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2 Anak Krakatau mountain (AKM) causes a rare tsunami phenomenon: impact around the Sunda strait, Indonesia

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Abstract. At the end of 2018, the rare tsunami phenomenon had been occurring at Sunda strait, Indonesia. This tsunami happened without feeling a huge earthquake, so many people did not know if there was a tsunami. Tsunamis occur at night and cause casualties, missing people, and damage around the Sunda Strait (Banten and Lampung). Previously, the observation of the activities of Anak Krakatau Mountain had been carried out intensively. Data collection is done from various sources. A literature study was also conducted to strengthen existing observations. From observational data open source obtained from the Badan Meteorologi Klimatologi dan Geofisika (BMKG) Indonesia, it was noted that earthquake activity by tectonic plates began in April 2018, while the intensity of the earthquake caused by increased activity of Anak Krakatau Mountain (AKM) began in June 2018. Eruptions and Tsunamis occurred on December 22, 2018. Although the alleged cause of the rare tsunami phenomenon has not been ascertained, the truth, from observations of satellite images and focus group discussions (FGD) from various society elements. Temporary allegations, the cause of the rare tsunami phenomenon is the AKM eruption, which makes the southwestern region of AKM island landslide of ~ 64 hectares to a layer below sea level. The impact that occurred after the tsunami has been reported by conducting surveys directly to locations on several beaches of Banten and Lampung. Damage that occurred around Banten and Lampung's coast was caused by houses very close to the coastline. Whereas in other areas that did not experience severe damage due to 2 factors, there are small islands that block the tsunami wave and the presence of mangrove vegetation around the Sunda strait.

1. Introduction

Indonesia is one of the countries included in the Ring of Fire area in the Asia-Pacific [1] so it has many rows of very active volcanoes [2]. Volcanic activity in Indonesia is influenced by the dynamics of the tectonic plate between the Eurasian plate and the Australian plate [3]. The meeting of the two plates, starting from the western coast of Sumatra to the southern islands of Indonesia [4]. In addition, Indonesia is one of the most active mountains in the world such as Mount Merapi, Mount Kelud, Mount Sinabung, Mount Bromo, Mount Soputan, Mount Lokon) [1]. Whereas in the history of volcanic eruptions in Indonesia, mountains that have a very dangerous history of eruption are Mount Tambora and Mount Krakatau [5].

The dynamic activities of tectonic plates and volcanoes also cause Indonesia to become one of the countries in the world that has the most track record of earthquakes in the world [6]. The earthquakes that occurred in Indonesia vary greatly in magnitude. Indonesia's Meteorology, Climatology and

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Geophysics Agency (BMKG) noted that almost every day in Indonesia experienced earthquakes along the volcanic front [1] (Fig. 1).

