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# The Effectiveness of the 2017 Mount Agung Eruption Emergency Response as Seen from GPS Monitoring Results

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ABSTRACT

The 2017 Mount Agung eruption in Bali represents a critical aspect of disaster risk reduction requiring rapid, effective, and well-coordinated emergency response. This study aims to provide recommendations for improving the effectiveness of emergency response in minimizing casualties and economic losses. A case study approach was employed, analyzing GPS -based monitoring systems, institutional coordination, and policy implementation. The findings indicate that response effectiveness is influenced by cross-stakeholder coordination, evacuation zoning based on disaster-prone area (KRB) maps issued by the Center for Volcanology and Geological Hazard Mitigation (PVMBG), resource assessment, fulfillment of basic needs, and public communication through social media. Regulatory support and institutional synergy further strengthen adaptive response. The study concludes that the integration of technology, system preparedness, and community participation enhances overall emergency response effectiveness in a comprehensive manner

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## INTRODUCTION

The volcanic crisis at Mount Agung, marked by an increase in earthquake events to over 27,000, is one of the most intense unrest episodes ever documented since the major eruption in 1963. This seismic activity was not only recorded instrumentally with high resolution but was also felt by communities around the mountain and even in relatively distant areas like Singaraja and Kuta, showing the high seismic energy released during the pre-eruption period (Syahbana et al., 2019 & Gunawan et al., 2020). Although instrumental earthquake data before the 1963 eruption isn't available, historical reports indicate that felt earthquakes occurred at least two days before the main eruption, suggesting a similarity in the phenomenological patterns between past pre-eruption activity and the recent volcanic crisis (Sutawidjaja et al., 2013 & Supendi et al., 2018). The 2017 eruption of Mount Agung in Bali was marked by a significant increase in volcanic activity since September and peaked in October 2017 (Figure 1), causing tens of thousands of residents to be evacuated and displaced.

In a global context, Mount Agung is part of a group of volcanoes with a Volcanic Explosivity Index (VEI) of V, which is quite rare and only found in a small number of volcanoes worldwide (Newhall & Self, 1982 & Pyle, 2015). For comparison, the 2010 eruption of Mount Merapi had a VEI of IV, which quantitatively indicates an energy scale about one order lower than VEI V (Cashman & Sparks, 2019 and Sparks et al., 2019). Additionally, the recurring high-VEI eruptions and the complex magma system dynamics make Mount Agung a key subject in volcanic disaster mitigation research, especially in understanding the relationship between earthquake patterns, magma migration, and the potential for explosive eruptions (Wellik et al., 2021 & Poland et al., 2017).

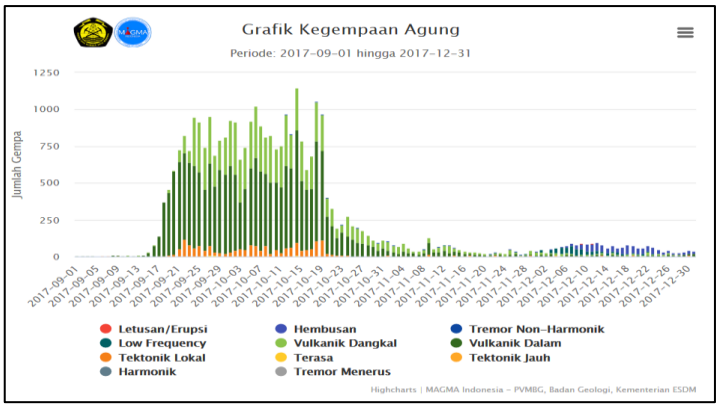
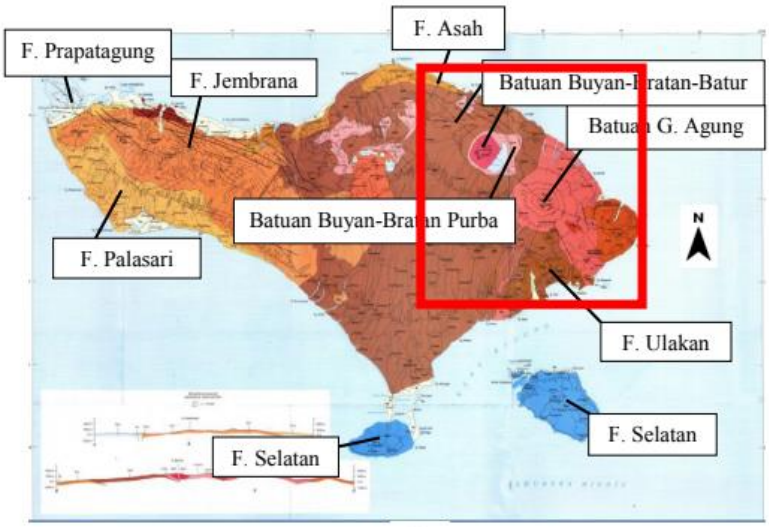


