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# The Characteristics of Volcanic Eruption in Indonesia

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## Abstract

This chapter discusses the unique characteristics of the volcanic eruptions in Indonesia. We know that Indonesia has 147 volcanoes and 76 of them are active volcanoes and spread along the islands of Java, Lesser Sunda, Sumatra, and Celebes. The characteristics of Indonesian volcanoes are quite unique in terms of the formation process, eruption phenomenon, and the resulting natural disasters. Most volcanoes in Indonesia consist of stratovolcanoes, but this does not mean that the resulting eruptions are always explosive and they have a long period. This can be seen from the activity of Semeru that always erupts effusively every day, Sinabung that has a very short eruption period, Tangkuban Perahu eruption that occurs suddenly with the lack of early signs, and Merapi and Kelud that have eruption period that is getting shorter. Based on the results of our study it can be known that the types of volcanic eruption are influenced by the structure of the constituent rocks of the volcanoes. However, the presence of external control factors in the form of large-scale earthquakes will affect their periodicity. The large earthquakes can affect the stability of the magma chamber that can trigger a premature eruption.

**Keywords:** volcanic eruption, natural disaster, Indonesia volcano

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## 1. Introduction

Indonesia is one of the equatorial countries located in the Pacific Ring of Fire. These areas have formed a horseshoe of approximately 40,000 km (25,000 miles) from South America to North America through the Bearing Strait, Japan up to New Zealand. Along the Ring of Fire, there are 452 volcanoes, of which 75% are in active status. It can be said that Indonesia is a country having the most active volcanoes in the world.

Indonesia has a great number of volcanoes in the world. There are 147 volcanoes, and 76 of them are the active volcanoes and spread along the islands of Sumatra, Java, Celebes, and Lesser Sunda (**Figure 1**). This means Indonesia has a tremendous opportunity to face eruption disaster in next future. It can be said that Indonesia is the windows of volcanic world.

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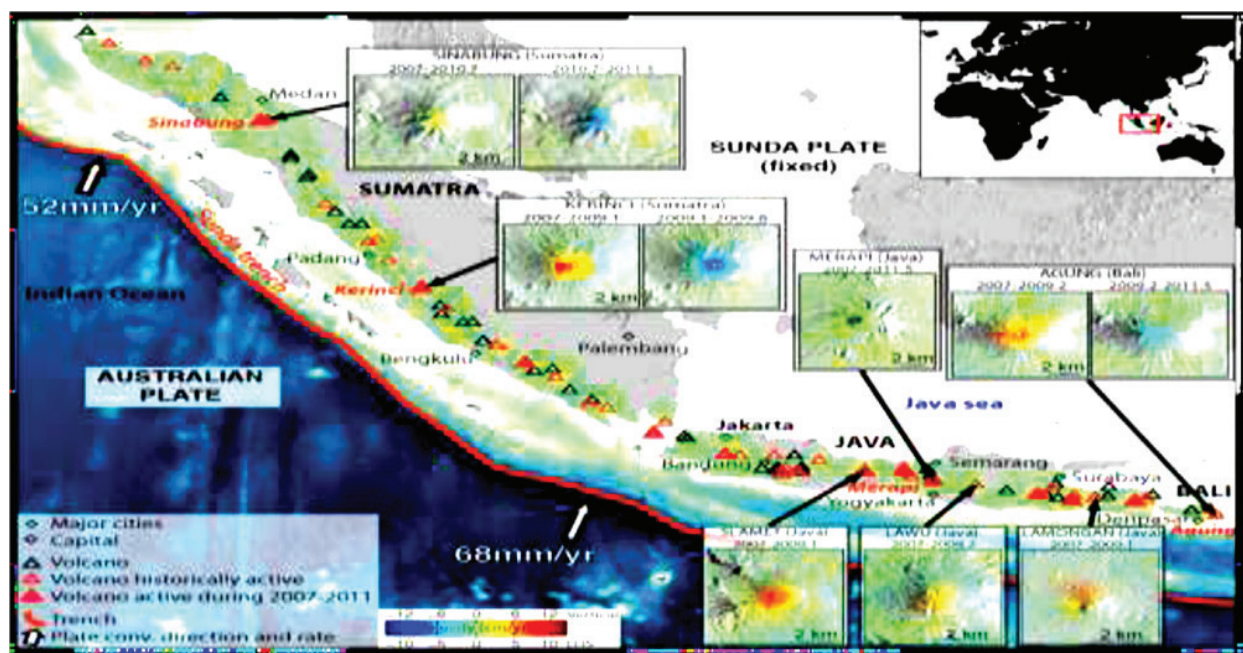


Figure 1. The map of volcanoes distribution in Java and Sumatera Island ([www.rsmas.miami.edu](http://www.rsmas.miami.edu)).

The volcanic eruption is one of the terrible types of natural disasters in Indonesia. In addition to the high casualties, the eruption disaster is also followed by large-scale infrastructure damage and by changes in social institutions and in the long-term economic impact. One example is the eruption of Mount Sinabung. Based on the record from the Center for Volcanology and Geological Hazard Mitigation or Pusat Vulkanologi dan Mitigasi Bencana Geologi (PVMBG), Sinabung has shown the eruptive activity since 2010 until now. Hot clouds (Indonesian = wedus gembel) and volcanic ash are constantly out of volcano ventilation. They damage most of the surrounding agricultural areas around the mountain. In addition to the economic impact, this condition is also very unfavorable for the psychological community. They live in the shadow of fear of eruption disaster.

Besides the Sinabung eruption, Indonesia has 20 most active volcanoes of Merapi, Kaba, Kerinci, Anak Krakatau, Papandayan, Slamet, Bromo, Semeru, Batur, Rinjani, Sangeang Api, Rokatenda, Egon, Soputan, Lokon, Gamalama, Dukono, Karangetang, Ibu, and Talang. Although the level of awesomeness is not as big as the previous disaster, the impact of the eruption on the environment and society is quite alarming. This is very disturbing to life and economic stability of the community around the volcanoes. Based on the record from the global database on natural and technological disaster or emergency events database (EMDAT), volcanic eruption is the third greatest disaster in Indonesia after flooding and earthquakes and also has the second highest number of casualties after the earthquakes (Figure 2).

