Analysis of land cover changes after the eruption of Mount Sinabung using satellite imagery

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Abstract. After hundreds of years experiencing a dormant period, Mount Sinabung erupted again in August 2010 to the last recorded in June 2018. Within eight years, significant land cover changes were seen in the area around Mount Sinabung. This study aims to analyse changes in affected areas using satellite imagery. The spatial analysis method is used to determine changes in various land cover. High-resolution images before the 2010 eruption and the latest recording images of 2019 are used as analytical material. The analysis shows that the affected area is in east-southeast and south-southeast directions of the peak of Mount Sinabung. In the east-southeast direction, the eruption material reaches 3.5 km and 4 km in the south-southeast with an area more than eleven thousand hectares. Some villages such as Bekerah, Simacem, and Suka Meriah have even been lost covered by material from the eruption of Mount Sinabung. The area is generally covered by pyroclastic materials in the form of ash, sand, lapilli, and bombs. Most of the areas affected by the eruption are plantation areas, then forest areas and settlements areas. The conclusion are Sinabung eruption in recent years has had a very significant impact on various aspects, one of which is land cover.

1. Introduction
Indonesia lies in the meeting of four active moving plates, namely the Eurasian Plate which moves relatively southeastward at the speed of approximately 0.4 cm/year, the Indo-Australian Plate which moves relatively northward at the speed of approximately 7 cm/year, the Pacific Plate which moves relatively westward at the speed of approximately 11 cm/year and the Philippine Plate which moves relatively northwestward at the speed of approximately 8 cm/year [1].

Based on tectonic province, Indonesia can be divided into two regions, namely the western part of Indonesia which involves the interaction of two plates, namely the Eurasian Plate and the Indo-Australian Plate and the eastern part of Indonesia which involves the interaction of three plates, namely the Indo-Australian Plate, Pacific Plate, Philippines Plate and several microcontinents. Thus the tectonic arrangement of eastern Indonesia is more complex than western Indonesia. The meeting of the four active moving plates resulted in the form of subduction zones, prismatic accretion zones, magmatic arcs, face basins, back basins, and geological structure patterns (Figure 1) [2].

The plates move and collide with each other so that the Indo-Australian Plate slides down the Eurasian Plate. The subduction of the Indo-Australian Plate that moves north with the Eurasian Plate moving south causes an earthquake line and active volcano sequence along the islands of Sumatra, Java, Bali and Nusa Tenggara, turning north to Maluku and North Sulawesi, parallel to the second subduction route plate. These plate tectonics creates 500 mountains, 129 of which are still active [3]. Therefore,
Indonesia is a disaster-prone area. There are at least 12 disaster threats grouped in geological disasters, hydro-meteorological disasters, and anthropogenic disasters. The geological disasters consist of earthquake, tsunami, volcano, ground/landslide movement. The hydro-meteorological disasters consist of floods, flash floods, droughts, extreme weather, extreme waves, forest, and land fires. While the anthropogenic disasters consist of epidemics disease and failed technology-industry accidents, Indonesia's Disaster Risk Index data shows that there were 205 million people living in disaster-prone areas in 2013 and disasters has increased significantly in the last decade [4].

Figure 1. Active fault distribution and destructive earthquake centers.

The Sumatra region is characterized by a large number of earthquakes at the boundaries between the subducting Indo-Australian Plate, the Sumatra Fault zone and several active volcanoes that are lined up along this fault zone. It has been suggested that some volcanoes in Sumatra have shown increases in volcanic activity possibly related to tectonic earthquakes. While, Sinabung is one of the volcanoes located in Sumatra that began to erupt on August 27, 2010, producing ash columns to 5 km above sea level and prompting the evacuation of surrounding communities. The renewed phase was accompanied by eruptions happen in September 2013, and the eruption continues after now, generating pyroclastic flows and lahars [5-7].

Sinabung is located only 25 km away from the Sumatran fault zone and 300 km from the subduction trench [7]. Sinabung volcano is a small stratovolcano < 5 km in diameter and 2460 m in height. It is located in northern Sumatra about 50 km northwest of the Toba caldera. It is underlain by Toba Tuff, which was produced y a VEI 8 eruption 74,000 years before present [8]. Sinabung erupted for the first time in August and September 2010, and then after three years of silence, a swarm of seismic at the volcano began on July 4, 2013, two days after the Bireun earthquake (Mw 6.1), located 252 km from the volcano. After this event, a series of new eruptions began on September 15, 2013, and continues to this day [7].

This study aims to analyze the land cover change in affected areas using satellite imagery. Satellite imagery used before and after the eruption is in 2010 and 2019. The use of satellite imagery to measure changes in land cover changes is one of the most efficient methods because with satellite imagery we can know the extent of land cover accurately.

2. Methods
In General, as we show in figure 2, we use two satellite images before and after the eruption in the year 2010 and 2019. Maximum likelihood classification was used for classifying the images. Ground truth points were collected and used for verification of image classification. The satellite images of this study area were downloaded from the ArcGIS Satelite Imagery base map for the year 2010 and Google Earth for 2019. The datasets were downloaded considering having a cloud cover less than 10% to avoid the
classification error. The next step is Image Pre-processing. Pre-processing of satellite images before change detection is essential and has the sole aim of establishing a more direct connection between data and biophysical phenomena on the field. The methodology used in this study uses various image pre-processing operations which are a geometric correction, atmospheric correction, image enhancement, and interpretation.