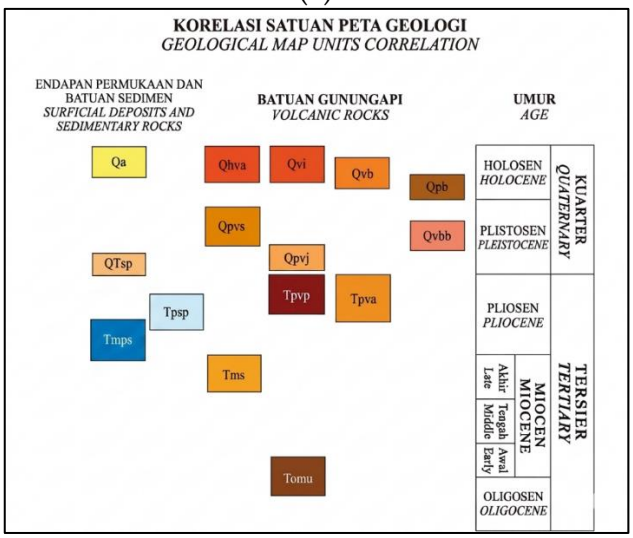

Figure 1. Seismic Activity Graph of Mount Agung (KESDM, 2017)

Most of the area of Bali Island is dominated by mountainous and hilly terrain that forms a chain stretching from west to east. This chain is part of an active volcanic system that includes Mount Agung at 3,031 meters and Mount Batur at 1,717 meters. Tectonically, Bali is part of the Sunda-Banda volcanic island arc, which stretches about 4,700 km from east to west, from Damar Island to Sumatra. This arc was formed due to the convergent interaction between the Indo-Australian Plate and the Eurasian Plate, with a subduction rate of around 0.07 m/year (Simandjuntak & Barber, 1996).

The tectonic process has controlled volcanic activity in Bali since the late Tertiary, marked by the formation of various volcanic complexes and the widespread distribution of volcanic rocks (Bemmelen, 1949 & Purbohadiwidjojo et al., 1998). Regionally, Bali's volcanic system can be divided into several main complexes: the Jembrana Formation volcanic complex in the west, the Buyan – Bratan – Batur Formation complex in the central part, and the Mount Agung rock complex in the east. From a geological perspective, Bali is relatively young, with the oldest rocks dating back to the Miocene as shown in Figure 2 (Purbohadiwidjojo et al., 1998). Stratigraphically, the rock units that make up Bali include the Ulakan Formation, Selatan Formation, Palasari Formation, Prapatagung Formation, Jembrana Formation, Asah Formation, Buyan – Bratan – Batur rocks, as well as rocks from Mount Agung's activity, reflecting the geological evolution and complex volcanic dynamics in this area.




