Bincang Sains dan Teknologi (BST)
DOI: 10.56741/bst.v4i01.873

E-ISSN 2961-8746
P-ISSN 2961-8932

Elevation Dynamics and Thermal Variations During the Eruption Phases of Mount Lewotobi Laki-laki

[1]Azmi Khusnani, [1]Adi Jufriansah*, [2]Yudhiakto Pramudya, [1]Dedi Suwandi Wahab, [1]Isma Alip, [3]Fazaki Ramadhani Anwar Samana, [1]Tuti Asmiranti Sina, [1]Servia, [1]Maria Deti

Corresponding Author: * saompu@gmail.com

[1] Universitas Muhammadiyah Maumere, Indonesia
[2] Universitas Ahmad Dahlan, Indonesia
[3] Agency for Meteorology Climatology and Geophysics (BMKG), Fransiskus Xaverius Seda Meteorological Station, Indonesia

Article submitted: 25 February 2025
Revised: 13 March 2025
Accepted: 15 March 2025

Abstract

Mount Lewotobi Laki-Laki since December 2023, the eruption status has increased, with a substantial increase in November 2024. This led to modifications in the distribution of temperature, the patterns of volcanic material flow, and the morphology of the land. The objective of this research was to examine the relationship between the elevation profiles and temperature fluctuations that occurred during the eruption of Mount Lewotobi Laki-Laki. This investigation illustrates the considerable impact of volcanic activity on the environment by employing satellite data-based methodologies, digital elevation models (DEMs), and thermal analysis. The results suggest that volcanic activity has a significant impact on the distribution of temperature and the alteration of geological structures. The observed temperature increase, which extends from the crater to the slopes and lowlands, has an impact on local ecosystems and atmospheric conditions. The precipitous elevation profile significantly impacts the flow pattern of volcanic material, such as lava and lahars, which can pose a disaster risk to settlements and community activities in the vicinity. This research underscores the necessity of ongoing monitoring for risk mitigation and community preparedness in volcanic disasters.

Keywords: *Digital Elevation Model (DEM), Elevation, Mount Lewotobi, Thermal, Volcanic Activity*

Introduction

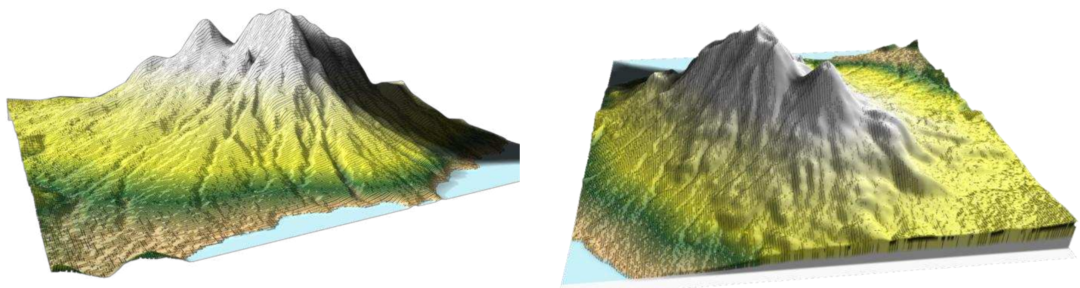
Geographically, Indonesia is located along the Pacific Ring of Fire, so it has high volcanic activity [1], [2]. The geological structure of the Eastern Indonesian region, particularly in Flores, East Nusa Tenggara (Nusa Tenggara Timur or NTT), is distinctive due to its location at the convergence of three major tectonic plates: the Pacific, Indo-Australia, and Eurasia. This interaction generates a series of volcanoes, complex faults, and an active subduction zone, resulting in a region that is abundant in geological phenomena, including volcanic activity and earthquakes [3], [4].

Mount Lewotobi Laki-Laki, located in Flores, is two twin active volcanoes, Mount Lewotobi Laki-Laki and Mount Lewotobi Perempuan [5], [6]. Mount Lewotobi Laki-Laki's most recent volcanic activity occurred in 2002 and was reactivated in 2023 with a significant increase since November 2024. Monitoring the volcanic activity of Mount Lewotobi Laki-laki during the eruption phase is essential. To facilitate mitigation efforts, it is necessary to observe thermal variations and elevation dynamics. This monitoring can be undertaken through a variety of methods, such as the analysis of remote sensing data using multispectral and thermal satellite imagery, seismic recordings, and field observations. Based on reports from the Lewotobi Laki-laki Volcano Observation Post, increased volcanic activity has been detected in certain periods. According to data obtained from the Ministry of Energy and Mineral Resources (ESDM) in November 2024, the lava flow that originates from the mountain tends to move to the west and northwest.

