The Evolution of Anak Krakatoa Based on Landsat Imagery

Sartika, Yohanes Fridolin Hestrio, Kiki Winda Veronica and Galdita Aruba Chulafak
Aeronautics and Space Research Organization, National Research and Innovation Agency (BRIN), Jakarta, Indonesia

Keywords: Anak Krakatoa, NDWI, Landsat, Image Processing.

Abstract: The Anak Krakatoa is a small volcano located in the Sunda Strait, specifically between the islands of Java and Sumatra, Indonesia. The Anak Krakatoa is currently still an active volcano. This mountain has erupted many times and has undergone various changes in its height, shape, and area, with the last eruption in July 2022. This study shows the changes in Anak Krakatoa, especially its shape and size, based on Landsat remote sensing data from 1990 to 2022. Landsat imageries used in this study are Landsat 5,7, and 8. To obtain information on the site of Anak Krakatoa, it begins by separating the sea and land around the mountain using the Normalized Difference Water Index (NDWI). After the land is detected, then the area is calculated. The volcano reached its minimum area in 1988 and its maximum area in 2022.

1 INTRODUCTION

Anak Krakatoa is a volcano located in the Sunda Strait between the islands of Java and Sumatra, Indonesia (Giachetti et al., 2012). The Krakatoa volcano erupted violently in 1883 and caused a tsunami to run 41 m and caused up to 36000 fatalities (Mutaqin et al., 2019), and destroyed 295 settlements around the Sunda Strait (Bruins et al., 2008). The eruption also formed a caldera with a depth of 200 to 280 meters below sea level (Umbgrove, 1926). Krakatoa Island initially consisted of several mountains, namely Mount Rakata, Mount Danan, and Mount Perboewatan, wherein the incident in 1883, Mount Danan and Perboewatan erupted (Umbgrove, 1926; Whittaker et al., 1989). After Krakatoa erupted in 1883, a new volcano appeared in 1927, later referred to as the Anak Krakatoa (Gardner et al., 2013).

Since Anak Krakatoa first appeared, it has been an active volcano. Anak Krakatoa has been growing and developing through volcanic activity. It emerged from the sea in the same location as the original Krakatoa volcano. The emergence of Anak Krakatoa is believed to have resulted from the same geological processes that led to the formation of the original Krakatoa volcano, namely the subduction of the Indo-Australian Plate beneath the Eurasian Plate. The ongoing eruptions and lava flows from Anak Krakatoa contribute to the island's growth. The lava cools and solidifies, creating new land that expands the size of the island. Over time, this can significantly grow the island's area. However, it's important to note that volcanic activity can also lead to sudden and destructive events, such as explosive eruptions, landslides, and tsunamis. Anak Krakatoa erupted 80 times through effusive and explosive eruptions from 1927 until 2006 (Igan, 2006) with Surtseyan and Strombolian eruption types (Ginting et al., 2021). In 2018 Anak Krakatoa erupted again and was the first eruption after the 1883 eruption, which also resulted in a tsunami (Grilli et al., 2019). This tsunami also caused damage and loss of life in the coastal areas of Lampung and Banten, Indonesia (Grilli et al., 2019). From a volcano under the sea, Anak Krakatoa grew to about 300 m above sea level before erupting in 2018 (Ye et al., 2020). One of the remote sensing data that can be used in observing the earth's urface, and the data is continuous, is Landsat. Landsat was launched in 1972 (Chen et al., 2020) and entered the ninth series in 2022 (Gross et al., 2022). However, not all regions were recorded in its early mission due to its limitations. For the Anak Krakatoa area, the data that can be used is data from 1988. Observations and research on Anak Krakatoa have certainly been very much done, such as about the tsunami that caused it (Grilli et al., 2019; Ye et al., 2020), the landscape (Ginting et al., 2021), its growth (Igan, 2006), the vegetation (Whittaker et al., 1989), the coral reef (Ferdiansyah et al., 2019), and many more. This study was carried out to observe the extensive development of the volcanic island of Krakatoa. To obtain information on the site of Anak Krakatoa, it begins by separating

Sartika, ., Hestrio, Y., Veronica, K. and Chulafak, G.
The Evolution of Anak Krakatoa Based on Landsat Imagery.
DOI: 10.5220/0012442500003848

In *Proceedings of the 3rd International Conference on Advanced Information Scientific Development (ICAISD 2023)*, pages 60-64
ISBN: 978-989-758-678-1

the sea and land around the mountain using the Normalized Difference Water Index (NDWI). Then, use the Otsu method to monitor the Anak Krakatoa area. This method can assist in the automatic tracking of Anak Krakatoa in the future without human intervention. Usually, monitoring is done using visual interpretation.

