ANALYSIS OF VOLCANIC ASH DISPERSION FROM THE MOUNT AGUNG ERUPTION USING HIMAWARI-8 SATELLITE DATA: CASE STUDIES FROM 25 NOVEMBER 2017; 28 JUNE 2018, AND 4 JULY 2018

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ABSTRACT

The eruption of Mt. Agung in Bali province over the last two years caused Ngurah Rai International Airport in Bali province, Lombok International Airport in West Nusa Tenggara province, and Notohadinegoro Airport as well as Blimbingsari Airport, both in East Java province, close. The eruptions of volcanoes have a major impact on human activities as airplanes are the fastest and most efficient transportation. Volcanic ash can ruin the jet engine and lead to flameout. Accurate information on the movement and dispersion of volcanic ash was required, considering the location of Mt. Agung is far enough from the affected airports. One of the identifications of volcanic ash was processed using Himawari-8 satellite data with several channels. The satellite data was processed using TVAP (Three Band Volcanic Ash Product), Split Window, and RGB (Red Green Blue) techniques to get the result of the trajectory of volcanic ash dispersion. The result can be used as a reference in airport operations. It showed the movement and dispersion of volcanic ash from Mt. Agung's eruption to the affected airport area, which resulted in the closure of the airports. The volcanic ash was dispersed in a west-southwest direction, impacting the central and southern regions of Bali Island.

Keyword: Volcanic ash, TVAP, Split window, RGB, Dispersion

1. Introduction

Indonesia is known as the country with the highest number of active volcanoes in the world, with more than 30% of the world's active volcanoes located within its territory [1]. One of the results of volcanic eruptions is volcanic ash. Volcanic ash can affect atmospheric conditions[2]. These particles are dangerous and can interfere with flight activities. Therefore, it is necessary to make accurate and fast predictions regarding the space-time dispersion of volcanic ash particles in improving flight operational safety standards ([3]. Volcanic eruption observation systems continue to evolve to prevent the resulting impact on the aviation world [4]. Monitoring and analyzing volcanic eruptions through satellite remote sensing is essential for understanding ash distribution, atmospheric changes, and the impact of eruptions on local and global ecosystems. Satellite observations provide good characterization of volcanic emissions and their movements as a basis for forecasting ([5].

Mount Agung, located on the Indonesian island of Bali, is one of the most active volcanoes and has experienced many eruptions. Many studies have utilized satellite data to analyze various aspects of the Mount Agung eruptions, including ash plume dispersion, thermal anomalies, and gas emissions. Based on the history of its eruption, Mount Agung is categorized as an active mountain that has an open crater eruption type based on its physical characteristics [1]. The impact of volcanic eruptions that emit volcanic ash particles is very important for flight planning because these particles can cause system damage abrasion in aircraft engines, which can eventually cause aircraft engines to fail [6]. The material released can cause changes in the global atmosphere from the surface to the upper troposphere layers [7]. Given the significant impact, the International Civil Aviation Organization (Volcanic Ash Advisory Centers) is paying close attention to the importance of information on volcanic ash dispersions that endanger flight paths [8][9].

Volcanic ash that affects atmospheric conditions has a major impact on human activities. One of its impacts is affecting air transportation. Aside from the disturbance of visibility, it also can cause severe engine damage or failure due to ash ingestion. This makes the information on the movement and dispersion of volcanic ash very important. This information is used to prevent accidents and losses, especially for the public. The usage of weather satellites with various techniques can be done to observe the trajectory and dispersion of volcanic ash so that the results can be used for making decisions and reducing impacts.

2. Methods

This study took a case study during the eruption of Mount Agung in Bali, Indonesia, on 25 November 2017, 28 June 2018 and 4 July 2018, which resulted in the closure of airports around the Mount Agung area. Himawari Satellite image data is processed with TVAP, Split Window and RGB technique to see how and where the trajectory of volcanic ash dispersion during the eruption. The TVAP, Split-Window, and RGB approaches were selected for their synergistic efficacy in identifying volcanic ash. TVAP offers quantitative precision, Split-Window exhibits exceptional sensitivity to thin ash strata, and RGB facilitates rapid visual analysis. Collectively, they augment reliability under various meteorological circumstances. Remote sensing is a fairly effective method for detecting and analyzing changes in volcanic eruption events, but real-time eruption characterization must continue to be improved for rarely monitored volcanoes [10]. Thermal observation analysis can be used to determine the eruption process in volcanic eruptions. The Advanced Himawari Imager (AHI) sensor can observe phenomena with eruptions with a spatial resolution of 2 km in an observation cycle every 10 minutes [11]. With this method, volcanic ash and meteorological clouds can be observed [12].