The characteristics of Indonesian volcanoes are enticing in terms of the formation processes, eruption phenomena, and generated impacts. Usually, the types of volcanoes are represented by stratovolcanoes. They were shaped as results of subduction of the earth crust in subduction zones, but this does not mean that the resulting eruption is always explosive and in long periods. This can be seen from the activity of Semeru as a stratovolcano that erupts every day

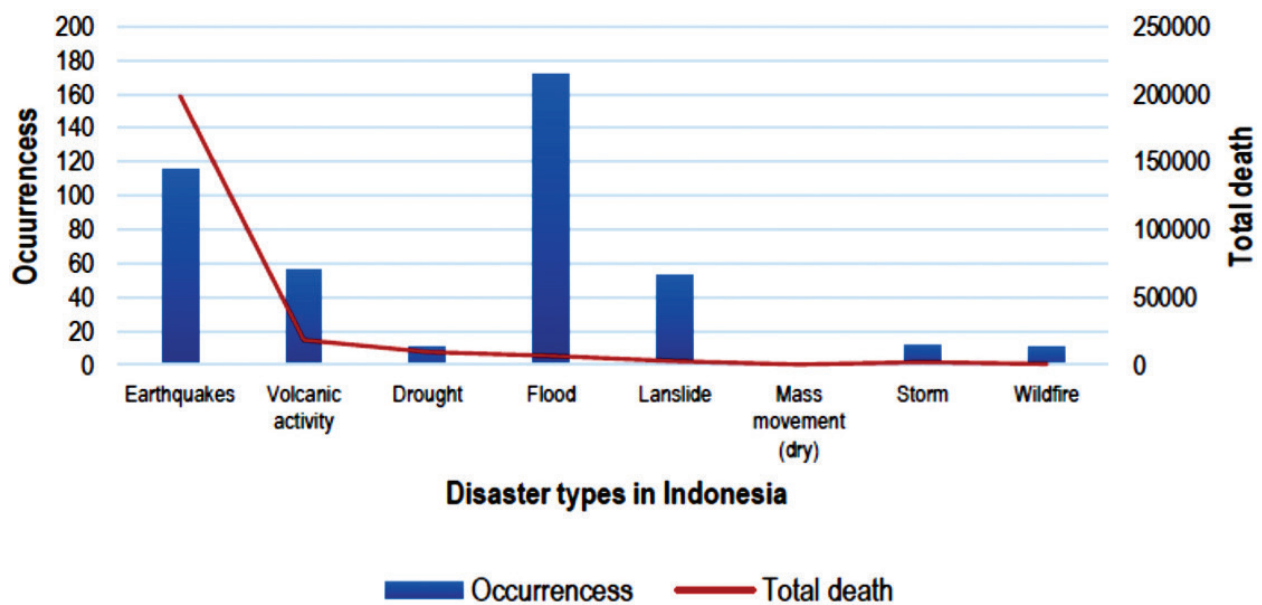


Figure 2. Disaster impact in Indonesia from 1900 to 2016 (modified from EMDAT, 2016) [1].

effusively with low explosive. Others from Sinabung relatively have short eruption duration and are unpredictable when it stops. Tangkuban Perahu eruption features occurred suddenly, showing weak initial signs. Merapi and Kelud have an increasingly short eruption period.

These phenomena are very interesting to be discussed in depth. Starting from eruption parameters until surrounding impact, there are many unanswered questions about the idiosyncrasy of volcanoes in Indonesia. This chapter will describe in detail the characteristics of several volcanoes and their impact on the environment and society. Through the study, it is expected to provide an overview of the volcanic eruption phenomena in Indonesia.

## 2. The profile of characteristic volcanic eruption in Indonesia

Some examples of Indonesian volcanoes are considered to have differences compared with the volcanoes in general, among others, Merapi, Semeru, Kelud, Tangkuban Perahu, and Sinabung. The five volcanoes represent the discrepancy of the characteristics of hundreds of volcanoes in Indonesia. The first four volcanoes occur on the Java Island, while Mount Sinabung is located on the Sumatra island.

Mount Merapi is a large Quaternary stratovolcano that is located in Sunda arc [2]. It is known as the most active volcano in the world and is considered the most dangerous volcano with pyroclastic flows generated by the collapse of the lava domes [3]. The mountain is an andesitic volcano and located in central sector of Java [4], between the Java Sea and the Indian Ocean, having a height of 2986 m above the sea level (Figure 3). The Merapi is located on 7° 32' 30" South latitude and 110° 26' 30" East longitude and lies in a subduction zone between the Indo-Australian and Eurasian plates. This location has controlled the volcanic activity in Sumatra, Java, Bali, and Lesser Sunda [5].





Figure 3. Merapi location map in central of Java (rinjanionline.com).

Mount Merapi is a volcanic cone having a magma composition from basaltic to basaltic-andesitic [6], with silica content ( $\text{SiO}_2$ ) ranging between 52 and 56%. Based on the silica content, it can be resumed that the eruption of Mount Merapi is mildly explosive. The nature of the basaltic andesitic magma is capable to flow from short to not too long distances and to destroy the surrounding settlements.

The unique characteristics of the eruption of Merapi can be seen from the changes in the eruptive cycle. As shown in **Figure 4**, since the sixteenth century, Mount Merapi erupted 80 times with a period of 4 years and a remaining time of about 1–18 years. From the starting eruption until the mid-eighteenth century, Merapi eruption index tended to increase but decreased in the mid-nineteenth century and increased in turn in the early twentieth century, with the volcanic explosivity index (VEI) ranging between 1 and 2.

The longest period of quiescence of the Merapi volcano was recorded in the eighteenth century, when the eruptions had a low index. In the middle of the twentieth century, the Merapi eruptions were consistent with the emplacement of effusive lava domes and generated pyroclastic materials having a small volume [7]. The pyroclastic flows dominated the eruptions in the twentieth century, but much larger eruptions occurred in the nineteenth century. Although the periodic interval is shorter, the Merapi explosivity index was constant at each eruption period and suddenly increased reaching the highest index (VEI 4) in the 2010 eruption (**Figure 4**).

The most dangerous eruption from Merapi is the hot cloud (Indonesian = wedus gembel). It is said “wedus gembel” because the resulting hot clouds are clumps like wool. This hot cloud is a pyroclastic flow generated from the lava dome fall due to mixtures between hot gases and volcanic particles and moving down the slopes of volcanoes with high speed [9]. The temperatures of the hot clouds range between 500 and 600°C and they are capable to move at speeds of up to 100 km/h. The high temperature of hot clouds can burn all the surrounding objects.