2 MATERIALS AND METHODOLOGY

2.1 Location

The research location is on the Anak Krakatoa Volcano Island in the Sunda Strait, Indonesia, as shown in Fig. 1. Mount Anak Krakatoa itself is administratively located in the South Lampung Regency, Lampung Province, Indonesia (Suwarsono et al., 2019).

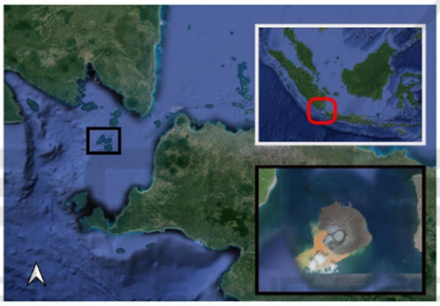

Figure 1: The location of the study area, with the upper inset showing the location of Sunda Strait in Indonesia and the lower inset showing the location of Anak Krakatoa in Sunda Strait.

2.2 Methodology

Figure 2 shows the flowchart of the method used for the study.

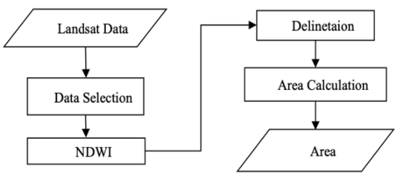

Figure 2: Flowchart.

The method can be divided into several parts: data selection, calculation of the NDWI, Delineation, and Compute the area of Anak Krakatoa.

- Data Selection
  The data used is Landsat data which consists of several Landsat series, namely Landsat-5, Landsat-7, and Landsat-8. These three types of Landsat imagery have a spatial resolution of 30 meters but have a different numbers of bands. The data selected is cloud and smoke-free, which can show a clear boundary between Anak Krakatoa Island and the ocean. The data consists of 5-year intervals from 1988 to 2018 and 1-year intervals from 2018 to 2022. The reason for choosing 5-year data intervals is because the eruptions between these ranges were not too significant until 2018, while the 1-year data is to see more specific changes per year that occurred after the major eruption in 2018. The data used is shown in Table 1.

Table 1: List of dates and types of Landsat satellites used.

Date	Landsat Type	Date	Landsat Type
1988-03-04	Landsat-5	2018-12-20	Landsat-8
1993-09-26	Landsat-5	2019-11-05	Landsat-8
1998-12-13	Landsat-5	2020-04-29	Landsat-8
2003-05-09	Landsat-7	2021-08-06	Landsat-8
2008-05-30	Landsat-5	2022-07-08	Landsat-8
2013-09-01	Landsat-8		

- NDWI
  Normalize Difference Water Index (NDWI) is a method that enhances the water's presence while eliminating the presence of vegetation and soil in remote sensing data (McFeeters, 1996). NDWI utilizes the NIR channel, which is strongly absorbed by water and strongly reflected by vegetation and soil (McFeeters, 1996). The formula of NDWI can be seen in equation (1).

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \tag{1}$$

  For Landsat-5 and 7, GREEN and NIR are located in Band 2 and 4, respectively (Chander et al., 2004; Markham et al., 2004). While in Landsat-8, the GREEN and NIR are located in Band 3 and 5, respectively (Wang et al., 2017). Figure 3 shows the comparison between the data in RGB and NDWI.

