gardens, fields, rice fields), and public facilities. The upper region is primarily covered by forests, some of which have been converted into fields/gardens. The central slopes are used for rice fields and gardens. According to the forecast map for land movements in West Sumatra, the disaster-prone area falls within a medium-high potential zone for landslides and materials flows [17]. The destruction of the slopes around Mount Marapi was not incidental. A number of factors contributed to this disaster. The steep slopes around the mountain provide an ideal path for unconsolidated volcanic material. The heavy rain exacerbated the situation by triggering erosion and mobilizing loose materials. Additionally, upstream land use changes, such as land clearing for agriculture or settlements, also contribute to increased surface erosion and accelerate the formation of material flows. Therefore, addressing natural disasters requires significant knowledge and education to enhance community preparedness for volcanic eruptions [1, 4]. When well-informed, people gain a better understanding of the causes, characteristics, and impacts of volcanic eruption [18, 19].

To effectively manage a volcanic eruption disaster, it is crucial to prioritize community education and knowledge dissemination. A comprehensive approach is needed to ensure that the community is well informed and prepared for potential eruptions.

1) The government and relevant agencies must ensure that the public is informed of the characteristics and potential dangers of eruptions from Mount Merapi and Mount Marapi, especially for those living nearby. To enhance public awareness, socialization and training activities must be carried out regularly. Various communication channels, both formal and informal, must be used to disseminate important information such as eruption history, early warning signs, danger zones, and evacuation routes.
2) The community should be encouraged to develop the household-level emergency plans, including supplies such as food, water, medicine, and communication equipment. In addition, the community should identify safe gathering places and cooperate with neighboring residents on evacuation plans similar to those in the Mount Merapi area. Regular training in self-rescue techniques, such as first aid and self-evacuation, is also essential.
3) The government should establish a disaster management system that incorporates local knowledge. The government can develop a more effective early warning system by leveraging public awareness of natural signs as self-warning indicators. Combining scientific and local knowledge will enhance the effectiveness of disaster warning and response systems. Strengthening local capacity is crucial. Training and forming rapid response teams, volunteers, and local community organizations can better prepare communities for disasters. A sense of shared responsibility will increase when communities actively participate in planning and implementing emergency response measures.

Table 3. Non-physical countermeasures

Activities	Mount Merapi	Mount Marapi
Strengthening and implementing regulations, such as vulnerable areas and evacuation routes	The community is ready	Socialization to the community through students and 70 Walinagari
Identification of disaster management system	Facilities and infrastructure are ready	In EWS installation
Building community preparedness	Ready with the involvement of neighboring villages	Still in the socialization stage
Capacity building of disaster management agencies	Disaster resilient villages have been formed	Disaster resilient villages at the socialization level
Multi-stakeholder collaboration to build a better	Still continuing to be improved	Still continuing to be improved

A holistic and participatory approach is expected to provide the community with adequate knowledge and preparedness in dealing with mountain eruption disasters. This will certainly increase the ability of the community to reduce disaster risk and accelerate recovery processes.

3.2 Cooperation between the government, disaster management agencies, and the community in preparing an evacuation system

The government plays significant role in coordinating disaster management efforts, while management institutions and the community play an active role in implementation.

The government is responsible for ensuring comprehensive planning, adequate budget allocation, and the availability of infrastructure to support evacuations.

The Regional Disaster Management Agency (BPBD) supports the Regent by coordinating, formulating policies, and implementing disaster management strategies. It ensures that the community has a clear emergency response plan, trained personnel and adequate equipment. This coordination helps ensure that all disaster management measures are carried out effectively and in an integrated manner [20]. Strong cooperation with local governments and communities in the Mount Merapi and Mount Marapi areas is strongly needed to ensure the rapid and effective mobilization of aid and resources during disasters. The community plays a crucial role in the evacuation process and the development of the evacuation system. From the very beginning, communities should be involved in the evacuation plan through socialization, training, and simulation. To improve community awareness, knowledge, and preparedness for volcanic eruptions, local communities can also participate in forming disaster preparedness teams that assist with evacuation and pre-disaster emergency management.

Evacuation maps are essential for identifying hazardous areas, safe locations, and evacuation routes, demonstrated by the communities in 70 Nagari on Mount Marapi. Preparing individuals, staff and organizations for emergency situations that require evacuation is known as evacuation simulations which teach people how to respond during a disaster. Various types of simulations, such as desktop simulation, field simulation, and full simulation, can be used. Developing evacuation systems and disaster management organizations comes with challenges and obstacles, highlighting the need for cooperation to address the issues.