(a)




(b)

Figure 2. (a) Geological Map of the Bali Sheet and (b) Map Unit Correlation. The thick red line marks the boundary of the study area (modified from Purbohadiwidjojo et al., 1998)

The rocks that make up the study area, according to Purbohadiwidjojo et al., 1998, consist of:

a) The Ulakan (Tomu) Formation is the oldest formation dating back to the Early Miocene. This formation is made up of volcanic breccia, lava, tuff, and interspersed limestone sedimentary rocks.
b) The Asah Formation (Tpva) has rock groups that date back to the Pliocene. This formation is made up of lava, volcanic breccia, and pumice tuff, interbedded with limestone sedimentary rocks.
c) The ancient Buyan-Bratan Group rocks (Qvbb) from the Pleistocene are made up of volcanic breccia and lava.
d) The rock groups Buyan-Bratan and Batur (Qpbb & Qhvb) are Holocene in age and are made up of volcanic breccia, lava, tuff, agglomerate, with some lava flows and ignimbrite (produced by the still active Mount Batur).
e) The rocks of Mount Agung (Qhva), which are Holocene in age, are made up of agglomerate, tuff, lava, lahar, and ignimbrite; as a result of the still-active activity of Mount Agung.

The intensity of the volcanic crisis, shown by the high frequency of earthquakes and the complexity of the magmatic system dynamics, not only has scientific implications but also requires preparedness and an effective, coordinated emergency response. In disaster management, the pre-eruption phase with a significant increase in seismic activity is a crucial period for quick decision-making, including determining the volcano's status, preparing hazard zones, and carrying out evacuations of affected communities (BNPB, 2017). The effectiveness of emergency response is greatly influenced by the integration of volcanic monitoring data, early warning systems, and institutional capacity to respond to threats in a timely manner (Hidayati et al., 2006). Therefore, studying the volcanic crisis of Mount Agung is not only important from a volcanology perspective but also for evaluating emergency response strategies. This is to minimize the risk of casualties and economic losses from explosive eruptions in the future.

## LITERATURE REVIEW

The volcanic crisis at Mount Agung, marked by an increase in earthquake events to over 27,000, is one of the most intense unrest episodes ever documented since the major eruption in 1963. This seismic activity was not only recorded instrumentally with high resolution but was also felt by communities around the mountain and even in relatively distant areas like Singaraja and Kuta, showing the high seismic energy released during the pre-eruption period (Syahbana et al., 2019 & Gunawan et al., 2020). Although instrumental earthquake data before the 1963 eruption isn't available, historical reports indicate that felt earthquakes occurred at least two days before the main eruption, suggesting a similarity in the phenomenological patterns between past pre-eruption activity and the recent volcanic crisis (Sutawidjaja et al., 2013 & Supendi et al., 2018). The 2017 eruption of Mount Agung in Bali was marked by a significant increase in volcanic activity since September and peaked in October 2017 (Figure 1), causing tens of thousands of residents to be evacuated and displaced.

## METHODOLOGY

To strengthen the disaster mitigation system for Mount Agung's eruption, researchers together with PVMBG gradually installed equipment including seismic and deformation instruments, with monitoring using GPS as seismic stations. Before the 2017 volcanic crisis, the equipment already installed on Mount Agung consisted of 4 seismic stations (TMKS, PSAG, RNDG, and ABNG) and 4 GPS stations (RNDG, PGBN, YHKR, and CEGI). In addition, the Mount Batur station, which consists of 4 seismic stations (BTR, SGN, DNU, and YMP) and 1 tiltmeter station, was also used to assist the seismic and deformation analysis of Mount Agung because it's relatively close (less than 20 km from Mount Agung's summit). During the crisis period, PVMBG strengthened the equipment setup by adding 5 seismic stations, 2 GPS stations, 2 tiltmeter stations, 2 CCTV stations, and mobile equipment like 1 DOAS Scanner, 1 MultiGAS, and 1 Thermal Camera. Mount Agung has 2 volcanic observation posts (PGA) located in Rendang Village (12.5 km south of Mount Agung's peak) and in Batulompeh, Tianyar Village (14 km north of Mount Agung's peak).