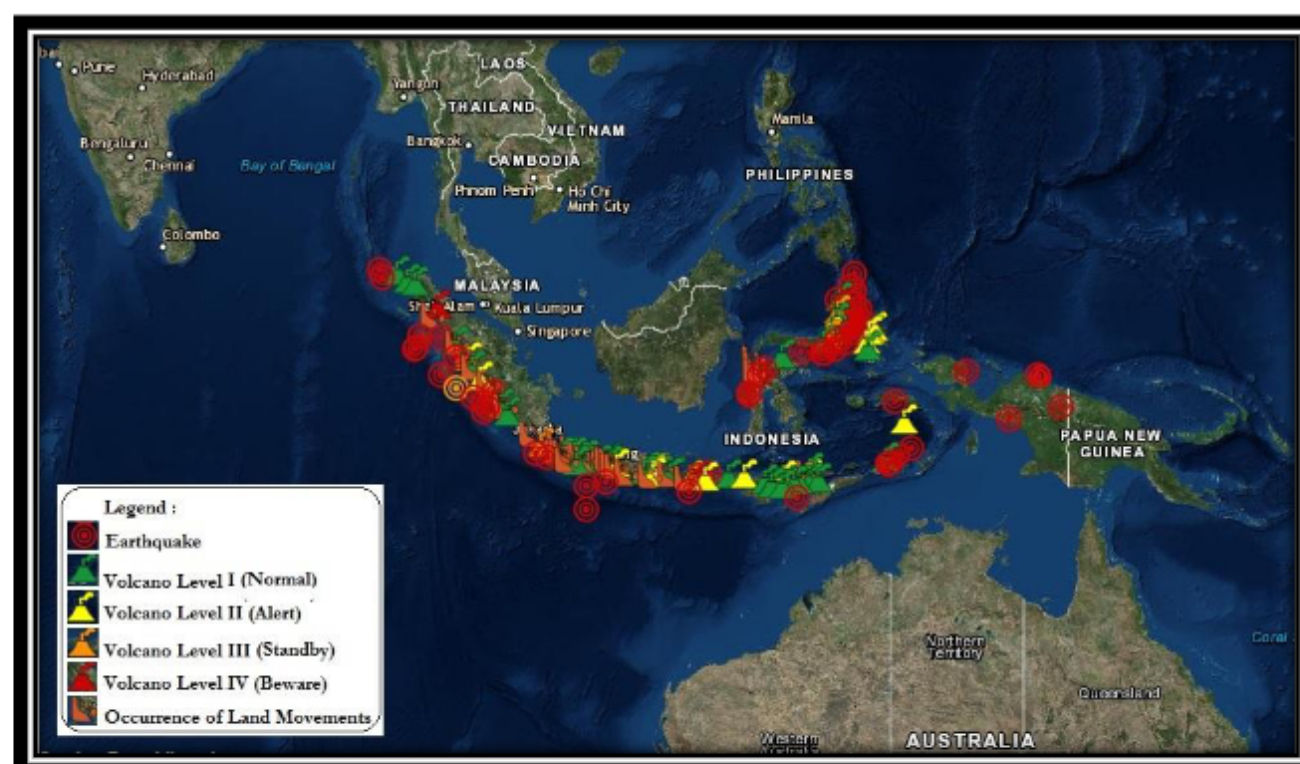


Figure 1. History of earthquakes, volcanic activity, and tectonic plate movements in the territory of Indonesia in 2018 (source: <https://magma.vsi.esdm.go.id/#>).

Earthquakes that originate from the dynamics of tectonic plates and volcanic eruptions can cause tsunamis [7]. The geographical factor of Indonesia which has the longest coastline in the world has caused a huge tsunami impact [8]. This is what causes Indonesia to conduct evaluations, observations, and mitigations to reduce the impact of natural disasters that often occur [9].

In this article, the author tries to discuss the observations of one volcano (AKM) activity throughout 2018, the impact of eruptions and tsunamis that occurred at the end of 2018, and data collection conducted through interviews, focus group discussions (FGD) after the eruption and tsunami in several Lampung-Banten regions. From these results, it is then discussed to obtain effective mitigation methods, especially in coastal or coastal areas.

2. Methods

2.1 Study Area

Krakatau Mountain is one of the mountains that has the most dangerous eruption history in the world [10]. In 1883, the huge Krakatau volcano eruption occurred in Indonesia [9,11]. The mountain eruption caused volcanic ash to rain, an earthquake and tsunami occurred. The tsunami that reached a height of ~ 30 meters. The number of fatalities recorded by the government at that time was 36,417 people were killed, None survived a total of 3,000 residents of Sebesi Island, located 13 kilometers from Mount Krakatau. Not only that, the tsunami that occurred has moved to the eastern part of Australia, and the southern part of Africa [7,9,12].

Krakatau's eruption caused a change in the geography around it. Several small islands around Krakatau Mountain were lost due to the Tsunami [13], the form of Mount Krakatau itself has undergone changes and formed a new location, namely Anak Krakatau Mountain (AKM) [12] (Fig. 2).

The geographical location of AKM is located at 6° 6' 5,8" LS dan 105° 25' 22,3" BT. AKM has a height of ~ 228 meters above sea level [12]. The type of rock around the AKM is volcanic rocks with ages below 100 years which are young rocks [10].

The presence of AKM in the Sunda Strait can cause Tsunami waves if an eruption occurs [14]. In the last decade during 2018, AKM activity has increased until it finally erupted at the end of 2018.