For classifying the images, there are two methods in image classification techniques to analyze the land cover classification. First is supervised classification; a method that uses the sample area (ground truth points on fields) from the land cover types that already known. The second type of classification is unsupervised classification; the type of land cover classification from the satellite image data when the user does not know about land cover types in the field. This study used the supervised type of classification using the known ground truth points. In this classification, the process has been controlled by managing, creating, evaluating, and editing signatures. The signatures are particular areas assigned for supervised classification. The signatures used to break the different classes like pyroclastic, forest, settlement, water bodies, and others. Tools like the Signature Editor require were grown using an area of interest layer that created in the layer creation option. After that, to perform some complex classifications with signatures that derived from more than one training method (supervised and unsupervised, parametric and nonparametric) merge signatures option was employed. The supervised classification is the most common method in obtaining land use/cover information.

3. Result and discussion

3.1. History of the Sinabung eruption

Sinabung volcano has unique phenomenon was changed from “B type” to “A type” volcano since the first historic eruptions in 2010 which previously was dormancy. This situation affected the society around Sinabung because it had not erupted in historic time (i.e., post-1600 CE). Precisely, in August – September 2010 marked the first historical eruptions at Sinabung volcano, Indonesia, producing ash columns to 5 km above sea level and prompting the evacuation of surrounding communities [5]. The Indonesian Center for Volcanology and Geological Hazard Mitigation (CVGHM) immediately issued a warning, and a second explosion occurred two days later on August 29, 2010. This led to the evacuation of over 22,000 people residing at distances of < 6 km from the summit of the volcano [9]. Sinabung was again accompanied by eruptions beginning September 15, 2013. The ensuing eruption sequence has included phreatomagmatic eruptions, explosive magmatic eruptions, and persistent lava effusion. In late 2013, as eruption frequency increased, seismicity increased, and SO2 continued to be detected [10].

In 2014, Mount Sinabung continued to experience the same conditions as in previous years, a series of eruptions and volcanic ash that increased the number of dead and lost and displaced victims. Since

![Figure 2. The workflow of the study.](image-url)
January 2014, pyroclastic flows have occurred repeatedly as part of the eruptive processes [8]. Based on the data of the National Board for Disaster Management (BNPB) shown that there were 11,113 people displaced due to the eruption of Mount Sinabung in 2015. In 2016 the Sinabung volcano erupted again and resulted in 9 deaths, and 15,508 people were displaced. Throughout 2017, the Sinabung Volcano continued to experience eruptions, recorded four eruptions this year. In May 2017, the status of Sinabung Mountain was increased to the alert marked by eruptions, and hot clouds, the material bursts from the eruption reached 4 kilometers, resulting in thousands of residents still must live in the refuge. Whereas in 2018 one eruption was recorded and resulted in 100 residents having to evacuate to safer places [11].

3.2. Land cover before and after eruption

Land cover in 2010 or before the eruption in Mount Sinabung (Figure 3) was dominated by plantations with an area of 3,080.43 Ha, followed by forest cover area of 1,574.05 Ha, bushes with an area of 742.90 Ha, vacant land of 604.90 Ha, and settlements with an area of 83.21 Ha. In the other side, land cover in 2019 or after the eruption in Mount Sinabung was dominated by plantations with an area of 2,660.87 Ha, followed by forest cover area of 1,360.37 Ha, pyroclastic materials with an area of 1,196.09 Ha, bushes with an area of 423.33 Ha, paddy field of 257.76 Ha, and settlements with an area of 100.05 Ha.

Most of the areas that have changed due to the eruption of Mount Sinabung are in the direction of east-southeast and south-southeast. The area directly affected by being covered by pyroclastic layers is plantations covering an area of 623.96 ha, then followed by bare land (333.53 ha), forest (144.94 ha), shrubs (81.84 ha), and settlements (11.81 ha). Whereas the area experiencing indirect land cover changes is in the area west of Mount Sinabung. In general, all land cover has decreased in an area except the pyroclastic and settlements area. The area of the settlement increases but its growth is southwest of the peak of Sinabung which is the area that is not the direction of the eruption flow.

3.3. The impact of the eruption

Sinabung Volcano awoke from over 1200 years of dormancy with multiple phreatic explosions in 2010. After a period of quiescence, Sinabung activity was producing frequent explosions, lava dome extrusion, and pyroclastic flows from the dome and lava flow collapses, becoming one of the world’s most active volcanoes and displacing over 20,000 citizens [9].