- Delineation
  The delineation is done using manual rather than automatic delineation or thresholding techniques. The manual delineation is used because the condition of Anak Krakatoa itself is pretty active, so in addition to considering cloud conditions, it must also consider smoke conditions. In NDWI, it can eliminate soil and vegetation presence but also

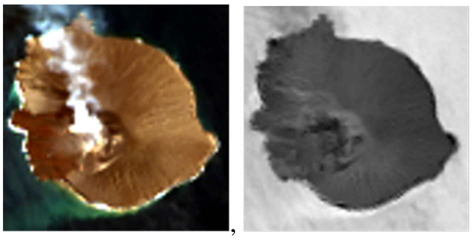

Figure 3: The comparison between the RGB (left) and NDWI (right) shows that the soil has a darker area than the water.

eliminate clouds and smoke so that when automatic delineation is carried out, clouds and smoke will also be detected as land (Choi et al., 2022). Because of this, it is necessary to select data entirely free of smoke and clouds if using an automated method, especially the one that intersects with the coast. Indeed, this will significantly limit the data that can be used. This deficiency due to cloud and smoke can be reduced by using SAR data such as Sentinel-1, but the data availability is not as much as Landsat data, which Sentinel-1 was only available in 2014 (Wegnüller et al., 2016).

3 RESULTS AND DISCUSSION

Changes in the Anak Krakatoa area from 1988 to 2018 as shown in Fig. 4. As can be observed from 1988, the lava flow was more directed to the north with a significant addition of area from 1988 to 1993. From 1998, the additional area was more inclined towards the west and south of the island, although not as wide as the change in previous years.

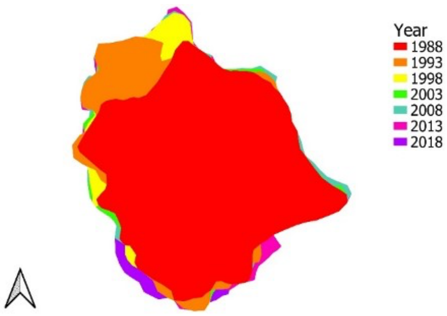

Figure 4: The change in the area of Anak Krakatoa from 1988 to 2018.

Figure 5 shows the changes that occurred before and after the eruption in 2018. Here, it can be observed that a region vanishes in the western portion of the island while there is an expansion of the region in the eastern part. The increase in the area in the east region could be caused by ocean currents carrying eruptive material in that direction.

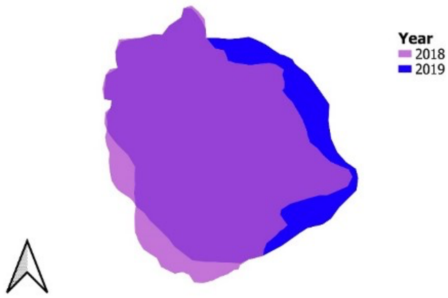

Figure 5: The change of Anak Krakatoa before and after the eruption on December 2018. The increase and loss of area have happened in several locations.

Meanwhile, Fig.6 illustrates the shift in the Anak Krakatoa region between 2019 and 2022. The west is where the changes are more pronounced. Naturally, the lava flow entering the region and causing changes cannot be separated. In other areas, not too much change has happened. If there are changes such as abrasion and accretion in other areas of Anak Krakatoa, it is most likely due to the influence of ocean currents.

Figure 6: The change of Anak Krakatoa from 2019 to 2022.

The changes in the area that occurred in Anak Krakatoa can be seen in Table 2.

Table 2: The area of Anak Krakatoa.

Year	Area (ha)	Year	Area (ha)
1988	251.727	2019	325.936
1993	264.571	2020	328.266
1998	293.334	2021	322.320
2003	295.039	2022	333.550
2008	296.609		
2013	300.691		
2018	306.829		

It is clear that between 1988 and 2018, the area expanded to 55.102 ha, and from 2019 and 2022, the area increased to 7.16 ha. The most significant increase in area is from 2021 to 2022 at 11.23 ha. Although the increase in area from 1988 to 1993 was greater (12,844 ha), it occurred for five years or had an average rise of 2.59 ha/year. The fact is that Anak Krakatoa's condition has increased yearly in the area even though there was an eruption in 2018. However, there is also a decrease in the area from 2020 to 2021, probably due to soil or rock conditions that are still unstable and easily carried away by ocean currents. The growth of the detected vegetation area from 1988 to 2018 also experienced an increase in area. The vegetation in Anak Krakatau is on the east side. After the 2018 eruption until 2022, no vegetation has been seen through Landsat imagery on Anak Krakatoa. Figure 7 shows some of the vegetation conditions of Anak Krakatoa through true composite color. Table 3 is an estimate of the area of vegetated areas in Anak Krakatoa.