Based on those instruments, we can observe the dynamics of Mount Agung's activity from normal periods to the current crisis period. The volcanic crisis that occurred at Mount Agung in 2017 likely went through a long phase of stress build-up. At least over the past ten years, from May 2007 to February 2009, InSAR satellite data recorded an inflation of about ~15 cm on Mount Agung's body. During the period 2009 - 2011, there was deflation of about ~7 cm. This means that after 2011, Mount Agung did not return to its original state because vertical deformation of ~8 cm was still compensated. From 2012 to 2016, the inflation and deflation trends were observed to be very weak and insignificant. The inflation and deflation from 2007 to 2016 occurred aseismically, meaning that even though inflation and deflation were recorded by GPS and happened on Mount Agung's body, there were no signs of increased seismic activity. This indicates that the process happening is still within the transition zone (ductile - brittle transition zone).

At the beginning of 2017, specifically from February to March, inflation occurred in Mount Agung, with the pressure source still located deep down, around more than 10 km below the crater of Mount Agung. The inflation that happened, similar to the period from 2007 to 2016, occurred aseismically. After March 2017, the GPS trend was relatively flat, indicating that the inflation had stopped. However, since the inflation stopped, local tectonic earthquakes, located about 50 km northwest of Mount Agung, began to be routinely recorded. In May 2017, a series of local tectonic earthquakes (swarm) was recorded and could be felt by some people around Buleleng and Tejakula Singaraja. After May 2017, the number of local tectonic earthquakes continued to be recorded, even though the number of felt earthquakes decreased.

**RESULT AND DISCUSSION**

From early to mid-September 2017, seismic activity started to show a progressive increase in a linear pattern. Therefore, on September 14, 2017, at 2:00 PM WITA, the status of Mount Agung was raised from Level I (Normal) to Level II (Alert), with the estimated danger zone set within a 3 km radius from the summit of Mount Agung.

During the 4-day period since it was set to Level II (Alert), the number of volcanic earthquakes increased from 13 to 366, or about 28 times higher. This significant increase was also marked by a rise in thermal energy, as shown in ASTER TIR and SENTINEL-2 satellite images. In addition, satellites observed an expansion of the hot area where smoke then appeared, and its intensity kept increasing. Hydrologically, this magmatic activity has disrupted the water system within Mount Agung, indicated by water coming from deep underground and regularly emerging to the crater surface. Considering all these monitoring aspects, on September 18, 2017, at 8:00 PM WITA, Mount Agung's status was raised again from Level II (Alert) to Level III (Standby).

On September 22, 2017, between 00:00 and 18:00 WITA, a total of 691 local tectonic, deep volcanic, and shallow volcanic earthquakes were recorded. Ambient-noise cross-correlation analysis indicated a rapid decrease in wave velocity within Mount Agung, suggesting a very significant increase in magma influx (Brenguier et al., 2008). This decrease in seismic velocity is generally associated with increased magma influx and pressure accumulation before an eruption, reflecting the more active internal dynamics of the volcanic system (Branca et al., 2019). There was an exponential increase both in the number and energy of earthquakes, along with a drastic decrease in wave velocity inside Mount Agung, supported by a significant rise in thermal energy shown in satellite images and uplift patterns from GPS. So on September 22, 2017, at 8:00 PM Central Indonesia Time, the status of Mount Agung was raised from Level III (Alert) to Level IV (Warning).

According to regulations, when a volcano is at Level III (Alert) or Level IV (Warning), the threat of potential eruptions spreads more widely and has an increasingly noticeable impact on the surrounding community and environment (PVMBG, 2014). Therefore, volcanic emergency response is carried out to help the affected people.

Emergency response for Mount Agung is carried out when Mount Agung is at Level III and Level IV. In responding to an emergency, several things that need to be done are:

**1. Coordinating with all stakeholders by building internal communication channels**

When the emergency status is first declared, coordination with stakeholders must be done immediately. The evacuation process, coordinated by the party responsible for the emergency, involves various agencies, including the military and police at both national and local levels, as well as local community leaders (Syahbana et al., 2017). This helps in getting the latest details about available resources and obtaining updated information regarding potential threats from Mount Agung's eruption. Some stakeholders that need to be contacted are PVMBG, BNPB, BPBD, BMKG, local governments, the Ministry of Public Works and Public Housing, the Ministry of Transportation, and some aviation stakeholders.