1) Ensuring effective collaboration among all parties is a significant issue. While the government must act as the main coordinator, disaster management agencies such as BNBP and BPBD must contribute to developing evacuation strategies and infrastructure. The community must also be involved in evacuation planning and implementation processes.
2) Facing increasingly diverse and complex disaster phenomena presents a significant challenge. Therefore, a flexible evacuation system capable of managing volcanic eruption disasters is essential. Evacuation strategies and infrastructure must be continuedly maintained and improved.
3) Understanding spatial planning policies and local knowledge is crucial. Each community possesses unique local knowledge on managing volcanic eruptions, whether on Mount Merapi or Mount Marapi. However, they are often not involved in disaster management planning. Therefore, disaster management agencies must collaborate with local communities in developing efficient spatial planning policies and address potential losses from volcanic eruptions.
4) Overcoming the complexity of inter-institutional cooperation is essential. BNPB and BPBD must coordinate with other institutions, including ministries or national institutions, educational institutions and the community. The government must ensure that all institutions work effectively in creating a comprehensive evacuation system.

The explanation above is a strategic step to enhance disaster management capabilities. With clear regulations, active participation from disaster management institutions and community contributions, this approach will reduce the number of victims and accelerate recovery process, thereby mitigating the negative impacts of volcanic eruptions as shown in Fig. 4 and Fig. 5.

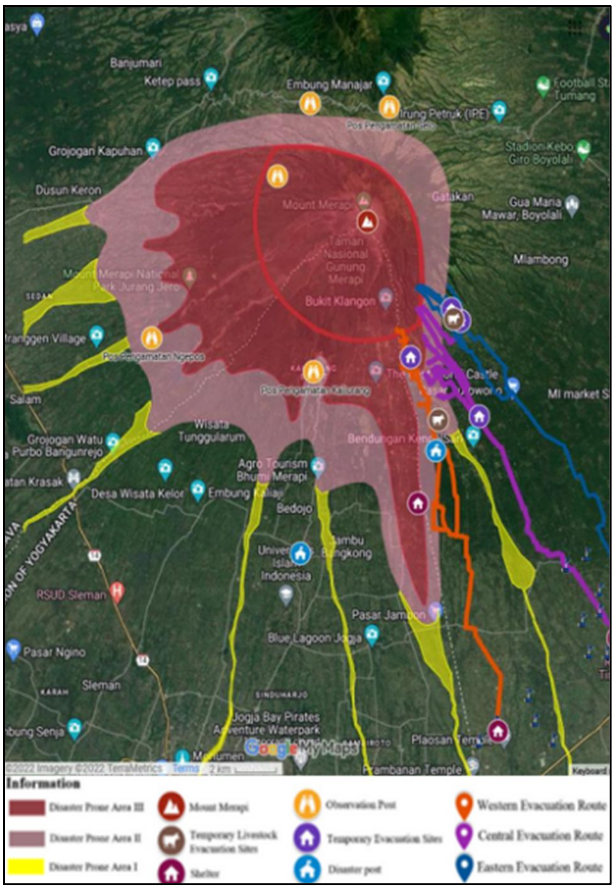

Fig. 4. Location map of ground motion and cold lava flow from the eruption of Mount Merapi in Central Java (source: BPBD Central Java, 2024)

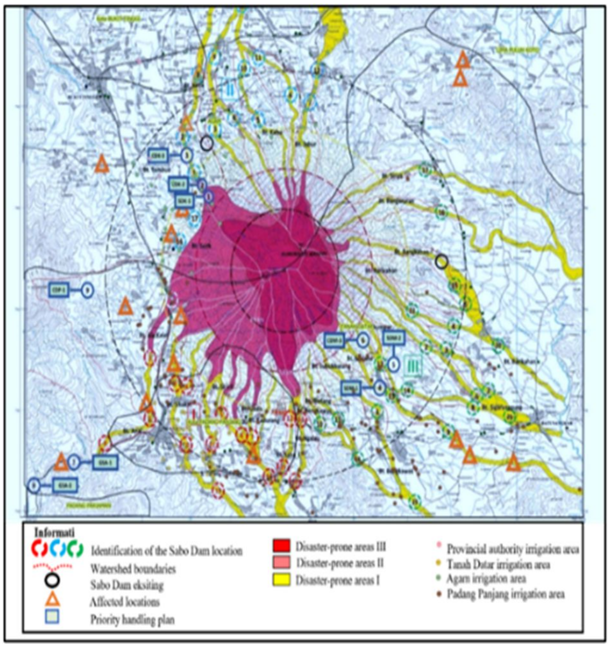

Fig. 5. Location map of ground motion and cold lava flow from the eruption of Mount Marapi in West Sumatra (source: BPBD West Sumatra, 2024)

3.3 Development of disaster mitigation

Disaster mitigation is a proactive measure taken before an emergency or disaster occurs to eliminate or reduce the impact and risk of harm [3, 18]. To mitigate the adverse impact of volcanic eruptions, efforts are underway to enhance disaster mitigation strategies for Mount Merapi and Mount Marapi. Both volcanoes remain active and experience significant explosive eruptions that pose severe risks to surrounding communities. Therefore, understanding and implementing effective mitigation strategies is essential.