The Japan Meteorological Agency (JMA) launched Himawari-8/9, an advanced geostationary meteorological satellite, to improve weather and atmospheric monitoring in East Asia and the Western Pacific. The satellite has an AHI with 16 observation bands with very high spatial resolution, a visible band of 0.5 km, and an infrared band of 2 km. In addition, Himawari has a short revision time, approximately 10 minutes for complete observation and 2.5 minutes for sectoral areas [13]. The use of satellite data that has a long duration and every 10 minutes allows observation over time, making it possible to estimate the parameters of the eruption source, which is very suitable for volcanoes with long-term eruption periods [14]

Volcanic eruptions produce high-temperature gas or magma and are released to the surface, so observations using thermal methods can be used to observe the eruption process [15]. The use of infrared data from the Himawari-8 satellite can identify hotspots in the stratosphere layer at the top of the eruption cloud [16]. Himawari 8/9, when compared to SEVIRI, has an additional channel that detects moisture in the 6.9 m canal, so that AHI has channels at 10.4, 11.2, and 12.4 m[17]. This advantage allows Himawari-8/9 to effectively monitor rapidly changing weather phenomena, such as the spread of volcanic ash. In the face of emergencies, researchers and related institutions can quickly obtain satellite data through various channels, such as satellite communication and cloud services. Himawari-8/9's outstanding monitoring capabilities help improve public safety and scientific understanding of the impacts of volcanic eruptions and other atmospheric phenomena.

This study used the channel of Himawari-8 satellite imagery data named B7 (3.9 µm), B13 (10.4 µm) and B15 (12.4 µm) with NetCDF format and 0.0181o (± 2 km) resolution. The specific function of each channel in volcanic ash detection has been elaborated. Channel B7 (3.9 µm) detects the thermal signature of volcanic ash, facilitating the identification of hot regions, whereas B13 (10.4 µm) effectively differentiates ash from clouds due to its sensitivity to both ash and water vapor. Channel B15 (12.4 µm) is predominantly utilized to distinguish volcanic ash from other atmospheric constituents, providing improved identification amid moisture or cloud cover. During the eruption of Mount Agung on 25 November 2017; 28 June 2018, and 4 July 2018. The methods used are the TVAP and Split-Windows technique combined to get the pixel value of volcanic ash that results in the trajectory of volcanic ash dispersion. The RGB technique was also used to compare the trajectory of volcanic ash dispersion. This study did not conduct validation of the results. The volcanic ash dispersion trajectory obtained from the TVAP, Split-Window, and RGB methodologies relied on satellite imagery data; however, further validation through ground-based observations or alternative remote sensing products is essential to improve the accuracy and reliability of the findings.

3. Result and Discussion

TVAP Technique Analysis. Analysis of volcanic ash can be seen by using the TVAP technique on the Himawari-8 satellite data at 10.7 µm (B13), 12.0 µm (B15) and 3.9 µm (B7) wavelengths. TVAP pixel values between 60-100 at night and 200-255 at day can be categorized as ash cloud [12].

Table 1. TVAP Algorithm

Algorithm	Pixel Value of Volcanic Ash
B = 60 + 10 (B15 - B13) + 3 (B7 - B13)	60-100 (night) 200-255 (day)

The eruption of Mount Agung on 25 November 2017 occurred at 21:50 UTC and moved to the east-southeast based on information from PVMBG (Pusat Vulkanologi dan Mitigasi Bencana Geologi). The eruption of Mount Agung was shown on the TVAP technique but with some noise around Bali Island. This can be caused by TVAP method using night pixel value is very thin volcanic ash. The three images illustrate the detection of volcanic ash from Mount Agung eruptions at various intervals. The initial image (25 November 2017) illustrates a broad dispersion of volcanic ash extending southwest, impacting regions next to Ngurah Rai Airport. The second image (28 June 2018) depicts a denser ash plume surrounding Mount Agung, with the ash predominantly dispersing southwestward, once more affecting Ngurah Rai Airport. The third image (4 July 2018) depicts a relatively confined ash dispersal, with the greatest concentration near Mount Agung and minimal effects on adjacent areas. Each map delineates the position of Mount Agung, adjacent airports, and the distribution of ash identified during these occurrences. (Fig 1) [12].