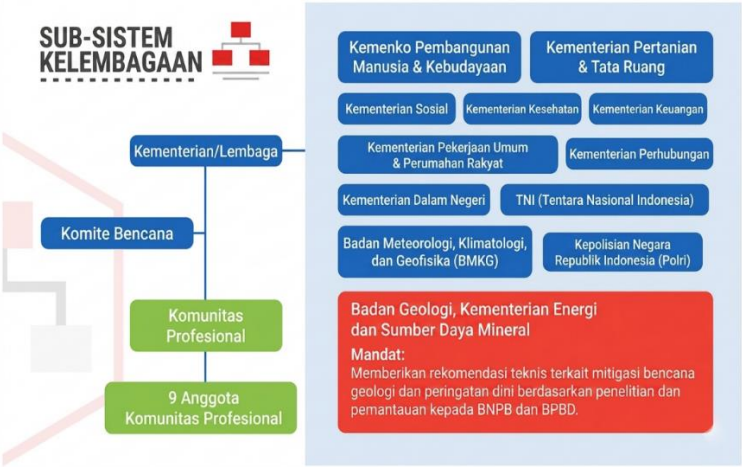



Figure 3. Emergency Response Coordination Flow

Creating communication media like a WhatsApp Group will be very helpful in maintaining regular communication and data sharing. Also, in a crisis situation, communication tools like radios can be used to reach areas with poor signal. Usually, HT (Handy Talkie) is used by local residents and volunteers to get information about the status of Mount Agung.

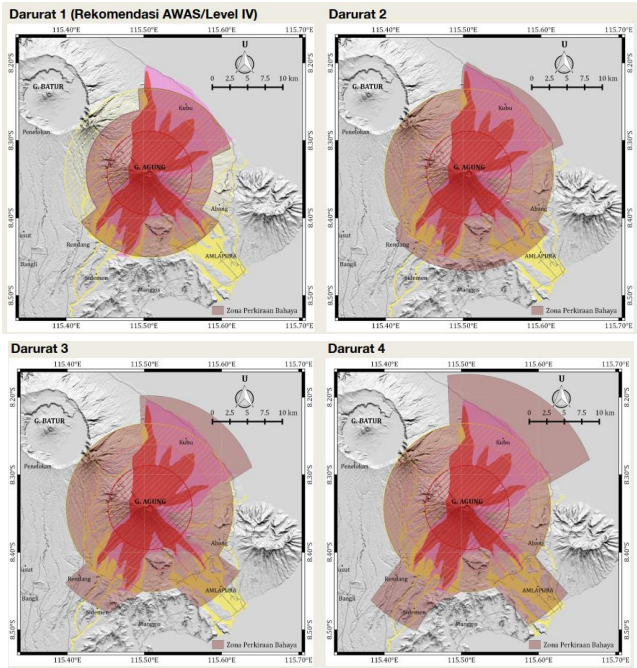
Figure 4. Infographic of the Relationship Between Researchers, Decision Makers, and the Community

PVMBG is a unit that plays a role in conducting research, investigation, and services related to volcanoes and geological disaster mitigation, as shown in Figure 4. Coordination with these institutions needs to be done intensively and regularly to make decision-making easier (Astuti & Rimawati, 2020). This is because the monitoring data on activity and hazard zone modeling produced by PVMBG is dynamic and can change at any time in a very short period. The hazard zone modeling made by PVMBG is commonly called the KRB Map (Disaster-Prone Area). Figure 5 explains the regulations regarding the KRB Map.

Figure 5. Flow of Explanation for the Disaster-Prone Area Map (KRB)

The Disaster-Prone Area (KRB) map is issued by PVMBG and will later be used as a reference by BNPB and BPBD to evacuate people who are in volcanic danger zones (Sari, 2017). Besides evacuation, the KRB map can also be

used to model possible hazard scenarios. In this case, four hazard scenario models have been made as shown in Figure 6.