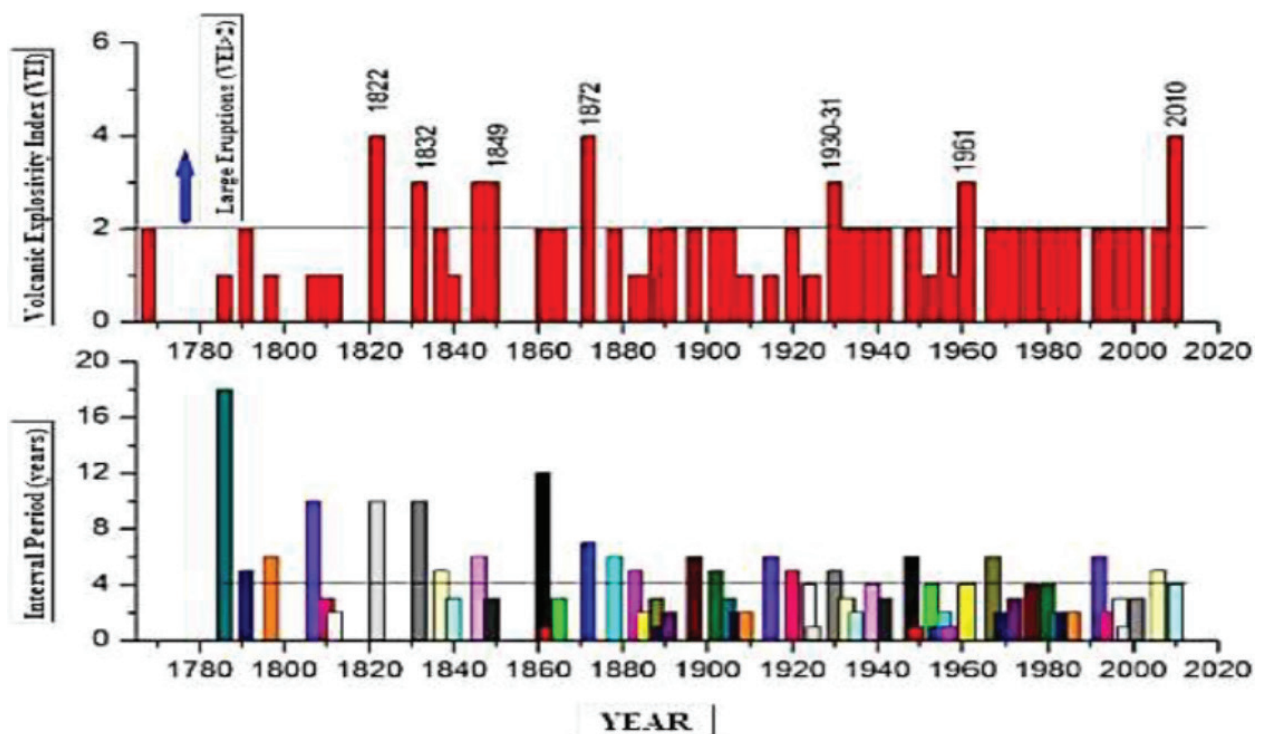


Figure 4. Merapi eruption statistics since the eighteenth century [8].

The eruption is also owned by Semeru. Semeru is one of the most active volcanoes in East Java. This mountain is better known as the peak of Mahameru because it has highest mountains on the Java island [10]. Semeru is located on 08°06.5' South latitude and 112°55' East longitude. It has a height of 3676 m above sea level. It is a stratovolcano composed of andesitic rocks, with a silica content ranging between 46.5 and 60%.

Mount Semeru eruption was recorded since 1818 with an average eruption period ranging between 1 and 3 years. The characteristics of the Semeru eruption are different from that of Merapi. The type of eruption of the Semeru is Strombolian, because it involves the fragmentation of low viscosity basaltic magma by volatile degassing [9]. Other volcanological studies have suggested that the Semeru eruption type is vulcanian with VEI ranging between 2 and 3, because it has generated eruption columns, lava dome growth, and small pyroclastic flow [11], has produced basaltic incandescent lavas; and was accompanied by hot clouds. The greatest eruption occurred in 1944. The eruption resulted in a hot cloud with a volume of 6.8 million m<sup>3</sup> and the number of victims of the hot cloud reached seven people [5].

Semeru is known as liquid lava that always comes out every day. **Figure 5** shows the location map of Semeru and drainage channel that was constructed in 2010. This lava path leads to S and SE volcano, which is a densely populated settlement.

Since 1967, on average, every 15 min there is an eruption with a low explosivity index [12]. However, the eruption of Mount Semeru is considered not dangerous. The local government still allows tourists to perform climbing activities that usually start from the village of Ranu Pane, located to the north of the volcano. People around Mount Semeru believe if eruptions

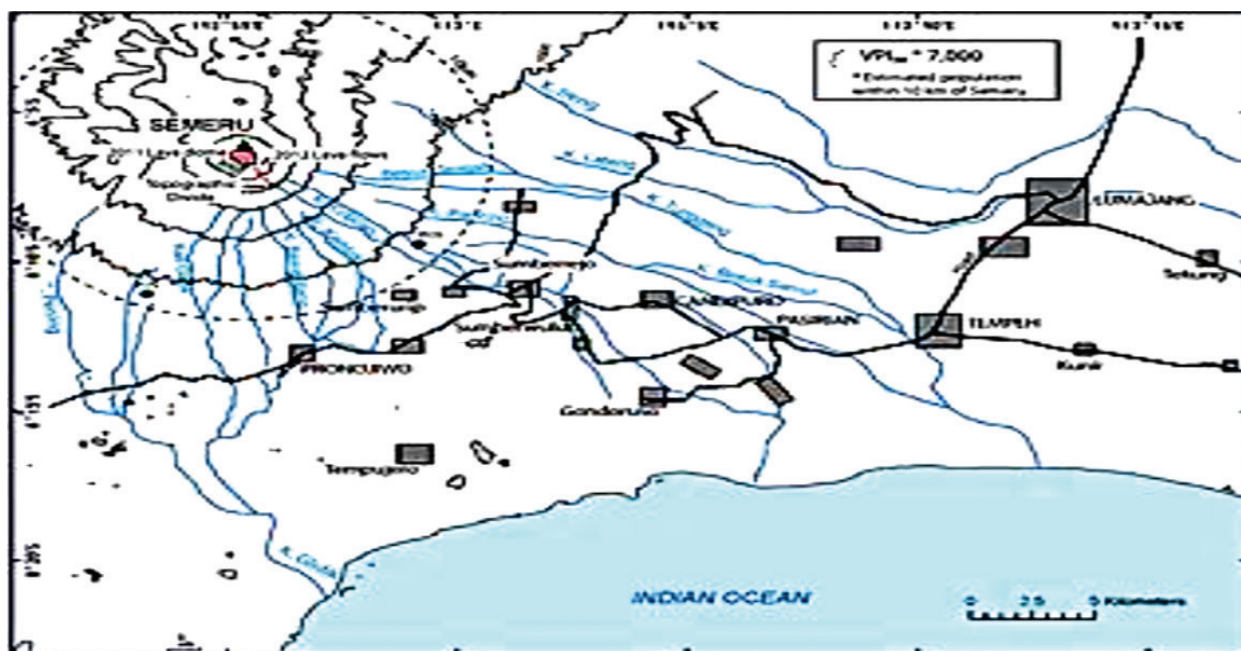


Figure 5. Semeru map and drainage channel (<https://volcano.si.edu>).

happen every day, Semeru remains safe because it will not be possible to erupt on a large scale. The increasing frequency of the Semeru eruption is becoming a unique geological phenomenon in Indonesia that is being investigated by volcanologists related to its causal factors.

The eruption characteristic is also experienced by Sinabung. It has happened in the last years and has been very difficult to predict. Mount Sinabung is part of an ancient volcano (Toba) and has an altitude of 2460 m asl, and the peak geography is in 3°10' North and 98°23.5' East latitude. The mountain was formed due to a fracture on the northwestern edge of the basin of Mount Toba [5]. It is located on the Sumatra Island belt produced from the Indo-Australian plate subduction process under the Eurasian plate [13].