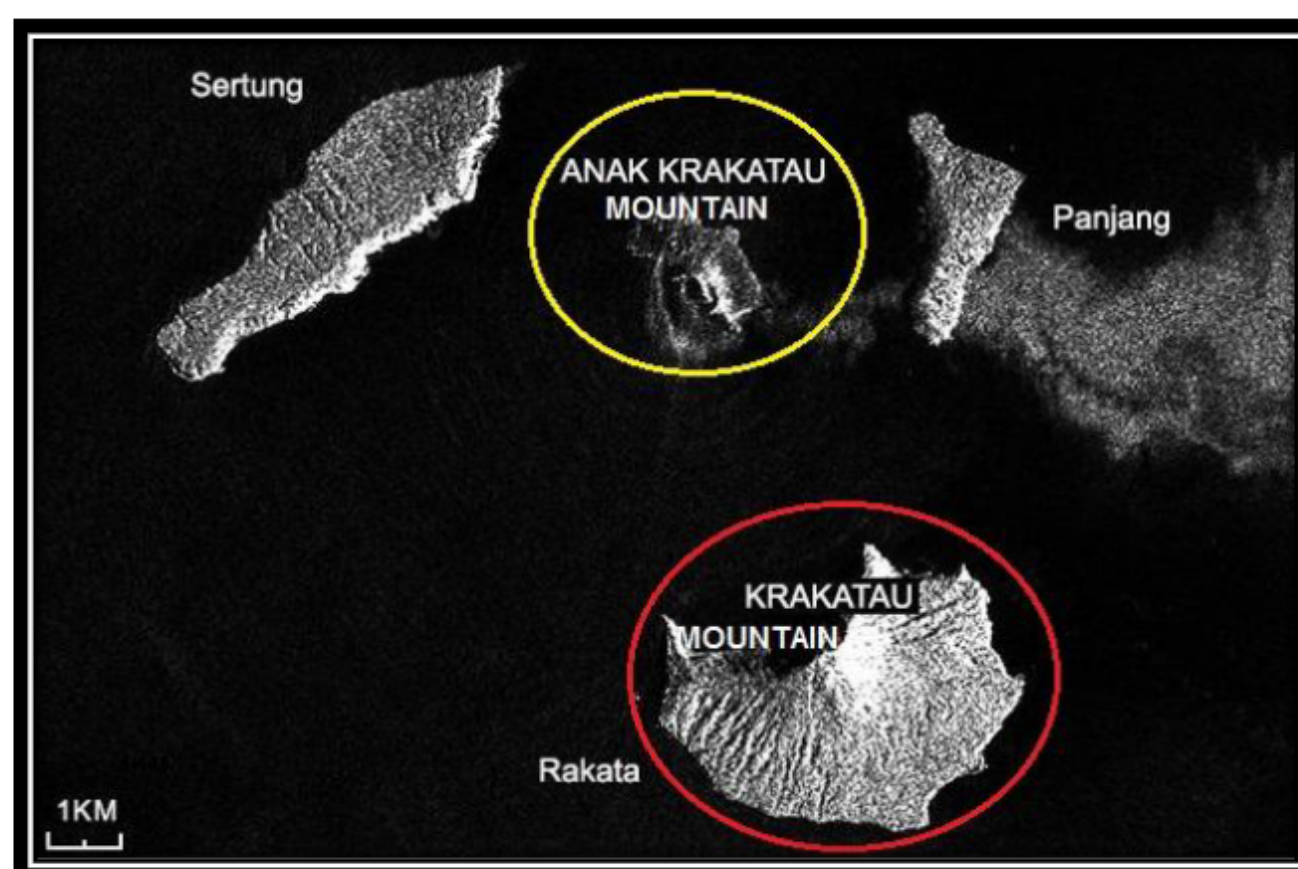


Figure 2. Location of Krakatau Mountain (red circle) and Anak Krakatau Mountain (yellow circle).

2.2 Method

This research was carried out in a literature study, and also direct observations from around the coastal area in southern Lampung and Banten. Information on volcanic activity data is obtained from BMKG and media information. Observation of geographical conditions around AKM is done using satellite imagery to obtain images before and after an eruption and tsunami disaster. In addition, data collection was also conducted through interviews, focus group discussions (FGD) used a qualitative approach with the latest data from various social elements (Fig. 3). The data is then discussed and evaluated to produce ideas and ideas as disaster mitigation measures, especially in coastal or coastal areas.