The creation and provision of maps of areas prone to volcanic eruption disasters, including volcanic hazard risk zones and volcanic geological maps are essential to understand potential hazards. Location maps showing ground motion and cold lava flow from the eruption of Mount Merapi and Mount Marapi can be seen in Figs. 4 and 5. Governments and volcanological institutions must monitor volcanic activity using specialized equipment such as seismographs and tiltmeters [21, 22]. The government has established clear and organized procedures to deal with emergency situations such as the eruption of Mount Merapi. It is in the process of preparing for potential eruptions of Mount Marapi. These procedures include evacuation plans, provision of emergency facilities, and coordination with relevant parties.

An early warning system (EWS) has been installed in the Mount Merapi and Mount Marapi areas to monitor and anticipate potential disasters and volcanic eruptions. In the Mount Merapi area, the system includes 42 seismic stations, 10 GPS stations, 13 tiltmeter stations, 2 geochemical stations, 5 rain or cold lava monitoring stations and 34 camera stations.

Meanwhile, in the Mount Marapi area, there are 11 EWS designed to provide early warning of volcanic eruption hazards and 20 units of EWS sensors by BNBP to detect and alert for potential floods caused by volcanic eruptions. However, EWS in the Mount Merapi and Mount Marapi areas requires further evaluation to improve its effectiveness in disaster management. The existing EWS faces several challenges, including:
Enhance community socialization. Although 11 EWS units have been installed on Mount Marapi, additional socialization efforts are needed to ensure that the community fully understands the use of land, buildings, and other infrastructure around the volcano. This will help the community become more prepared and responsive to early warning signals. Expand the coverage of the early warning system. Although BNBP has installed 20 units of EWS sensors in rivers around Mount Marapi, there are still areas that are not covered. For example, the Siagarungguang trunk, which is upstream from Mount Marapi and downstream from Pasar Batusangkar, is a river with potential risk of flash floods and cold lava flow that require monitoring. Improves the speed and accuracy of the early warning system. Although sirens can provide rapid alerts, they are less effective in cases of hot clouds moving at speed of 100 km/h. Enhancing the early warning system to address these high-speed phenomena will improve its effectiveness.

Sabo dams are a robust alternative solution for managing lava flows and sediment from volcanic eruptions. Sabo dams are designed to capture sediment and lava, particularly after heavy rains. Observations in the Mount Marapi area, show only 2 sabo dams, which limits their effectiveness given the 25 rivers that flow downstream from Marapi and have potential flooding risks. In contrast, the Mount Merapi area benefits from 272 sabo dam units, which significantly help control and redirect volcanic material. To improve the disaster mitigations in the Mount Marapi area, increasing the number of sabo dams at several points is required. This will help prevent damage to infrastructure and the surrounding environment and mitigate the risk of lava floods caused by volcanic eruptions.

Strengthening human resources and support systems is also crucial for effective disaster mitigation. Personnels involved in disaster management should receive proper training and development. In addition, improved facilities and infrastructure are needed, such as evacuation routes and emergency services. The community must be aware of evacuation locations and understand what constitutes a safe area. It is vital that people are prepared with essential supplies, such as medicine and food, and that they follow guidance and instructions provided by the relevant authorities.

4 Conclusion and recommendations

4.1 Conclusion

The eruptions of Mount Merapi and Mount Marapi have had a great negative impact on the community, such as casualties, injuries, economic impacts, damage to infrastructure and livestock. The eruption of Mount Merapi in 2010 had a greater impact than the eruption of Mount Marapi in December 2023, highlighting the higher and more destructive volcanic activity of Mount Merapi. To improve the community's ability to deal with volcanic eruption disasters, cooperation among the government, disaster management agencies, and the community is essential.

The flash flood disaster or locally known as “galodo’ that affected the districts of Agam, Tanah Datar, Padang Pariaman and the city of Padang Panjang was caused by lava flows following the eruption of Mount Marapi. To reduce disaster risk, several immediate actions are recommended:

1) Evacuation: Residents living along riverbanks upstream from Mount Marapi should evacuate to safer locations if it rains upstream. If there are signs of hazardous material flows, the community should quickly move away from the area and report the incident to authorities.
2) Infrastructure Development: Developing River flow control infrastructure, such as sabo dams, is crucial for mitigating the impact of flash floods. Additionally, repairing culverts, normalizing river channels, and improving water flow conditions are necessary to prevent flooding.

3) Coordination and Education: Effective coordination among local governments, relevant agencies, and the community is vital. Continuous socialization and education about soil movement and disaster mitigation efforts should be conducted to raise public awareness and preparedness for potential disaster threats.

4.2 Recommendations

There are several recommendations that can be made for the government, response agencies, and the community around the Mount Merapi and Mount Marapi areas:
1) Increasing cooperation between the government, disaster management agencies, and the community in dealing with volcanic eruption disasters.
2) Develop effective preparedness learning programs to improve community knowledge and skills.
3) Relocating of settlements in disaster-prone areas, intensively monitoring material flow, developing effective flood control infrastructure, and providing socialization and education on disaster mitigation are the main recommendations to protect and ensure the safety of communities around Mount Marapi.

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