This phenomenon is consistent with the topographic characteristics of the region, which feature a steep slope that enables lava to adhere to the descending morphological contour [7]. The distribution of thermal energy released during the eruption is also influenced by the intricate topography surrounding Mount Lewotobi Laki-laki. In this context, temperature fluctuations are a critical parameter for comprehending the correlation between volcanic activity and environmental changes [8]. The release of thermal energy from magma activity is frequently indicated by elevated surface temperatures in the vicinity of volcanic areas. This phenomenon can be detected through direct monitoring or the analysis of infrared sensor-based satellite data [9]. The aim of this research is to conduct a thorough examination of the relationship between temperature dynamics and elevation during the eruption of Mount Lewotobi Laki-laki. It is anticipated that this analysis will yield information regarding the mountain's volcanic characteristics and their potential effects on the surrounding environment.

Material And Methods

The research area of this study is Mount Lewotobi Laki-Laki, which is situated on Flores Island, East Nusa Tenggara, Indonesia, and is a component of the Pacific Ring of Fire volcanic chain [10]. This mountain is created from layers of pyroclastic material, ash, and lava that are produced by the eruption of an active stratovolcano with a steep cone shape [11]. Fig. 1 illustrates that Mount Lewotobi Laki-Laki, which ascends to approximately 1,584 meters above sea level, is one of the two primary peaks of Mount Lewotobi.



(a) (b)

Fig. 1. 3D Cross Section of Mount Lewotobi Laki Laki, a) Left part and b) Right part

Data from the Center for Volcanology and Geological Disaster Mitigation (PVMBG) report was employed to conduct monitoring. The primary source of information for comprehending the dynamics of mountain morphology prior to, during, and subsequent to the eruption is data from PVMBG. This study incorporates satellite imagery and data processing using Google Earth Engine (GEE) and QGIS to enhance the analysis of the elevation profile. The combination of these two software allows mapping of

E-ISSN 2961-8746
DOI: 10.56741/bst.v4i01.873
P-ISSN 2961-8932

high-resolution elevation changes, including Digital Elevation Model (DEM) analysis to identify the impact of volcanic activity on the topography of the mountain.

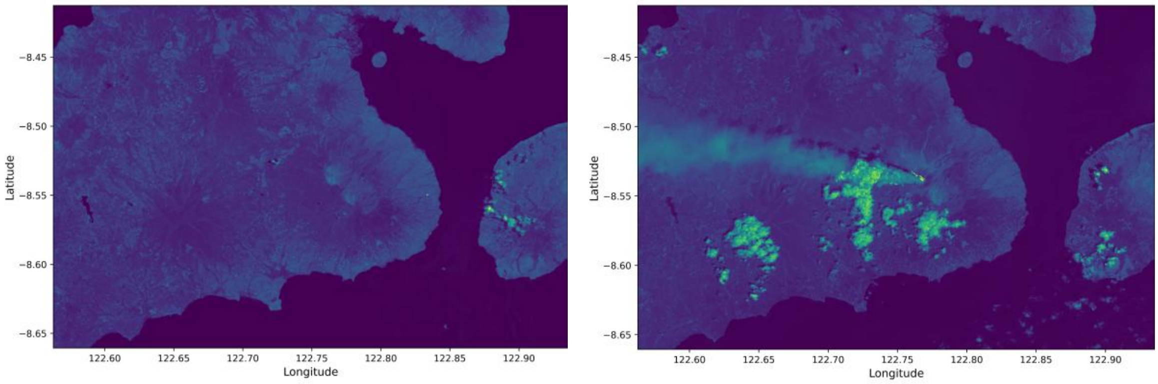
Satellite data was employed to analyze temperature fluctuations. Thermal anomalies associated with volcanic activity were identified through the examination of surface temperature profiles. This temperature monitoring encompasses the crater area, slopes, and regions that have been impacted by lava flows and fumaroles. Thematic maps that illustrate changes in elevation and temperature during various eruption periods are generated by processing the elevation and temperature data collected using GEE and QGIS. To summarize the trend of changes and identify patterns of thermal and elevation anomalies that reflect volcanic activity, descriptive statistical analysis was conducted. Additionally, visual observations were conducted in accordance with PVMBG reports and documentation. The objective of this observation is to document the physical changes that have resulted from volcanic activity, such as lava flows, gas releases, and alterations in crater morphology. Quantitative data obtained through satellite monitoring methods are supplemented by visual documentation from PVMBG and field data analysis.