Sinabung includes a stratovolcano showing its activity after a period of quiescence of 400 years [3]. This type of volcanic edifice is characterized by a tall conical building structure and is built by many layers of hardened lavas, tephra, pumices, and volcanic ashes [14]. The characteristics of the Sinabung eruption are different from that of the other volcanoes in Indonesia. In addition, they are difficult to predict, although a relatively short duration of the eruption has been observed. One of the volcanic products of Sinabung is a hot cloud capable of damaging the surrounding environment (Figure 6).

The relationships between the Sinabung and the Toba volcanoes are very close. This context can be known from the structure of their constituent rocks. Based on the results of the morphologic study of the Sinabung rocks, it can be known that the basement of the Sinabung volcanites consists of limestones and of the pyroclastic deposits of Toba [5]. These lithologies should have controlled the Sinabung eruptions that were always accompanied by thick eruptive products with a relatively high frequency of eruption.





Figure 6. Sinabung eruption with hot clouds [15].

On the other hand, Mount Kelud is one of the active volcanoes in eastern Java. Now it has entered into a period of quiescence after a major eruption occurred in 2014. Although the altitude of the volcano is lower than Merapi, Semeru, and Sinabung (1731 masl), Mount Kelud is also classified as a stratovolcano. This mountain was formed after the subduction of the Indo-Australian and Eurasian plates. Mount Kelud eruption was known due to the volume of ashes that were distributed widely until the radius, reaching hundreds of kilometers and covering almost all of the Java Island (**Figure 7**). Besides flowing lavas and resulting ashes, the eruption disaster also comes from the mud flows and from the floods that damage the surrounding environment.



Figure 7. Distribution of Kelud ash in Java [15].

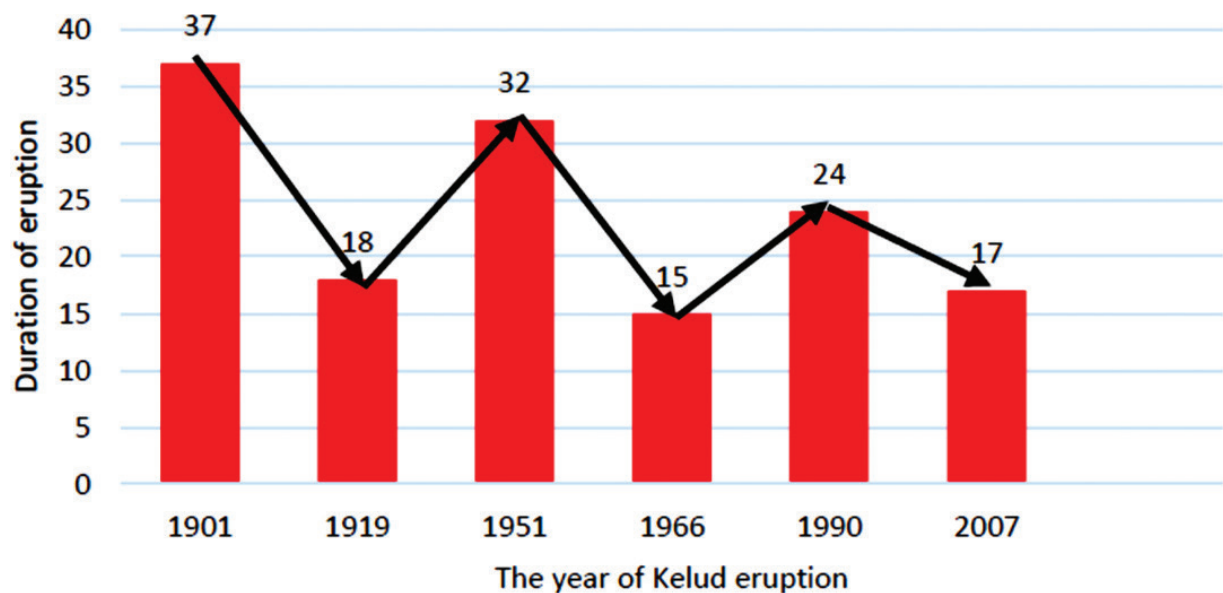


The eruption phase of Kelud is well ordered relatively and got into a rest period after a major eruption in 2014. The Kelud activity is still present. This can be seen from the various signs of volcanic activity that were recorded by the monitoring officer. One of the interesting natural phenomena is the birth of the Kelud Son (Anak Kelud), which occurred during the 2007 eruption. It indicates that the volcano is still active.

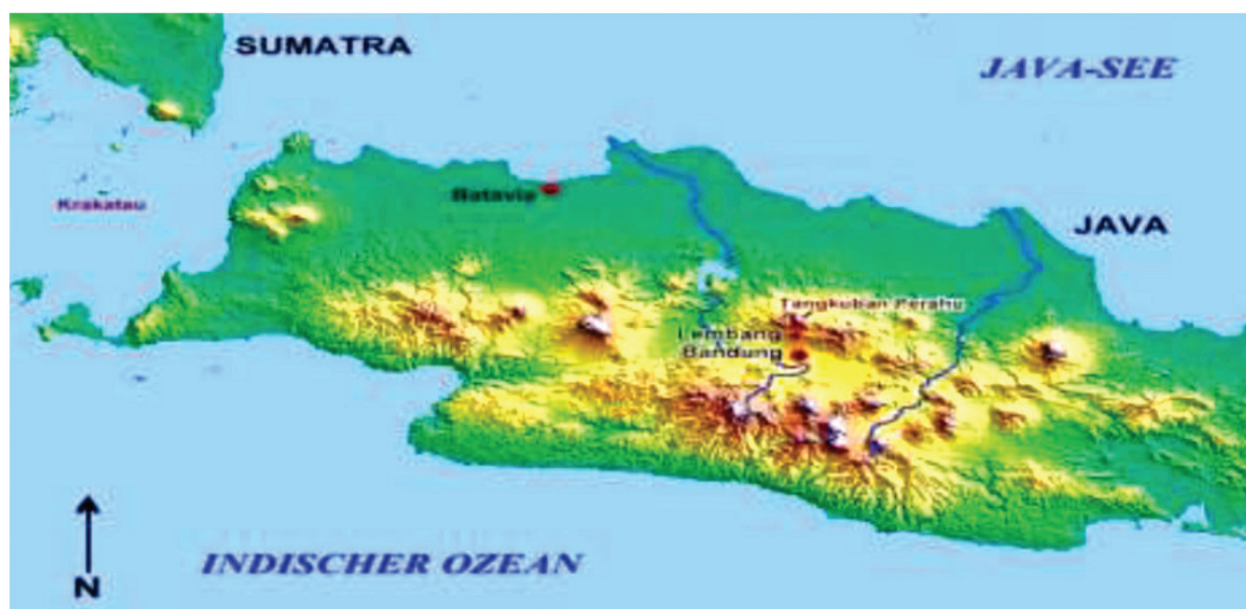
The characteristics of the Kelud eruption were influenced by the silica content, relatively high. The eruption type is Pelean, attributed by thick lava bursts containing more than 66%  $\text{SiO}_2$  [16] that inhibit the flow of gas and steam. This causes great shocks during eruptions and produces a very high explosive sound, which can disturb the upper atmosphere layers (ionosphere) [17]. The body structure of Kelud is stronger than the other volcanoes. The volcanic products are represented by pyroclastic rocks due to flows, fall-out, or lavas with the composition of K-basalts and K-andesites. This composition controls the factor that the probability of lava dome collapses is small, so that the hot clouds are not generated from the Kelud eruption.