Based on information from PVMBG, the eruption that occurred on 28 June 2018, at 08:00 UTC is moving west-southwest. Although, the eruption on 4 July 2018 at 14:20 UTC is not visible by the observer but recorded in seismic data. Based on the TVAP technique analysis (Fig 1 and 2), It showed the eruption of Mount Agung 25 November 2018, at 23:40 UTC and eruption on 28 June 2018, at 14:00 UTC had same trajectory of volcanic ash dispersion according to PVMBG information. The Volcano Observatory Notice for Aviation (VONA) provided the subsequent information concerning the activity of Mount Agung: On 20171125/10082Z, the Aviation Colour Code was elevated to ORANGE following an eruption that produced a volcanic ash cloud, noticed at 0920 UTC (1720 Local Time), with the eruption and ash production ongoing. The ash cloud was observed advancing toward the west-southwest. On June 28, 2018, around 0601Z, persistent ash emissions were recorded since 0230 UTC (1030 Local Time), and they continued, with the ash plume advancing westward. On July 4, 2018, at 0420 UTC (1220 Local Time), a volcanic eruption produced an ash cloud; however, the eruption and ash emission had ceased, and the ash cloud was drifting westward.

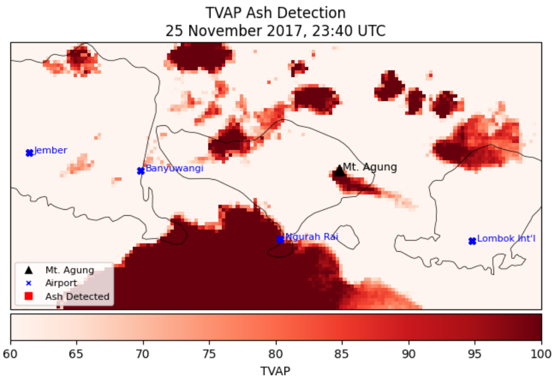

Figure. 1. TVAP value 25 November 2017

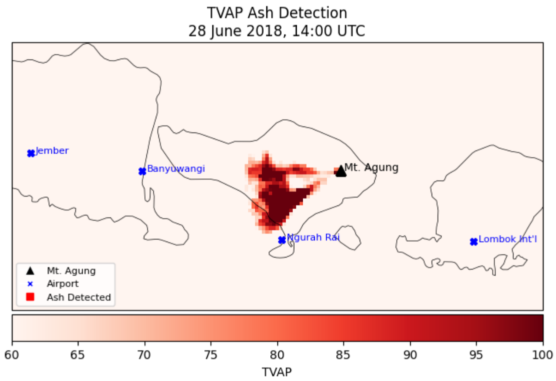

Figure. 2. TVAP value 28 June 2018

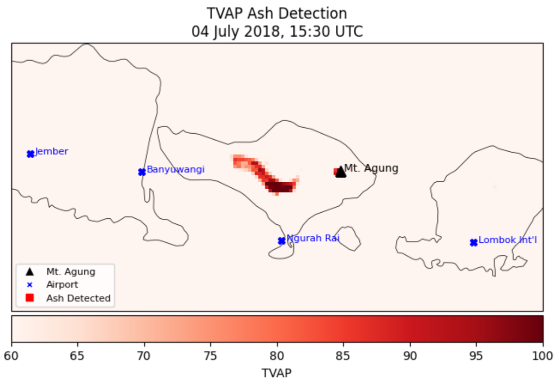

Figure. 3. TVAP value July 4th 2018

Table 2. PVMBG Information Mt. Agung 20171125/2150Z

Agung 20171125/2150Z	
(1) VOLCANO OBSERVATORY NOTICE FOR AVIATION - VONA	
(2) Issued	**:** 20171125/2150Z
(3) Volcano	**:** Agung (264020)
(4) Current Aviation Colour Code	**: RED**
(5) Previous Aviation Colour Code	**:** orange
(6) Source	**:** Agung Volcano Observation
(7) Notice number	**:** 2017AGU18
(8) Volcano Location	**:** S 08 deg 20 min 31 sec E 115 deg 30 min 29 sec
(9) Area	**:** Bali, Indonesia
(10) Summit Elevation	**:** 3142 FT (982 M)
(11) Volcanic Activity Summary	**:** Eruption with volcanic ash cloud at 2145 UTC (0545 LT) Eruption and ash emission is continuing.
(12) Volcanic Cloud Height	**:** best estimate of ash-cloud top is around 64858 FT (19654 M) above sea level, may be higher than what can be observed clearly. Source of height data: ground observer.
(13) Other Volcanic Cloud Information	**:** Ash cloud moving to **east-southeast**
(14) Remarks	**:** Seismic activity is characterized by low frequency earthquakes.
(15) Contacts	**:** Center for Volcanology and Geological Hazard Mitigation (CVGHM) Tel : +62-22-727-2606 Facsimile : +62-22-720-2761 Email: pvmbg@esdm.go.id
(16) Next Notice	**:** A new VONA will be issued if conditions change significantly or the colour code is changes. Latest Volcanic information is posted at VONA | MAGMA Indonesia Website. Link:https://magma.esdm.go.id/v1/vona