The subsequent phase involves the simulation of temperature and elevation fluctuations using the data that was gathered during the eruption. In order to facilitate data integration and comprehensive analysis, mathematical modeling is implemented to forecast elevation and temperature fluctuations. Data are systematically collected and analyzed to guarantee quality and consistency. The results of this analysis are employed to establish the correlation between the eruptive activity of Mount Lewotobi Laki Laki and the changes in elevation and temperature. Additionally, they are employed to enhance comprehension of the mechanisms of change that occur during the eruption and its effects on the surrounding environment.

Results and Discussions

A satellite image of Mount Lewotobi Laki-Laki on October 9, 2024, is depicted in Fig. 2(a), which offers a comprehensive view of the volcanic conditions prior to the eruption. The image demonstrates that the region surrounding the mountain is still primarily characterized by relatively intact vegetation, which suggests a stable ecosystem. There are no signs of noteworthy volcanic activity, such as eruptions or the accumulation of ash, which suggests that Mount Lewotobi Laki-Laki was inactive during this time. This condition can serve as an initial reference for comprehending the dynamics of volcanic changes that transpire in the subsequent period. In the interim, Fig. 2(b) illustrates a satellite image of Mount Lewotobi Laki-Laki on November 13, 2024, which employs the false-color composite method to emphasize the transformations in land cover that have resulted from volcanic activity. This image demonstrates that Mount Lewotobi Laki-Laki is currently undergoing an active eruption, as evidenced by the presence of volcanic ash plumes that envelop the crater and the surrounding area. The volcanic dynamics that transpired within a brief period are revealed through the examination of the differences between the two. The variations in satellite imagery suggest a substantial increase in volcanic activity, which has implications for the distribution of volcanic material, changes in mountain morphology, and potential risks to the environment and settlements in the vicinity of the affected area.

DOI: 10.56741/bst.v4i01.873
P-ISSN 2961-8932



(a) (b)

Fig. 2. (a) 9 October 2024, (b) 13 November 2024

The dynamics of seismic and volcanic activity at Mount Lewotobi Laki Laki during November 2024 are illustrated in Fig. 3. At the commencement of the period, there was a substantial increase in deep tectonic activity, with over 12 events. Subsequently, it decreased and exhibited minor fluctuations. This suggests the potential for the volcanic system to become unstable due to the movement of deep plates. At the same time, the local tectonic activity experienced a surge at the beginning of the period, with over nine events. This could be indicative of fractures in the earth's crust surrounding the mountain. The movement of magma at depth, which has the potential to rise to the surface, was indicated by a sharp spike in deep volcanic activity at the beginning of the observations, with over 80 events. Subsequently, the activity decreased. A similar pattern was observed in shallow volcanic activity, which began with an initial surge of over 40 events and subsequently experienced a significant decline. This decline was indicative of the movement of magma, which was approaching the surface but not sufficiently close to trigger a direct eruption.

In addition, harmonic vibrations exhibited a substantial peak between the 22nd and 25th days, which frequently suggests a more consistent and consistent movement of magma toward the surface. This is consistent with a sharp increase in gas-blowing activity, which at certain points exceeded 70 events, suggesting the release of high internal pressure because of increased magmatic activity. The activity of sudden volcanic impacts or earthquakes (clashes) also experienced a spike from the 16th to the 20th day, which was most likely caused by rock fractures because of the increasing magma pressure. In addition, the eruption activity exhibited a gradual increase pattern with more stable fluctuations than other categories, suggesting that the eruption occurred in multiple phases that were not immediately explosive but more continuous. This demonstrates that the eruption of Mount Lewotobi Laki-Laki was preceded by a gradual increase in seismic and volcanic activity, which began with deep tectonic activity, the movement of magma from depth to the surface, and then culminated in an increase in gas pressure that initiated the eruption. The general volcanic activity model is consistent with the spike in blowing, clashes, and harmonics categories in the middle to late period, which suggests a critical phase prior to an eruption. This pattern offers critical insights for the monitoring and mitigation of future eruption risks.