**Figure 8** shows the Kelud eruption activity during the twentieth century, when the times of eruption were getting shorter and shorter. Based on this figure, it can be predicted that the Kelud volcano will erupt again at intervals of around 21.3 years. Then the next eruption is predicted to occur after 2030.

The next interesting discussion deals with the eruption of Tangkuban Perahu. This is one of the active volcanoes in Indonesia. It is a stratovolcano located on the highland area of Bandung West Java, with the height of 2087 masl (**Figure 9**). Tangkuban Perahu was formed from the calderic collapse of the Sunda Mountain [18]. Rows of mountains when viewed from a distance looks like a boat upside down and then were called Tangkuban Perahu, which means an upside down boat.



**Figure 8.** An interval of eruption of Kelud after twentieth century [5].



**Figure 9.** Tangkuban Perahu location in West Java (en.wikipedia.org).

The effusive pattern of the eruption with minimal signs makes the eruption of Tangkuban Perahu quite unique. Besides, it has a great geothermal potential, and the eruption characteristics of this volcano are different from that of the other volcanoes in Indonesia. Since the nineteenth century, the eruption of Tangkuban Perahu volcano is phreatic by producing ash without lava flow, hot clouds, or incandescent rocks. However, it does not mean that the eruption of Mount Tangkuban Perahu is not dangerous for the people around it. One of the eruption products to watch out for are the poisonous gases  $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{SO}_2$  that harm human health or even cause death if inhaled in large quantities.

The large eruption of Tangkuban Perahu occurred in the eighteenth century by spewing material eruption enough and until the formation of eight crater lakes. After that eruption, its activity became weak. One of the uniqueness of the eruption of Tangkuban Perahu was the lack of eruption signs that were not very clear. Sometimes only detected the appearance of earthquakes tremor by monitoring stations sign the volcano have been erupted. This makes it very difficult for volunteer observers to determine the eruption status. However, the weak eruption still makes an eruption activity not too dangerous to the surrounding community.

### 3. The changes of volcanoes' behavior in Indonesia

Volcanoes and earthquakes are interconnected phenomena. But, in general, earthquake is one of the physical parameters to recognize volcanic activity. If the quantity and frequency of the earthquake are higher, it can be said that the activity of the volcano is higher too. This earthquake is called a volcanic earthquake. Based on the results of the latest geological research, an earthquake can affect the activity of the volcano, especially the earthquake that has a high Richter scale (RS) rating [19]. Earthquakes with great power affect the viscosity of magma and eruption style [7].

The effects of the earthquakes on the eruptive behavior are experienced by several volcanoes in the world. Based on the results of previous studies, it was shown that the large earthquakes followed by the eruptive activity include the earthquakes in the Hawaiian Islands, followed by Kilauea and Mauna Loa volcanic eruptions, the Landers earthquake, which triggered the eruption of Caldera Long Valley in 1992 and Denali Earthquake in 2002, triggering a local volcanic activity in North America [20].

Figure 10 shows the differences of volcanic eruption patterns before and after big earthquakes. Before the earthquakes, the volcanic eruption around the earthquake fields had a large time interval and the eruption frequency small. On the contrary, after the earthquakes, the eruption time interval tends to be small and the frequency large.

The impact of large earthquakes on changes in volcanic behavior is also experienced in Indonesia. In 2001 and 2006, the central Java region experienced an earthquake with a strength of 6.3 RS. The earthquake in 2001 caused the rise of Merapi fumarole temperature, while the earthquake in the year of 2006 caused the increase of magma extrusion and pyroclastic flow [21].

One example of changes in volcanic eruption behavior is Mount Merapi. It is one of the most active stratovolcanoes in Indonesia characterized by the growth of lava domes and dome falls accompanied by dangerous pyroclastic flows [22]. Over the past decade, Merapi had a small eruption every 2–6 years with an average VEI <3 and a low eruption volume ( $1 \times 10^6$ – $4 \times 10^6$  m<sup>3</sup>) [23].