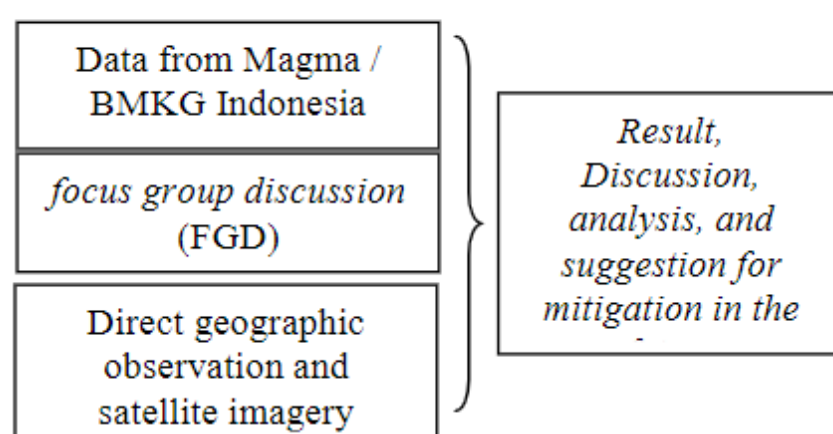


Figure 3. Research methodology (observation and data collection).

3. Results and Discussions

3.1 AKM's daily seismic activity

Volcanic activity (AKM) recorded by the Magma / BMKG Indonesia, shows that increased earthquake activity [15] by AKM starting from April 2018 (Fig. 4). The magnitude and number of earthquakes per day recorded on seismicity has dynamic data. This earthquake was recorded as coming from the activities of AKM (yellow) and tectonic plates (purple) (Fig.4 & Fig.5).

Increased tremor and earthquake intensity due to AKM activity increased significantly seen at the end of June 2018 - September 2018. Based on (Fig. 5.) tremor not recorded, is an AKM eruption or a

small eruption occurs. This small eruption occurred in the middle of July 2018, the end of July 2018, the beginning of August 2018, and until finally in September 2018 there was a large eruption.

Based on satellite image information carried out by BMKG and we get it from the media, the lava or magma that comes out, moves towards the southwest of the AKM and causes landslides in the southwest area of the AKM. In addition, based on the results of the FGD interviews in the Rajabasa sub-district, South Lampung, the boom or eruption sound was quite strong. Given the location of the Rajabasa sub-district, South Lampung is ~ 30km away [9] from the outermost areas of the island of AKM. The sound of AKM's small eruption activity is heard not only during the day, but also at night.