After getting information about the danger zone map, BNPB and BPBD must immediately form a Quick Response Team (TRC). The TRC's job is to quickly and accurately assess the disaster's impact and provide support for emergency disaster management (BNPB, 2017). The results from the TRC are reported to the Head of BPBD and the Head of BNPB in forming emergency response institutions, as shown in Figure 7. From this assessment, BNPB can find out the types of needs required by the community. The rescue and evacuation of victims, protection of property, fulfillment of basic needs, refugee protection, and recovery of facilities and infrastructure should also be done as quickly as possible (BNPB, 2017). BNPB and BPBD must also constantly coordinate with PVMBG regarding changes in Mount Agung's activity levels.

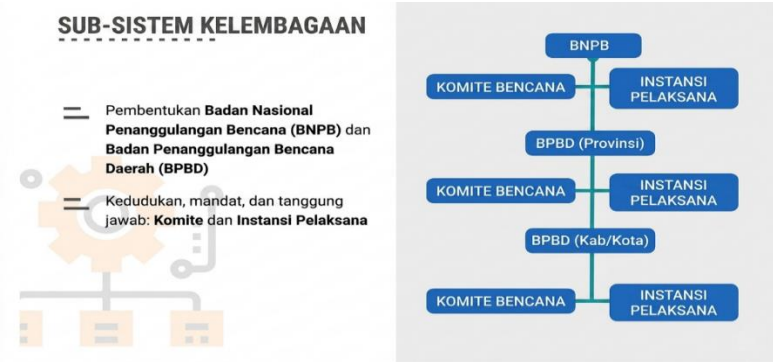



Figure 7. Institutional Sub-System

Coordination with BMKG is needed to get information about the ash from eruptions when Mount Agung starts to erupt. The distribution of volcanic ash, its direction, and thickness in the air can be observed by BMKG's Himawari satellite. This also serves as a basis for determining which areas are most affected by volcanic ash. The information provided by BMKG is usually updated every 10 minutes after an eruption occurs.

Meanwhile, coordination with the local government is more about getting real population data for the affected areas, the demographic distribution of the residents, and the availability of public facilities, especially healthcare. Together with PVMBG, the local government can also do socialization about the dangers of Mount Agung's eruption. The goal is to educate the public and fight hoax news that usually circulates on social media.

Coordination with the Ministry of Public Works and Housing (PUPR) is done to get information about which infrastructure might be affected by the eruption of Mount Agung, especially residential housing. Information on road access for transportation can also be obtained from PUPR (Bappenas & BNPB, 2011). If some facilities are damaged, together with the local government, the recovery of facilities and infrastructure can be repaired together.

The Ministry of Transportation, especially the Directorate General of Aviation and aviation stakeholders, need to get information about the eruption of Mount Agung. This will serve as the basis for the ministry to decide whether it's necessary to close airports or reroute flight paths. Information about the eruption is usually obtained from PVMBG, commonly referred to as VONA (Volcano Observatory Notice for Aviation – Eruption information for aviation). This was also done in the study by Setyawan and Edralin in 2023. AirNav and the Darwin VAAC (Volcanic Ash Advisory Center) will then evaluate the Impact of volcanic ash distribution on flight routes or airports (Prata, 2015).

**2. Determining Safe Evacuation Areas for Affected Communities**

The determination of a safe evacuation area can be made using the KRB Map created by PVMBG. Besides safety, the next parameter that needs to be considered when deciding an evacuation site is the availability of public facilities and adequate road access (Fariza & Handayani, 2022). This will make it easier for BNPB to supply basic necessities. Information posts and aid posts also need to be set up to receive help from the community and provide accurate information regarding the eruption of Mount Agung.

Some areas sometimes require guard posts to keep people from entering the danger zone of the volcano (Syahbana et al., 2017). Guard posts are sometimes placed at the homes of evacuees to look after their belongings during

the evacuation process. Pregnant women, the elderly, and toddlers are the top priority for evacuation assistance (Hidayati et al., 2006).

Figure 8 explains the planning for emergency response conditions related to evacuation areas. It is divided into two categories: Buffer Villages and Sister Villages. Buffer villages are villages/areas around the volcano that are located outside the danger zone. Sister villages are neighboring villages/areas but are also located outside the danger zone.