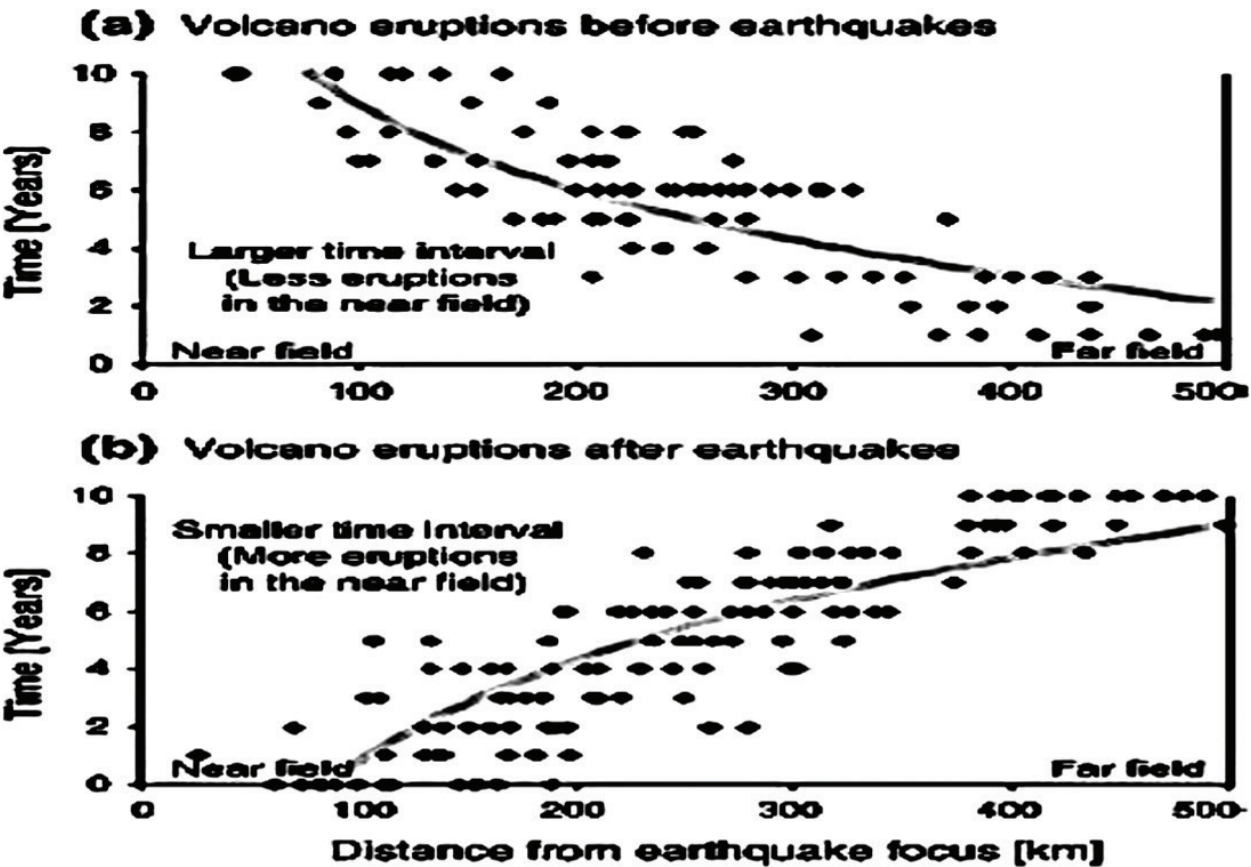
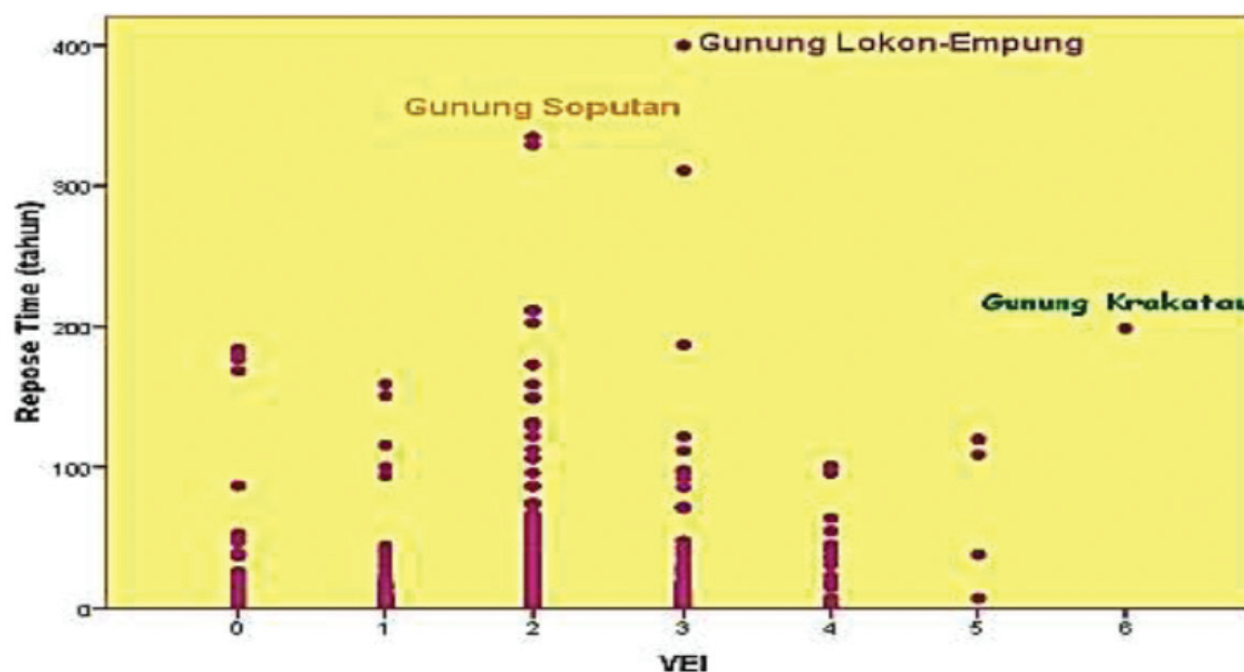


Figure 10. Scatter diagram of the relationship between the distance and time of eruption (a) before and (b) after the earthquake in Kuril and Kamchatka Islands [20].





**Figure 11.** Correlation between repose time and VEI for multiple volcanoes in Indonesia [24].

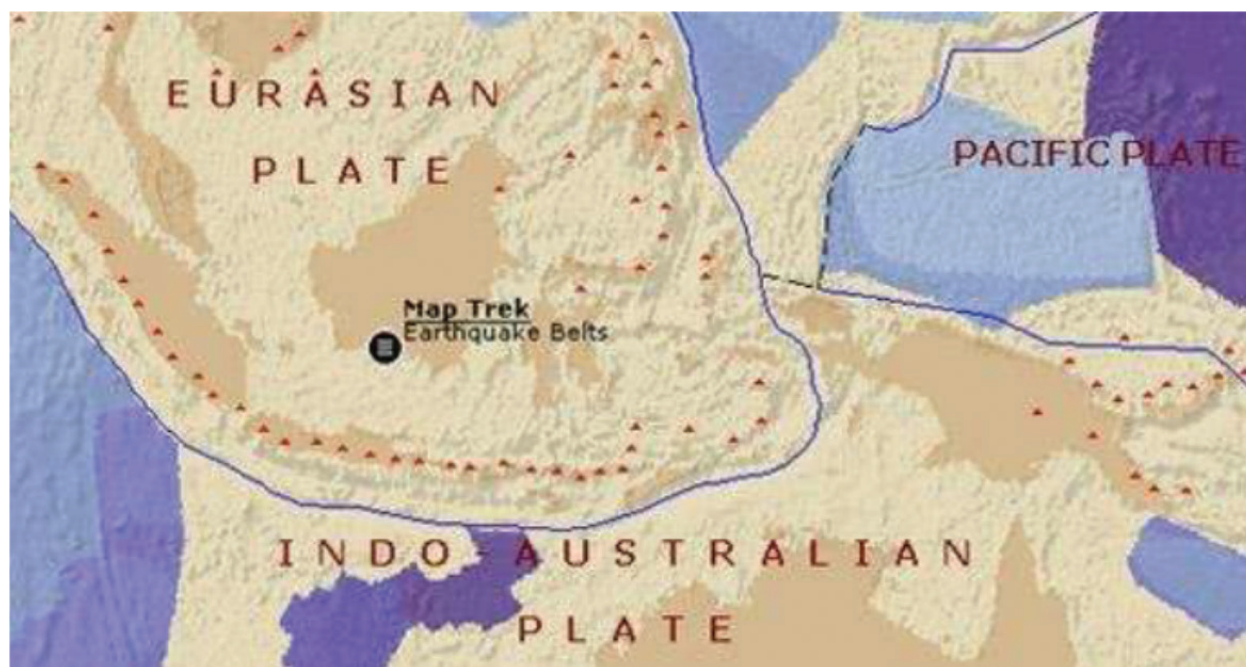
The changes in volcanic eruptive behavior in Indonesia can be seen both from the VEI and the repose time (**Figure 11**). As a general rule, the longer the repose time of the volcano, the bigger the eruptive activity, but it's not so now. This statement is supported by a study that pointed out that the repose time does not affect the volcanic eruption index in Indonesia [24].

#### 4. The eruption crisis of Indonesian volcanoes in the last decade

Indonesia cannot be separated from the volcano phenomenon [25]. This is a consequence as an equatorial state located at the meeting of three giant plates (Eurasian, Indo-Australian, and Pacific) (**Figure 12**). The three plates collide with each other (the Indo-Australian plate slips under Eurasia); therefore, Indonesia becomes the epicenter of earthquakes, volcanic tracks, and faults or ruptures [26]. Plate meeting areas allow for earthquakes and other disaster.