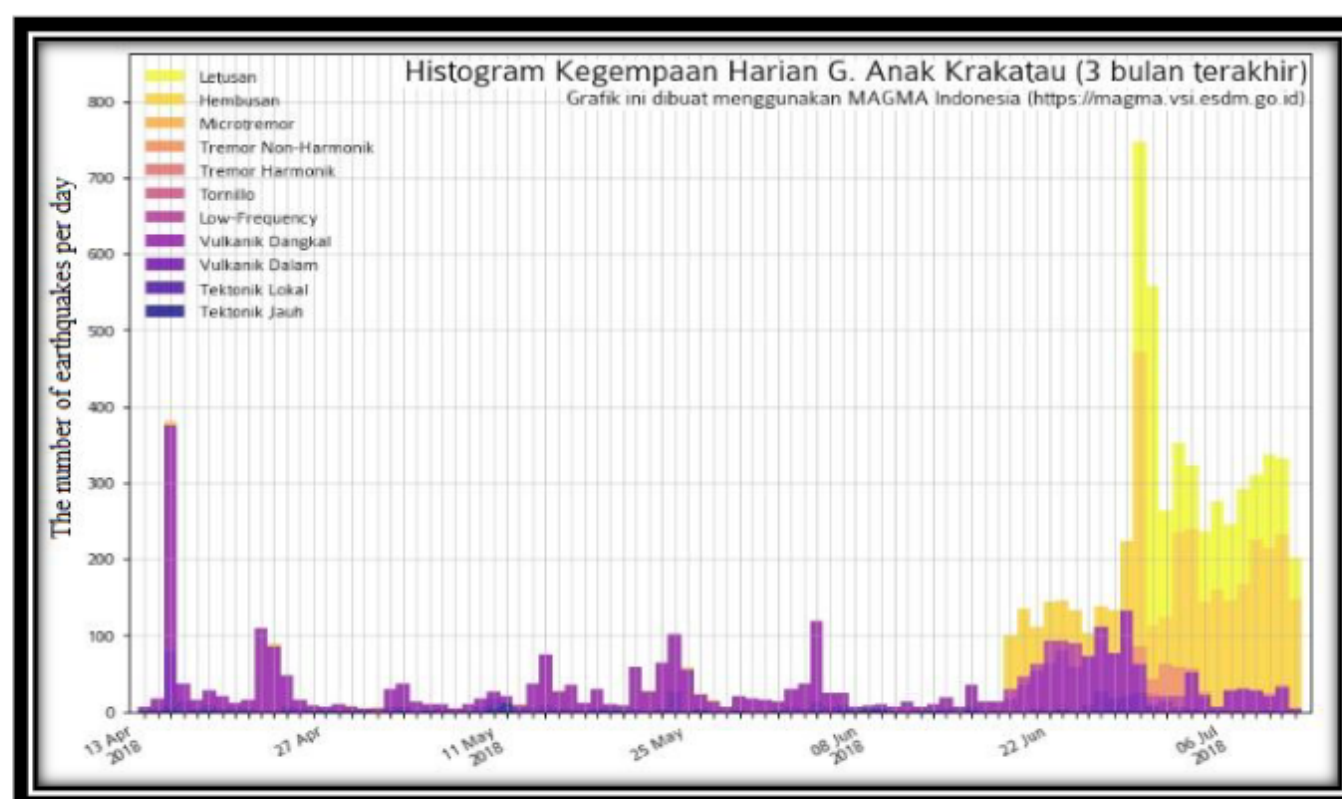


Figure 4. Histogram of AKM Daily Seismicity period April 2018 - July 2018 (Source: Magma Indonesia).