DOI: 10.56741/bst.v4i01.873
E-ISSN 2961-8746
P-ISSN 2961-8932

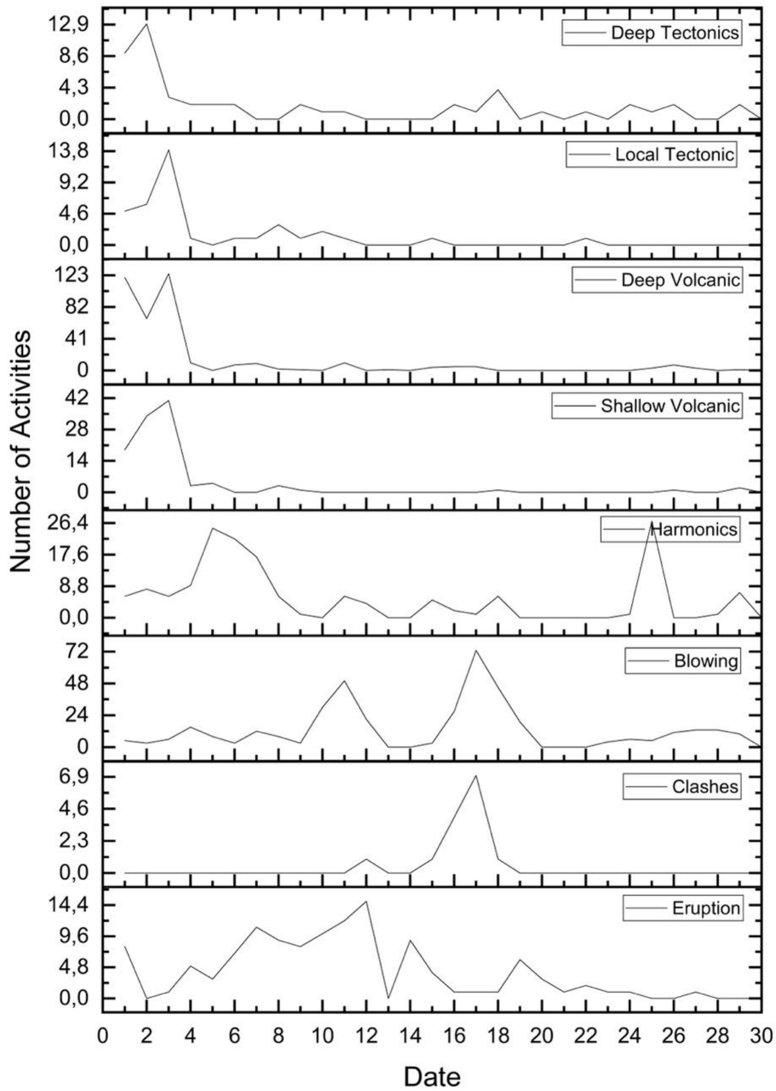


Fig. 3. Number of Activities During November 2024

The stability of the volcanic system can be influenced by tectonic activity in the deep layer, which can create new pathways for magma to move, as per [12]. The reduction in deep tectonic activity depicted in Fig. 3 may be indicative of a temporary stabilization of pressure beneath the earth's surface or a redirection of energy to other activities, such as the movement of magma to shallower zones. Local tectonics exhibits a comparable pattern, with a peak of activity at the commencement of the observation period, followed by a decline, despite the presence of minor fluctuations. This local tectonic activity is frequently an early indicator of magma movement, as it can create pathways that enable magma to ascend to the surface. Local tectonic activity, despite its smaller scale than deep tectonic activity, plays a critical role in enabling magma movement, as stated by Zhang et al. [13]. The local tectonic pressure is still active, as evidenced by the minor fluctuations observed following the initial peak. However, these fluctuations are not substantial enough to induce significant changes in the volcanic system. The pattern of deep volcanic activity is intriguing, as it exhibits a high intensity at the outset of the observation, which subsequently diminishes significantly. This suggests that the magma in the primary reservoir has commenced its migration to a shallower region. The movement of magma from the main reservoir to the surface through previously formed pathways is frequently reflected in deep volcanic activity, as explained by Caricchi et al. [14]. This decrease in activity can be interpreted as a sign that most of the magma has relocated to the shallow zone, which is subsequently observed in an increase in shallow volcanic activity. This transition is crucial for comprehending the dynamics of the volcanic system, as it illustrates the initial stages of the process that may result in an eruption.