Table 3: Estimated area of vegetation in Anak Krakatoa.

Year	Area (ha)	Year	Area (ha)
1988	23.388	2019	0
1993	36.232	2020	0
1998	52.657	2021	0
2003	57.484	2022	0
2008	61.033		
2013	75.951		
2018	76.091		

Compared with its elevation, Anak Krakatoa loses more in elevation than in area. In (Saputra et al., 2021), it was stated that Anak Krakatoa's height was 338 m to 110 m after the eruption. The condition of the area certainly, in contrast, has increased from around 306,829 ha to approximately 325,936 ha.

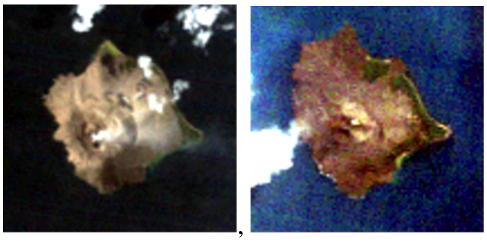

Figure 7: 1988 and 1998.

Figure 8. Vegetation condition (green area) of Anak Krakatoa that shows the expansion until the eruption in 2018.

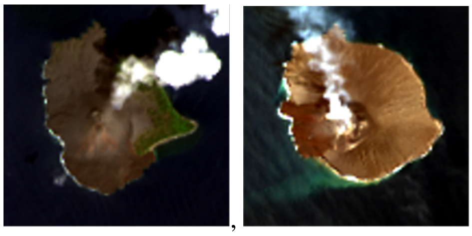

Figure 8: 2008 and 2022.

4 CONCLUSION

The condition of the Anak Krakatoa continues to develop from year to year in terms of its area. Despite the eruption, the volcanic island's area increased from around 306.829 ha to approximately 325.936 ha while its height decreased. During observations using Landsat data, the area of Anak Krakatoa had a minimum size of 251,727 ha in 1988 (the earliest data used) and a maximum area of 333,550 ha in 2022 (the latest data that was used). The most significant increase in the area occurred from 2021 to 2022, with an additional area of 11.23 ha. For further research, a study will be carried out using multi-sensor remote sensing data to monitor Anak Krakatoa's development.

ACKNOWLEDGEMENT

The authors would like to thank the Research Center for Remote Sensing for providing the data used in this study and the anonymous reviewers for their valuable comments to improve this article.

REFERENCES

Bruins, H., MacGillivray, J., Synolakis, C., Benjamini, C., Keller, J., Kisch, H., Klügel, A., and Plicht, J. (2008). Geoarchaeological tsunami deposits at palaikastro (crete) and the late minoan ia eruption of santorini. *J. Archaeol. Sci*, 35:191–212.

Chander, G., Helder, D., Markham, B., Dewald, J., Kaita, E., Thome, K., Micijevic, E., Ruggles, T., The, A., and Mapper (2004). L.-t.: Landsat-5 tm reflective-band absolute radiometric calibration. *IEEE Trans. Geosci. Remote Sens*, 42:2747–2760.

Chen, F., Fan, Q., Lou, S., Yang, L., Wang, C., Claverie, M., Wang, C., Junior, J., Goncalves, W., and Li, J. (2020). Characterization of mss channel reflectance and derived spectral indices for building consistent landsat 1-5 data record. *IEEE Trans. Geosci. Remote Sens*, 58:8967–8984.

Choi, Y.-J., Ban, H.-J., Han, H.-J., and Hong (2022). S.: A maritime cloud-detection method using visible and near-infrared bands over the yellow sea and bohai sea. *Remote Sens*, 14:793.