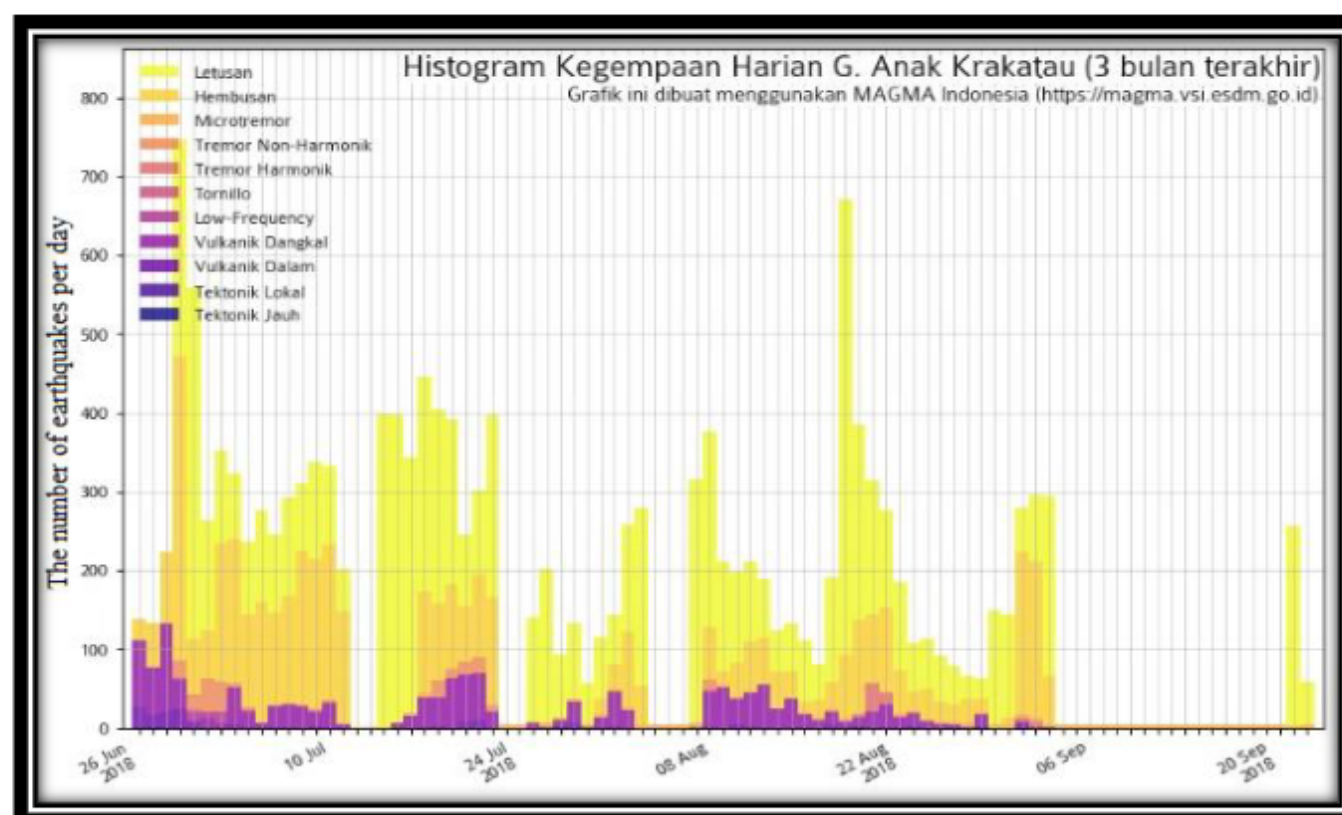


Fig. 5. Histogram of AKM Daily Seismicity for July 2018 - September 2018 (Source: Magma Indonesia).



Fig. 6. Anak Krakatau Mountain released a hot cloud (Left), Anak Krakatau Mountain erupted and released incandescent lava (Right)

3.2 AKM Erupts and makes waves of the Tsunami

On December 22, 2018, a rare tsunami phenomenon caused by the AKM eruption hit the coastal or coastal areas of Banten and Lampung. The number of victims reached 426 people killed, 7,202 injured and 23 people missing due to this incident.

From the results of the FGD of residents around Banten and Lampung, sea waves or tsunamis reached ~ 2 meters in the west coast area of Banten, and ~ 1.5 meters in the coastal area of southern Lampung. This tsunami wave occurred unnoticed by the local residents, because before the tsunami reached the coast of Banten and Lampung, the community did not feel a big earthquake. During this time, the community assumed that a tsunami would occur after a large earthquake [16].

In addition, from the results of BMKG observations use satellite imagery (Fig. 7), eruptions occur causing landslides [17] covering an area of 64 hectares in the southwestern region of AKM. Landslides at the bottom of the AKM island also occur and cause large shocks [18], so that an increase in sea waves [19] high (tsunami) [20]. According to the results of the FGD interview in the Banten region, before the Tsunami arrived at Banten Beach, there was a thud or the sound of the AKM eruption that sounded bigger than before.

Hasil direct observation, to areas affected by natural disasters after the eruption and tsunami (Fig. 8), it was seen that severe damage occurred in the sub-district of Rajabasa, southern Lampung and Banten. If observed from the existing geographical conditions, this damage occurs because the residential area is very close to the shoreline [20]. In areas damaged by the tsunami, there are no small islands that cover, one week the tsunami that comes will directly hit the coast or coast without any reduction or weakening of the tsunami wave [7].

We have also done observations in other areas affected by the tsunami but did not experience extensive damage. From the results of observations in the field, the area that did not experience major damage was caused by the tsunami waves which were blocked by small islands such as sebesi island, sebeku island, and legundi island (Fig. 8). In addition, there are forests or vegetation mangroves are one of the factors that can reduce tsunami waves [21].