After a decline in deep volcanic activity, shallow volcanic activity exhibits a substantial increase. Magma has reached the shallow zone beneath the crater, as evidenced by the fact that the activity reaches its zenith in the middle of the observation period. The accumulation of gas pressure in the near-surface zone is frequently a direct precursor to an eruption, as evidenced by this shallow volcanic activity. According to Edmonds et al. [15] and Sharkov [16], shallow volcanic activity is a critical factor in the preparation of the volcanic system for eruption, as the trapped gas pressure is gradually released. This pattern suggests that the volcanic system is currently in a critical phase, during which internal pressure is approaching the threshold that can initiate an eruption.

Stable and continuous magma movement is typically the source of harmonic activity. The intensity and stability of magma movement toward the surface are suggested by a significant increase in harmonic activity following the peaks of shallow volcanic activity. This harmonic activity is frequently employed as one of the primary indicators of eruption potential due to its ability to reflect the increasing internal pressure and open magma pathways [17]. The harmonic activity peak observed in this graph suggests that the volcanic system is currently in a highly active phase, with a high likelihood of an eruption in the near future. This pattern also demonstrates a close relationship between harmonic activity and shallow volcanic activity, which collectively reflect the internal dynamics of the volcanic system.

Moreover, the harmonic activity reaches its peak almost simultaneously with the blowing activity, which may indicate the release of gas or steam from the crater. This suggests that the gas pressure in the volcanic system is being released in a substantial manner, a defining feature of the phase preceding an eruption. Intense gas release frequently occurs prior to or during an eruption, as gas that has been trapped in magma is released into the atmosphere [18]. Additional evidence that the volcanic system is in a critical phase is provided by the blowing activity depicted in this graph, which indicates that internal pressure has reached extremely high levels. The seventh graph (Fig. 3) illustrates the pattern of clash activity, which is comparable to that of blowing activity. A peak of activity is observed, followed by a significant decline. It is probable that this activity pertains to minor earthquakes that are produced by the interaction between magma and the surrounding rocks. According to Donovan & Oppenheimer [19], clash activity frequently corresponds to sudden pressure releases or new cracks that manifest in shallow zones. This pattern suggests that the volcanic system is currently experiencing substantial changes, as internal pressure continues to rise, thereby initiating interactions between magma and the surrounding rocks. During the observation period, there were numerous minor peaks in eruptive activity.

This eruptive activity is indicative of the release of volcanic material, including ash, lava, and other pyroclastic material, to the surface. In comparison to other indicators, the relatively low eruptive activity indicates that most of the volcanic energy may have been released through seismic or gas activity prior to the material reaching the surface. Eruptive activity is frequently the consequence of a series of intricate processes, such as the movement of magma, the release of gas, and the interactions between magma and the surrounding rocks [14]. The patterns depicted in this graph offer significant insights into the way various forms of seismic and volcanic activity interact to generate eruptions.

In-depth analysis of the temperature distribution pattern in the mountainous region in relation to topographic variations and atmospheric conditions is provided in Fig. 4. The mountain peak registers the highest temperature at the graph's inception, with an approximate value of 35°C. The intensity of solar radiation at the peak, which is not obstructed by vegetation or other atmospheric factors, is one of the primary factors contributing to the high temperature. Furthermore, this elevated temperature may also indicate the potential impact of volcanic activity, as the release of heat from the subsurface magmatic system can elevate the temperature in the vicinity of the peak. Nevertheless, the temperature experiences a significant drop as the elevation decreases from the peak to the lower region. This phenomenon is consistent with the adiabatic temperature gradient principle, which states that the temperature of the air decreases as elevation increases because of the expansion of air under reduced atmospheric pressure. According to a study conducted by Kattel et al. [20], the average adiabatic temperature gradient in the troposphere is approximately 6.5°C per kilometer, which is consistent with the decreasing temperature trend depicted in this graph.