Ferdiansyah, M., Widiastuti, E., Ismail, T., and Susanto (2019). G.n.: Inventarization of coral reefs in the waters of rakata island, krakatau islands. *AQUASAINS*, 8:775.

Gardner, M., Troll, V., Gamble, J., Gertisser, R., Hart, G., Ellam, R., Harris, C., and Wolff (2013). J.a.: Crustal differentiation processes at krakatau volcano. *Indonesia. J. Petrol*, 54:149–182.

Giachetti, T., Paris, R., Kelfoun, K., and Ontowirjo (2012). B.: Tsunami hazard related to a flank collapse of anak krakatau volcano, sunda strait, indonesia. *Geol. Soc. London, Spec. Publ*, 361:79–90.

Ginting, F., Gusnidar, N., M., R., Minasny, B., and Fiantis, D. (2021). Changes in anak krakatau landscape after december 2018 eruption. *IOP Conf. Ser. Earth Environ. Sci*, 708:012088.

Grilli, S., Tappin, D., Carey, S., Watt, S., Ward, S., Grilli, A., Engwell, S., Zhang, C., Kirby, J., Schambach, L., and Muin, M. (2019). Modelling of the tsunami from the december 22, 2018 lateral collapse of anak krakatau volcano in the sunda straits, indonesia. *Sci. Rep*, 9:11946.

Gross, G., Helder, D., Begeman, C., Leigh, L., Kaewmanee, M., and Shah (2022). R.: Initial cross-calibration of landsat 8 and landsat 9 using the simultaneous underfly event. *Remote Sens*, 14:2418.

Igan, S. (2006). Pertumbuhan gunung api anak krakatau setelah letusan katastrofis 1883. *Indonesia. J. Geosci*, 1:143–153.

Markham, B., Thome, K., Barsi, J., Kaita, E., Helder, D., and Barker, J. (2004). Scaramuzza, p.l.: Landsat-7 etm+ onorbit reflective-band radiometric stability and absolute calibration. *IEEE Trans. Geosci. Remote Sens*, 42:2810–2820.

McFeeters, S. (1996). The use of the normalized difference water index (ndwi) in the delineation of open water features. *Int. J. Remote Sens*, 17:1425–1432.

Mutaqin, B., Lavigne, F., Hadmoko, D., and Ngalawani (2019). M.n.: Volcanic eruption-induced tsunami in indonesia: A review. iop conf. ser.earth environ. *Sci*, 256:012023.

Saputra, I., Armijon, A., and Fadly (2021). R.: Analisis perubahan topografi gunung anak krakatau pasca erupsi tanggal 22 desember 2018 menggunakan data foto udara dan demnas. *J. Geod. Geomatics*, 1:43–55.

Suwarsono, N., Prasasti, I., Nugroho, J., Sitorus, J., and Triyono (2019). D.: Detecting the lava flow deposits from 2018 anak krakatau eruption using data fusion landsat-8 optic and sentinel-1 sar. *Int. J. Remote Sens. Earth Sci*, 15:157.

Umbgrove, J. (1926). The first days of the new submarine volcano near krakatoa. *Leidse Geol. Meded*, 2:325–328.

Wang, Q., Blackburn, G., Onojeghuo, A., Dash, J., Zhou, L., Zhang, Y., and Atkinson (2017). P.m.: Fusion of landsat 8 oli and sentinel-2 msi data. *IEEE Trans. Geosci. Remote Sens*, 55:3885–3899.

Wegnüller, U., Werner, C., Strozzi, T., Wiesmann, A., Frey, O., and Santoro, M. (2016). Sentinel-1 support in the gamma software. *Procedia Comput. Sci*, 100:1305–1312.

Whittaker, R., Bush, M., and Richards, K. (1989). Plant recolonization and vegetation succession on the krakatau islands, indonesia. *Ecol. Monogr*, 59:59–123.

Ye, L., Kanamori, H., Rivera, L., Lay, T., Zhou, Y., Sianipar, D., and Satake, K. (2020). The 22 december 2018 tsunami from flank collapse of anak krakatau volcano during eruption. *Sci. Adv*, 6:1–10.