Agung 20171125/2150Z	

Table 3. PVMBG Information Mt. Agung 20180628/0800Z

Agung 20180628/0800Z	
(1) VOLCANO OBSERVATORY NOTICE FOR AVIATION - VONA	
(2) Issued	**:** 20180628/0800Z
(3) Volcano	**:** Agung (264020)
(4) Current Aviation Colour Code	**: ORANGE**
(5) Previous Aviation Colour Code	**:** orange
(6) Source	**:** Agung Volcano Observation
(7) Notice number	**:** 2018AGU31
(8) Volcano Location	**:** S 08 deg 20 min 31 sec E 115 deg 30 min 29 sec
(9) Area	**:** Bali, Indonesia
(10) Summit Elevation	**:** 3142 FT (982 M)
(11) Volcanic Activity Summary	**:** Continuous emission observed since 0230 UTC (1030 Local) and still continuing.
(12) Volcanic Cloud Height	**:** best estimate of ash-cloud top is around 54298 FT (16454 M) above sea level, may be higher than what can be observed clearly. Source of height data: ground observer.
(13) Other Volcanic Cloud Information	**:** Ash cloud moving to West and Southwest.
(14) Remarks	**:** Increasing in seismic activity (tremor)
(15) Contacts	**:** Center for Volcanology and Geological Hazard Mitigation (CVGHM) Tel : +62-22-727-2606 Facsimile : +62-22-720-2761 Email: pvmbg@esdm.go.id
(16) Next Notice	**:** A new VONA will be issued if conditions change significantly or the colour code is changes. Latest Volcanic information is posted at VONA | MAGMA Indonesia Website. Link:https://magma.esdm.go.id/v1/vona
Agung 20180628/0800Z	

Table 4. PVMBG Information Mt. Agung 20180704/1432Z

Agung 20180704/1432Z	
(1) VOLCANO OBSERVATORY NOTICE FOR AVIATION - VONA	
(2) Issued	: 20180704/1432Z
(3) Volcano	: Agung (264020)
(4) Current Aviation Colour Code	**: ORANGE**
(5) Previous Aviation Colour Code	: orange
(6) Source	: Agung Volcano Observation
(7) Notice number	: 2018AGU44
(8) Volcano Location	: S 08 deg 20 min 31 sec E 115 deg 30 min 29 sec
(9) Area	: Bali, Indonesia
(10) Summit Elevation	: 3142 FT (982 M)
(11) Volcanic Activity Summary	: Eruption with volcanic ash cloud at 1416 UTC (2216 local).
(12) Volcanic Cloud Height	: Volcanic ash is not visible/observed.
(13) Other Volcanic Cloud Information	: Eruption not visible from ground observation.
(14) Remarks	: Eruption recorded on seismogram with 22 mm maximum amplitude and duration about 197 second.
(15) Contacts	: Center for Volcanology and Geological Hazard Mitigation (CVGHM) Tel : +62-22-727-2606 Facsimile : +62-22-720-2761 Email: pvmbg@esdm.go.id
(16) Next Notice	: A new VONA will be issued if conditions change significantly or the colour code is changes. Latest Volcanic information is posted at VONA | MAGMA Indonesia Website. Link:https://magma.esdm.go.id/v1/vona
Agung 20180704/1432Z	