The method for taking satellite imagery in 2010 and 2019 was used to analyze changes in land cover around the eruption of Mount Sinabung. Furthermore, the use of the Global Positioning System (GPS) is used to capture and model the transfer of magma from the period before the eruption and after the eruption [12]. Volcanic eruptions have an impact on infrastructure damage [13], one of the infrastructures affected is the disruption of the electricity network. A volcanic eruption can destroy the electrical cable network around the slope. This, of course, will indirectly have an impact on the condition of the surrounding settlements which are cut off from electricity. Another impact that can be felt is
related to transportation networks. The results of pyroclastic eruptions, in general, will cover road access around the slopes. The road network that was cut off due to being covered by pyroclastic material was estimated to reach 2.3 km. Closed road access will certainly hamper the activities of residents and the movement of assistance for disaster victims. Next is the piped water network to meet the needs of the affected villagers. This will cause difficulties for residents in obtaining clean water supplies. The impact of the eruption also caused various social facilities to be covered with pyroclastic material, including educational facilities. There are one junior high school and two elementary schools that are covered with pyroclastic material. Gurukinayan 2 Public Middle School, Public Elementary School 040486 Gurukinayan and Public Elementary School 047175 Sigarang-Garang must close all activities at school because it is no longer possible to use it. Also, there are still educational facilities that are very prone to be covered by pyroclastic material namely Perbaji Elementary School 040503, Sukunanlu Public Elementary School 14029, Tigander Elementary School 040488, Tiganderket Public Middle School 1, Namanteran 1 Public Middle School, Tiganderket Public High School 1. The educational facility is very vulnerable because it has a radius of ≤5 km from the peak of Mount Sinabung.

Eruption eruptions can have an impact on environmental conditions [9], the impact of volcanic eruptions will be very fast. The impact on the environment of volcanic activity includes the relationship between humans and volcanic activity and human movement. For example, the eruption of Mount Tambora on the island of Sumbawa in 1815 in three days covered an area as large as France with ash cover. The incident killed at least 75,000 to 92,000 people. Likewise, the Sinabung eruption has an impact on the environment, for example, in 2016 the Sinabung eruption caused nine deaths, and 15,508 people were relocated. The impact of the eruption also affects soil, groundwater, and vegetation. Pyroclastic material covers fertile soil, disturbed catchment areas. This appears to be a non-functioning network of groundwater piping from water sources to homes or other social facilities. The impact on vegetation can be seen from reduced forest area reduced by 202 ha or around 12.8% during the period of 2010 to 2019.

The other biggest impact is from the Sinabung eruption including the resort population and plantations around the volcanic area of Mount Sinabung. Residents have not felt the effects of the eruption directly, they have received information from various institutions, and this has confused the local community [8]. Good communication between institutions and government agencies with residents is urgently needed, this has been applied by the community around the Kelud mountain in response to eruptions that occur in their area [14]. When this goes on it will certainly minimize the number of casualties.

Global trends and development regarding natural disasters and their impacts must be carried out immediately. The total death toll in the 35 years from 1947-1981 was 1,208,008 people, with an average of 34,514 deaths per year worldwide. This is a significant increase in annual deaths from the period 1947-1967 with an average of 21,041 deaths per year [11]. From these data it can be concluded that the potential and threat of natural disasters is always increasing; this can occur because the human population is increasing. If disaster-oriented development in the sense of building an active and responsive community in the face is achieved, it will minimize the threat of existing disasters.

The next impact that must be considered is how much pyroclastic material is deposited and will potentially cause secondary lava threats. These explosions finally sent ash columns as high as 7-9 km above the volcanic peak and produced a pyroclastic density current reaching up to 5 km from the crater hole [9]. The results show that the total volume of estimated lava and pyroclastic deposits, produced during the period 2010 to mid-2015, is around 2.8 × 108 m³ [15]. On September 22, 2014, the lava flow was 2.9 km long and had volume 1,03 ± 0.14 × 108 m³, which leads to an average estimated discharge rate 4.8 ± 0.6 m³ s−1 [16]. This lava flow leads to the southeast from the peak of Mount Sinabung and has the effect of closing the area with pyroclastic material in subsequent years. Mount Sinabung eruptions that occurred from 2010 to 2019 caused changes in land cover. Land cover around a radius of 5 km to the southeast consisting of plantations, vacant land, forests, shrubs, and settlements turned into pyroclastic material with a total area of 1,196.08 Ha. It is estimated that this pyroclastic volume can be used to predict the magnitude of future hazards secondary lava, which is also related to
the capacity of rivers in the area [15]. In addition to the potential for lava floods, this change in land cover also caused many affected residents to leave their homes and plantations. The relationship between changes in land cover and land degradation is strong in most environments [17]. The landlords who change the land feel very big impact on the people around Mount Sinabung, changes in land cover make them also have to find other jobs to meet their needs because the land that has existing plantations cannot be cultivated again. In the end, the economic activities of the people around Punakan were affected.

4. Conclusion
The results of the analysis of digital satellite images in 2010 and 2019 show that there has been a change in land cover. The most obvious object is the increase of the area of the pyroclastic layer which is the result of the explosion of material from Sinabung. This material is generally spread southeast from the top of the mountain and causes a direct impact on the buried area. Whereas in areas other than that, it still experiences indirect impacts due to the eruption of Mount Sinabung, such as the destruction of various types of infrastructure and declining environmental conditions. Sinabung eruption in recent years has had a very significant impact on various aspects, one of which is land cover changes.

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