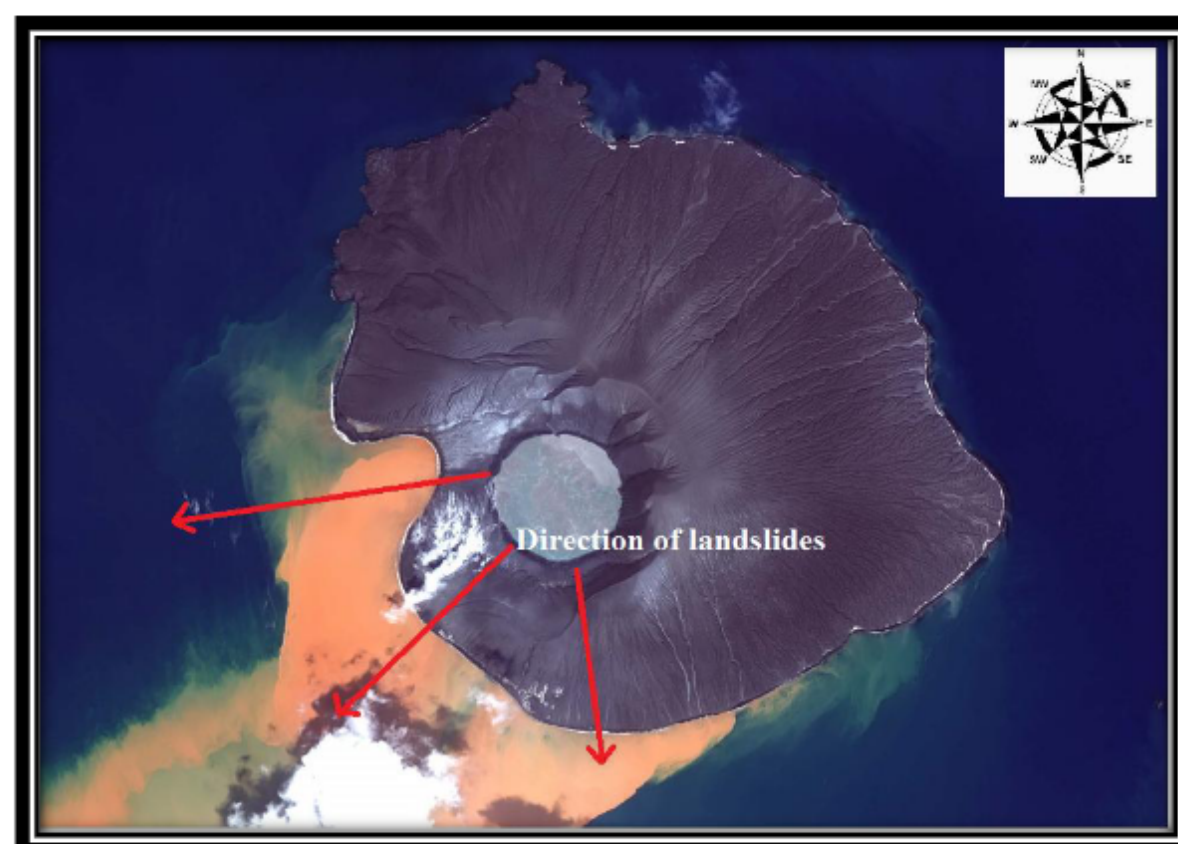


Figure 7. The direction of the landslide (southwest) is based on satellite imagery of 2018.