Split Window Technique Analysis. In identification using split windows, the distribution of volcanic ash can be clearly seen in contrast to the cloud region, but if the image has a temperature close to the cloud temperature, it will be difficult to distinguish [18]. Analysis of volcanic ash using the Split Window technique at 11 µm (B13) and 12 µm (B15) wavelengths by utilizing differences in absorption character is used to distinguish ash and water/ice particles. This method can also be used to analyze volcanic ash and clouds based on both wavelengths. Volcanic ash can be analyzed if the difference in pixel values of 11 µm (B13) and 12 µm (B15) is negative and the difference in pixel value of 3.9 µm (B7) and 11 µm (B13) is positive [19].

Table 5. Split Window Algorithm

Algorithm	Pixel Value of Volcanic Ash
B13 – B15	< 0
B7 – B13	> 0

The eruption of Mount Agung on 25 November, 2017, occurred at 23:40 UTC and moved to the west-southwest based on information from PVMBG. Based on Split Window technique analysis, it didn't detect any difference in the absorption of wavelength between volcanic ash and clouds (Fig 4).

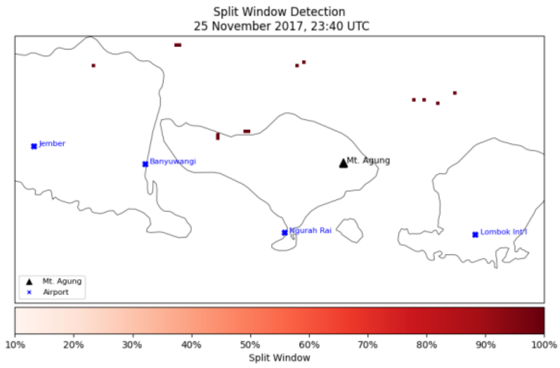

Figure. 4. Split Window value 25 November 2017

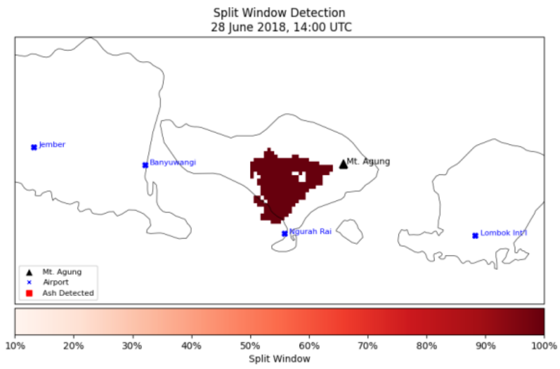

Figure. 5. Split Window value 28 June 2018

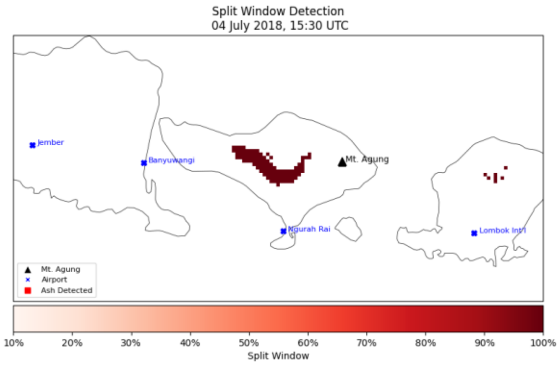

Figure. 6. Split Window value 04 July 2018

Based on information from PVMBG, the eruptions that occurred on 28 June 2018, at 14:00 UTC is moving west (Fig 5). The volcanic ash dispersion on 4 July 2018, at 15:30 UTC is detected moving to west-southwest. On the other hand, based on Split Window technique analysis (Fig 5), it showed the eruption of Mount Agung on 28 June 2018 at 14:00, had the same trajectory of volcanic ash dispersion according to information of PVMBG.