Being a country prone to eruption disaster, 10% of the Indonesian population lives in a volcanic region [27]. This condition is potential for large casualties when the eruptions occur. The Merapi eruption, which occurred in 2010, included a large eruption with the death of 386 residents and about 17,000 people facing respiratory problems [28].

The volcanic eruption activity in Indonesia has a diverse impact on the environment. The last 5 years of eruption of Merapi, Kelud, and Sinabung produced abundant materials that are beneficial for soil fertility. But many problems arise from excessive material eruptions, such as lava floods that can endanger the surrounding community. The volcanic products can pose a significant disaster if it affects people, agricultural areas, transportation and facility networks, and other social infrastructure [29]. Explosive eruption of volcanic with VEI > 3



**Figure 12.** Indonesia is located between three wide plates, such as the Eurasian plate, the Pacific plate, and the Indo-Australian plate (Indonesia geology map library, 2017).

as experienced by Kelud in the eruption of 2014. Volcanic material and gas of the mount can directly reach the height of the stratosphere [30], where aerosols stay for a long time, affecting the weather and climate [31–33].

Aerosol stratosphere plays an important role in climate regulation and atmospheric chemistry [34]. The gas emissions significantly affect the environment at different scales, depending on the extent of the gas emissions removed from the source prior to the deposition [35]. The explosive eruption injects sulfur into the stratosphere in the form of  $\text{SO}_2$  and  $\text{H}_2\text{S}$  that bind to form aerosol ( $\text{H}_2\text{SO}_4$ ) [36].

In small eruptions, sulfate aerosols formed after  $\text{SO}_2$  oxidizes to form  $\text{H}_2\text{SO}_4$  and can increase Earth's albedo by scattering short-wave radiation [37]. This greatly helps the global temperature drop.

Some volcanoes to watch out for in the last decade are Sinabung. Based on PVMBG data on the evaluation report of volcanic activity level recorded in June 2017, there was one volcano at level IV, 5 volcanoes at level III, 17 volcanoes at level II, and 49 volcanoes at normal (level I). The eruption type of Mount Sinabung is a vulcanian that is characterized by a smoke cloud as high as 5–6 km and effusive lava and causes the evacuation of 12,000 inhabitants [38]. Based on data of BNPB, temporary losses due to eruption of Mount Sinabung since 2013 until 2014 reached 1.49 trillion [15]. A large number as a result of sustained eruption and due to a continuous and unpredictable eruption have a negative impact on the community psychology around Sinabung. Significantly reducing hazards is necessary in order to minimize the damage [39].

In general, the number of people affected because of an eruption is relatively larger compared to other natural disasters in Indonesia. Based on **Figure 13**, the biggest eruption-affected population is on the island of Java. Once of the dangers of the volcanic eruption in Indonesia with all its characteristics and changes, there needs to be an improvement of the pattern of improving public preparedness in facing it. One way of doing that is by developing a pattern

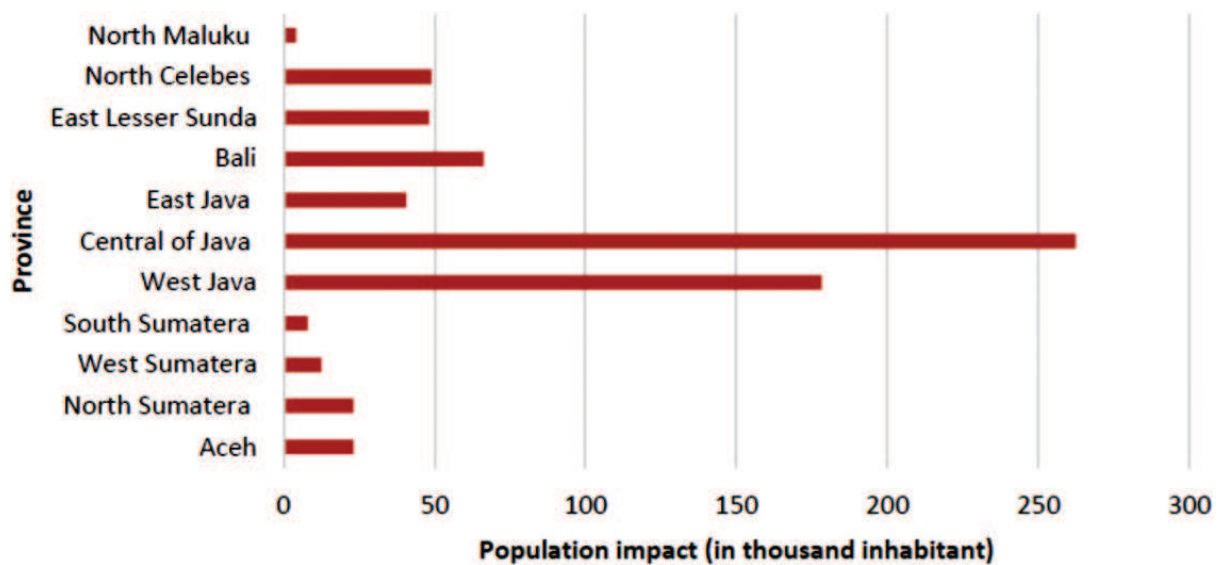


Figure 13. Matrix of population affected by the eruption of a volcano [26].

of mitigation into adaptation. Adaptation to the environment is indispensable when danger is inevitable [40]. The people must be aware that besides the blessings given by the volcano, there are hidden disasters that will come any time. If the people are more aware of the environment around the volcano, they more certainly will be safer in the face of danger.

## 5. Mitigation experience and public preparedness

Almost all the countries that have volcanoes will face the problems of eruption disaster and Indonesia is currently experiencing it. The problem of dealing with eruption disaster in Indonesia lies in the high number of people living around the volcanoes [41]. Due to the increase of population around the volcano, the impact of eruptions on communities increased. This condition is getting worse due to lack of public awareness of the eruption disaster.

Merapi eruption experience in 2010 left a bitter memory for the history of volcano eruption in Indonesia. As a result of eruptions and hot clouds, up to 277 people were killed [42]. But this number is relatively smaller than the previous eruption victims. It all depends on the level of eruption that occurred. The higher level of volcanic eruption have an impact on the more damage. However, the number of victims will be minimized if disaster mitigation is well implemented.

The characteristics of eruptive disasters differ from one disaster to the other natural disasters. They may occur at any time and they are difficult to predict [43]. The lack of historical data of Indonesia volcano eruption causes the preparation in the face of eruption disaster must be improved. This should be done to anticipate volcanic behavior changes that occur often lately.

The difficult case is predicting volcanic activity of the Sinabung eruption. The Sinabung activity is difficult to predict. After it entered a 400-year rest period, Sinabung has erupted continuously until now. The government continues maximizing the techniques and monitoring equipment of the volcano by providing more accurate information in accordance with the latest volcanic activity in Indonesia. This is closely related to mitigation efforts of the community.