Figure 8. Emergency Response Condition Planning Map

In setting up evacuation areas, BNPB also needs to quickly provide basic necessities that help refugees get by during their stay. These basic needs usually include food, access to clean water, beds, blankets, public toilets, and medicine (Damayanti et al., 2017).

**3. Conducting an Assessment of Human Resources Affected by the Mount Agung Eruption and the Availability of Facilities and Infrastructure**

After the evacuation is done, assessing the affected human resources needs to be carried out immediately. This can be used as a reference for distributing aid so that the aid distribution can be effective and efficient. Recording the availability of public facilities (both damaged and undamaged) also needs to be done so that it's clear which facilities can be used or need urgent repairs.

**4. Meeting Basic Needs**

After getting the number and distribution of refugees, the next step is to meet the basic needs of the refugees. Fulfilling these basic needs can use APBN, APBD funds, or aid from the community. Meanwhile, the construction of public

facilities can be done in cooperation with the Ministry of Public Works and Housing.

The provision of basic needs is carried out as soon as possible after the refugee data has been obtained. Health checks for refugees also need to be done regularly. In addition, sometimes refugee support is needed to take care of their mental health, considering the uncertainty of when the Mount Agung crisis might end (Astuti & Rimawati, 2020).

**5. Survey of the Affected Area Location**

Location surveys of affected areas can be done by the TRC to find out the real conditions on the ground. The results of this survey can also later be used by PVMBG or BNPB to remap the affected area (to make it more accurate).

**6. Socializing with the Community About the Risks and Threats that Might Occur**

Socialization about the dangers of volcanic eruptions is given to the community with the aim of educating and providing understanding of the potential hazards. In addition, socialization can also give a sense of security to the evacuees, as it shows the presence of the government among the people (Astuti & Rimawati, 2020). Socialization can also help fight against hoax news. It is usually carried out in evacuation areas or places provided by the local government or nearby residents.

Socialization activities are carried out by delivering directions and information clearly and in a way that is easy for the community to understand. This information includes explanations about various potential threats that may occur during the eruption of Mount Agung. Additionally, explanations are also provided regarding the types of hazards that might arise, along with education on the mitigation steps that the community needs to take to avoid and reduce the risks from these threats (Fariza & Handayani, 2022).

**7. Ensuring Transportation Routes to Make Mobilization and Evacuation Easier**

The readiness of transportation infrastructure is a crucial component in supporting effective mobilization and evacuation during the emergency response phase. This effort is needed as a precautionary measure against potential sudden changes in Mount Agung's activity, which could lead to an expansion of disaster-prone zones (BNPB, 2017). With optimal planning and preparation of transportation routes, the evacuation of residents and resource mobilization can be carried out more quickly, efficiently, and in a well-coordinated manner (Fariza & Handayani, 2022).

**8. Using Social Media to Share the Latest Information and Counter the Spread of Hoaxes in the Community**

The use of social media during the Mount Agung eruption became an important part of emergency response to quickly spread information about the volcano's status, danger zones, and evacuation routes (Fariza & Handayani, 2022). In addition, social media was used to clarify hoaxes that could cause panic. In this way, social media helps spread accurate information, improves digital literacy, and assists people in making the right decisions during disasters (Astuti & Rimawati, 2020).

## CONCLUSIONS AND RECOMMENDATIONS

Based on the research results, the effectiveness of emergency response to Mount Agung's eruption, as seen through GPS monitoring results, shows that the success of disaster management is largely determined by the integration between technology-based monitoring systems and solid institutional coordination. Emergency response strategies, including strengthening communication across stakeholders, setting evacuation zones based on disaster-prone area (KRB) maps, assessing resources, and fulfilling the basic needs of the community, have been proven to minimize the risk of casualties and losses.

Besides that, regulatory support and the role of institutions, especially the synergy between PVMBG and BNPB, are key factors in ensuring a structured and coordinated response. Using social media to spread information also helps raise public awareness and reduce the spread of false information. So, an emergency response approach backed by infrastructure readiness, inter-agency coordination, integration of information systems, and community participation becomes an important element in improving the effectiveness of handling volcanic eruptions comprehensively.

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