RGB Technique Analysis. Himawari satellite images can be processed using the RGB method, namely by combining several satellite image channels so that one image can be analyzed [20]. The study shows that satellite observations can be used for weather or climate modeling input data that provide characteristics of volcanic ash emissions, trajectories and SO_2 conversion [5]. The resulting atmospheric modeling allows the production of directional forecasts and dispersions of volcanic ash from volcanic eruptions [21]. Detection of volcanic ash and distinguishing it from meteorological clouds is very important because visually, the two are similar, so advanced detection methods are needed [22].

Identification of volcanic ash dispersion using RGB technique by utilizing three channels of Himawari-8 satellite with the composite of SP (IR1-IR2) in red (red), S2 (IR4-IR) in green (green), and IR4 with a wavelength of 3.9 µm as blue. Volcanic ash will be shown in red-light red color.

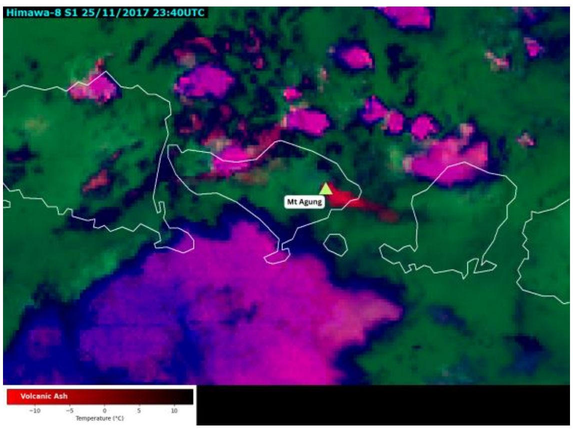

Figure. 7. RGB value 25 November 2017

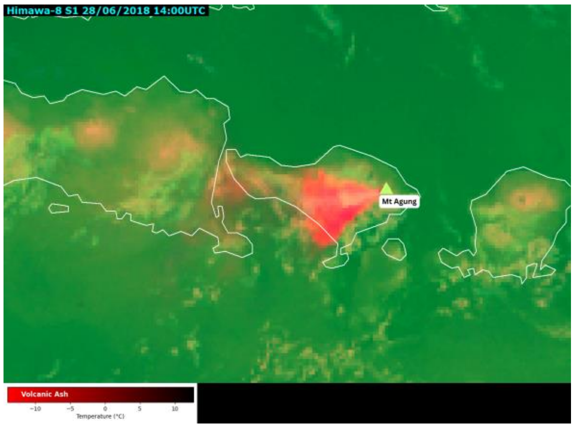

Figure. 8. RGB value 28 June 2018

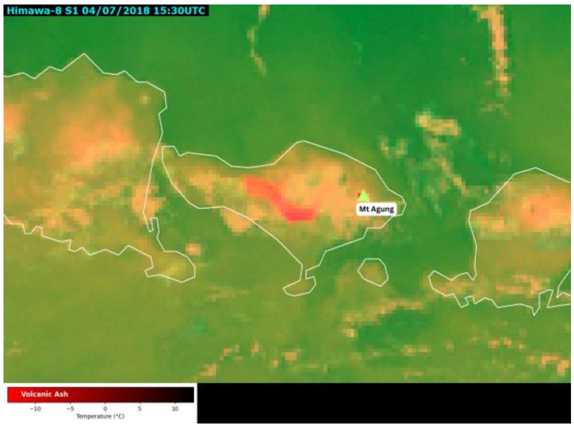

Figure. 9. RGB value 04 July 2018

The eruptions of Mount Agung on 25 November 2017, 28 June 2018 and 4 July 2018 can be shown that marked with red-light red color. Based on RGB technique analysis, the eruptions that occurred on 25 November 2017, are moving to the west-southwest, and 28 June 2018, and 4 July 2018, are moving to the west. They showed the same trajectory of volcanic ash dispersion according to PVMBG's information, except 4 July 2018 that volcanic ash cannot be seen by observer. The detection of TVAP was influenced by cloud interference, as it is dependent on thermal bands that are sensitive to cloud emissions, which made it challenging to differentiate between ash and clouds. In contrast, the RGB technique employs visible light, which is less influenced by clouds, thereby enabling a more precise identification of ash. In order to mitigate this issue, it is possible to enhance TVAP by employing cloud masking algorithms or incorporating supplementary spectral regions that are less susceptible to cloud cover. Conversely, the accuracy of ash detection could be improved by integrating data from various satellites or sensors, even in the presence of clouds.

Volcanic ash from the eruption can be clearly identified by the Himawari satellite if there are few clouds around the eruption site [23]. This is because Himawari satellite images can be difficult to distinguish from cloud-cover images [24]. In the Himawari RGB satellite imagery, volcanic ash is indicated by a pink color while a bright color can be interpreted as SO_2 [25].

This study was only conducted on one eruption event, so the potential for bias in the resulting analysis was immense. For other eruption events with different characteristics, different intensity, duration, or atmospheric conditions may lead to less accurate analysis results. Therefore, a larger number of samples is needed to obtain more accurate and representative analysis results. The increase in the number of eruption events studied can not only improve accuracy but also help understand the pattern of variation in eruption characteristics and their impact on the surrounding environment. The comparison of the three methods that have been carried out depends on the ability of satellite imagery to detect volcanic ash. The main obstacle faced in the event of a volcanic eruption is weather conditions, such as thick cloud cover that hinders the image interpretation process. The condition of thick cloud cover can make it difficult to distinguish volcanic ash material from other atmospheric elements so that the analysis process is carried out.