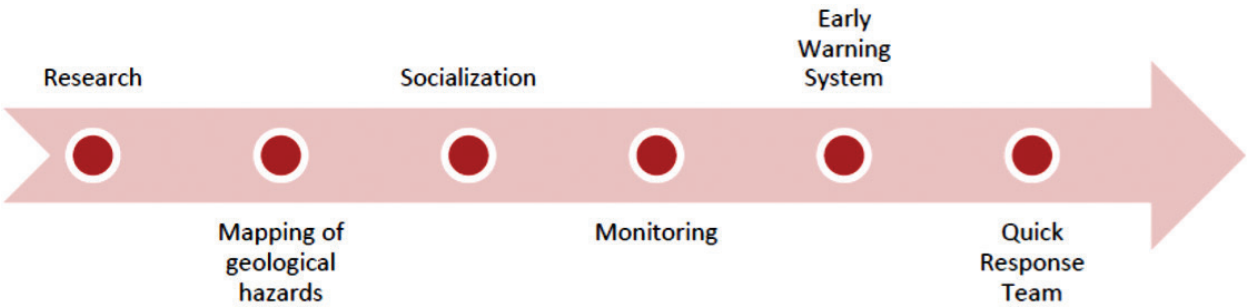


Figure 14. Step of geological hazard mitigation effort in Indonesia.

The Indonesia government has implemented six stages in efforts to minimize the victims of eruption disasters (Figure 14). This was done to support the accuracy and speed in providing services to the society in the face of eruption disaster. Research is conducted to analyze eruption model to support early warning system. Mapping of geophysical hazards to produce disaster maps that are indispensable for identifying disaster areas. Socialization to build public awareness and knowledge in eruption disaster areas. Monitoring has been done to observe, record, and analyze volcanic activity. Early warning system (EWS) to describe the status of volcanic activity and quick response team (QRT) to evaluate the condition of volcano during the crisis and the results were presented to the government and the community.

The concept of eruptive disaster mitigation in Indonesia is well developed. One of the handlings that was considered successfully by the international community is the evacuation of the population due to eruption of Merapi that occurred in 2010, the eruption of Kelud in 2014 without a victim, and the Sinabung eruption in 2017. There is a significant decrease of loss of lives from the successful mitigation of the government.

The success of mitigation in Indonesia can be seen in Table 1. Based on the table, there is a significant relationship between the number of casualties and the evacuated people. If the number of people evacuated is larger, then the victims of eruption become smaller.

The greatest challenge in implementing the disaster mitigation program in Indonesia is the awareness of the local government and the community. The problems of eruption are not

Countermeasures	Time period	Number of refugees	Fatalities
No mitigation action yet	1700–1920	0	More than 150,000
There has been a countermeasure system but not yet perfect	1950–1979	More than 5000	1613
The countermeasure system is good, using modern equipment to monitor volcano, communication network is good, public understanding about the danger of eruption has increased	1980–2004	232,197	105

Source: PVMBG 2014 Presentation.

Table 1. Mitigation effects to eruption fatalities in Indonesia.

only the responsibility of community or government separately, but it also becomes part of all components of the nation together. All of them must be involved in finding solutions. If all the components of the nation act in accordance with their role, Indonesia will be better prepared to face the challenges of eruption in the future.

## 6. Disaster risk reduction based on ethno mitigation

Indonesian society has a different perspective on volcano. Volcano is considered as a representation of greatness and beauty. Its existence is very important for the life of the people who live around. The communities on the slopes of the mountains have the belief that the eruptions cannot be separated from the contribution of supernatural forces. This can be seen from the belief of the people on the slopes of Merapi. They thought that Mount Merapi is not just a mountain, but a settlement of spiritual beings or invisible spirits [44].

Volcano disaster provides a meaningful example of how communities apply cultures, religions, and ceremonies to communicate and remember disaster risks and mitigation strategies [45]. But the understanding of the society is based on myth only and it is not based on scientific knowledge and the existence of the culture is not widely understood by the community. The culture role is very important to reduce disaster risk and people's vulnerability [46].

The ritual offerings tradition was packaged in local culture by involving almost all elements of society that are able to build strong emotional bonds between communities around the mountain. The attitude of togetherness and mutual cooperation are very important in building community resilience in the face of eruption. The culture of mutual cooperation promotes positive values such as social harmony and mutually beneficial relationships within disaster-affected areas.

Local people's knowledge of the volcano environment around also greatly contributes to the success of the eruption disaster. Based on information from the people who live on the slopes of Kelud, it is known that the animals that descended the slope because of the eruption of Kelud include wasps, birds, monkeys, deer, and pythons. The changes in animal behavior were caused by the changes of environmental conditions, including higher local temperatures, increased gases concentrations (it can cause disruption of animal respiratory systems), and increasingly polluted environment due to the aerosols released. These signs are very important for local people in predicting eruptions.

Each or group of animals has a specific frequency range [47]. Birds are unable to hear the ultrasonic sound ( $>20,000$  Hz) but they are capable of hearing an infrasonic sound ( $<20$  Hz) [48]. These specific frequencies are used by animals to identify unknown threats from nearby environments. Based on the review of some literatures, the threshold frequencies of various animals are presented in **Table 2**.

Bangbara has the ability to hear high-frequency (ultrasonic) sounds, deer and mountain monkeys are able to respond to sounds at a medium level or equal to the hearing (audiosonic), and birds and pythons are able to hear infrasound frequencies. When volcanoes started to activate by emitting gas with high-frequency sound waves, only Bangbara wasps responded to these and this frequency level cannot be heard by others.

No.	Animal name	Family	Threshold frequency (Hz)
1.	Bangbara	Insect	25,000–50,000
2.	Deer	Mammals	500–32,000
3.	Monkey	Mammals	63–16,000
4.	Birds of Knee	Aves	200–4000
5.	Python	Reptile	80–160

**Table 2.** Threshold frequency of some animals on the slopes of Kelud.

The python has the lowest threshold frequency compared to other animals. This causes the snake to be able to respond to low-frequency vibrations. In addition, python snakes crawl on the ground and are less sensitive to changes in temperature and air conditions. The python is more sensitive to the vibrations it senses through its body than the smell through the nose [49]. At the time of vibration caused by the volcanic activity with increasing amplitude, the snake will soon evade. This condition can be a final marker when the Kelud will erupt.

The ability of animals around the slopes of Kelud in response to environmental changes can be arranged in sequence based on the level and speed of response. Changes in animal behavior are very interesting to be studied more deeply. It is very likely to be a traditional volcanic eruption warning system or traditional volcanic alert level (TVAL). This system will be more easily communicated to the people on the slope of Kelud as it is in accordance with the local knowledge and indispensable as a consideration in making decisions [50].

Local wisdom of mountain community is very potential as a basic in developing disaster risk reduction model that suits with the characteristics of the local community. In addition to preserving local wisdom as a local culture, it can help communities to face the eruption disaster.

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