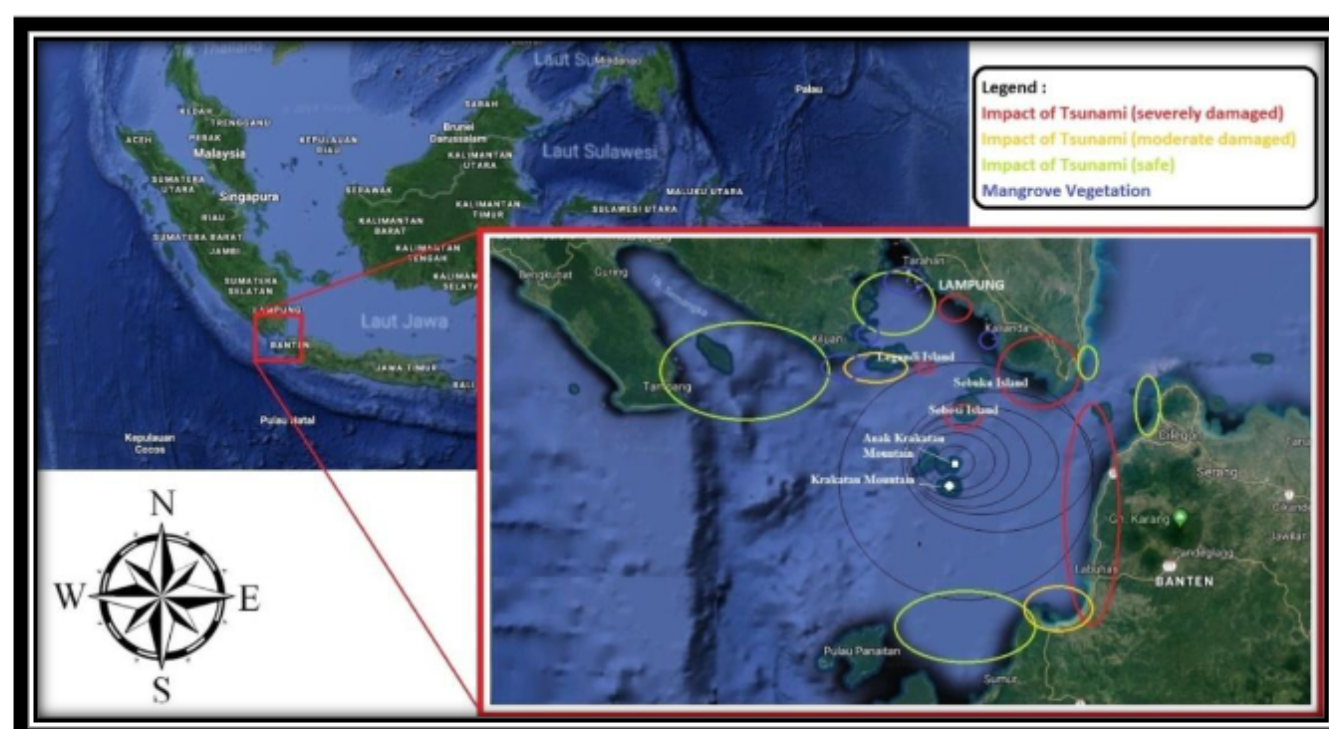


Figure 8. The impact after the tsunami in the Lampung region - Banten is based on direct observations to the location.

3.3. Discussions

Volcanic activity will increase due to the movement of plates that subduce into the earth. This subduction movement results in an increase in the amount of magma below the volcano [14]. Based on the time and history of volcanic activity in the Sunda Strait region, about ~ 135 years of volcanoes (AKM) did not experience major eruptions. This causes the amount of magma under the volcano to increase until it finally erupts.

The results of BMKG Indonesia's observations, AKM activities that took place starting from April 2018 ~ December 2018 should be reported every day not only on the internet, but also on television media intensively so that the people, especially in the coastal areas of Sunda (Banten and Lampung), knew and were alert. In addition, to reduce casualties, the process of evacuating or securing people near the coast should be carried out if there are signs of increased volcanic activity. Even though there were only a small earthquake and the release of volcanic ash or hot clouds.

The FGD results also received information that at least all communities on small islands such as Sebesi Island, Sebeku Island, and Legundi Island were conducted after the tsunami wave occurred. This is a delay in the process of evacuation or safety. However, the harmony that occurs on Sebesi Island, Sebeku Island, and Legundi Island is not so large, because there are trees or mangrove vegetation [22], and houses that are at a height and quite far from the beach.

Geographical survey results were carried out in two ways, namely direct field surveys and surveys based on satellite images after natural disasters occurred. The results of this survey, get good information as a disaster mitigation effort in the future or in other regions. Good, very effective and economical disaster mitigation can be carried out by carrying out preservation or replanting of mangrove vegetation [23]. Based on research conducted by [24] states that mangrove vegetation can reduce tsunami waves by up to 50% [19,20] and also more effective compared to hard or wave breaker concrete material [24]. In addition, the construction of large high-rise buildings in the coastal area is also needed as a place to save from the tsunami if there is no evidence around the coast [27].

4. Conclusion

Based on the research results, observations, recording volcanic activity are very important and needed to be informed and evaluated. This observation can be used as a reference for disaster mitigation efforts. Besides, the history of volcanic activity, earthquakes, plate tectonic dynamics is also very important to observe so that researchers in the fields of geology, geophysics, and geochemistry can predict when natural disasters such as earthquakes, volcanic eruptions, and tsunamis will occur even if they cannot know when the time will occur.

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