The comparison of these three methods is less than optimal because the accuracy of detection depends on the quality, resolution, and availability of satellite data at the time of the incident. To improve accuracy in subsequent studies, an approach that considers variations in atmospheric conditions as well as the limitations of satellite sensing is needed. One method that can be applied is the use of additional data sources, such as the results of other satellite imagery and integration with the numerical model of volcanic ash dispersion. With this more comprehensive approach, it is hoped that future research can provide more accurate and useful results.

4. Conclusion

Volcanic ash from the eruption can be clearly identified by the Himawari satellite if there are few clouds around the eruption site. Split-Window, RGB, and TVAP techniques each exhibit optimal performance under distinct circumstances. TVAP is reliable for detecting dense ash clouds across a variety of conditions due to its exceptional quantitative precision, although it may necessitate modifications to account for varying ash compositions. When the ash is less dense, the Split-Window technique is extremely sensitive to thin ash layers and is effective. However, its reliability is reduced under heavy cloud cover or mixed ash conditions. The RGB method is advantageous for rapid visual interpretation, as it provides immediate insights into ash dispersion. However, it is not as precise in detecting low ash concentrations or narrow plumes. These techniques are mutually beneficial, with TVAP being the most dependable for dense ash, Split-Window for thin layers, and RGB for visual assessments.

Information of the trajectory of volcanic ash dispersion can be identified using three types of techniques, such as TVAP , Split-Window and RGB technique. All these techniques can identify volcano eruptions with same pattern, except Split-Window technique can detect volcanic ash on 28 June 2018. This disparity is probably attributable to many impacting variables. The Split-Window approach, utilizing the thermal infrared disparity between two channels (often between 11 µm and 12 µm), exhibits heightened sensitivity to volcanic ash, even in thin layers or when intermixed with water vapor or clouds. On that particular date, meteorological conditions (characterized by low moisture content and limited cloud cover) may have facilitated the clearer identification of ash using the Split-Window approach. Alternative approaches may exhibit diminished sensitivity owing to signal interference from clouds, fluctuations in surface temperature, or suboptimal channel combinations for ash detection. This proved that the usage of the combination of three techniques can give information which are used in the operation of flight transportation. This information is used to prevent accidents and losses, especially for public. The usage of weather satellite with various techniques can be done to observe the trajectory and dispersion of volcanic ash, so that the results can be used for making decisions and reducing impacts.

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