The graph displays annotations about the observations made on the west side of the mountain on November 11 and 12, at approximately 2500 meters from the peak. The temperature at this location was observed to have decreased to approximately 20°C, which suggests that the combined influence of local microclimate conditions and elevation factors was present. The presence of denser vegetation cover in this region may lead to lower temperatures by reducing the absorption of heat from solar radiation and maintaining a higher relative humidity. Furthermore, the loss of temperature can be exacerbated by the airflow patterns from higher slopes, particularly when there is a drainage effect of cold air flowing downslope. The specific observation locations used to monitor temperature changes in relation to volcanic or atmospheric dynamics around the mountain are most likely reflected in the annotations in the graph at this point.

An additional annotation in the graph displays observations from the west and northwest sides of the mountain from November 12 to November 30, at approximately 3800 meters. Temperatures in this region were within the 15°C range, suggesting a continued decline in temperature as the horizontal distance from the summit and elevation decrease. However, this phenomenon can also be influenced by other factors, such as the dominant wind direction and the distribution of humidity in the area and can be accounted for by the principle of a continuous temperature gradient in mountain systems. According to Pepin et al. [21], the temperature distribution in mountainous regions is frequently impacted by the intricate interactions between wind, land cover, and topography, in addition to changes in elevation. This may account for the more substantial temperature fluctuations observed in certain regions of the graph, even though they are in accordance with the fundamental principle of the adiabatic temperature gradient, which is a downward trend.

Temperatures below 15°C were observed on the northeastern side of the mountain between November 13 and November 30, at approximately 4340 meters. This more substantial temperature decrease suggests that the temperature distribution pattern in this region is influenced by factors other than elevation. The orographic effect generated by the mountain's topography is one of the primary factors that can impact the temperature decrease on the northeastern side. Temperatures in this region are expected to be lower than those in other locations with comparable elevations due to the potential for cold air flow from the northeast to transport cooler air masses from higher regions or from outside the mountain system. The temperature distribution in mountainous regions is significantly influenced by the dominant wind direction and local topography, particularly on slopes that face the primary wind direction [22], [23]. Consequently, the observed decrease in temperature on the northeastern side is most likely the consequence of a combination of cooling effects caused by local wind circulation patterns and adiabatic temperature gradients.

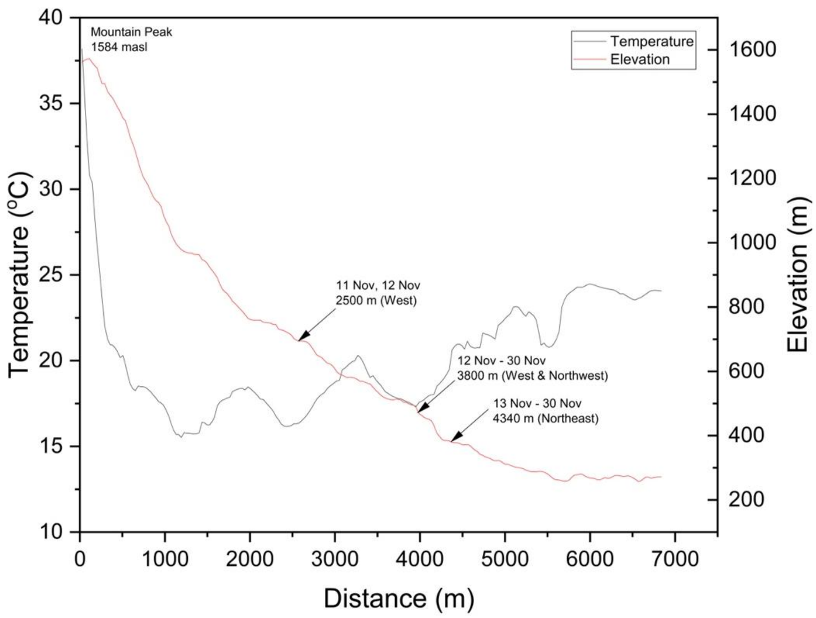


Fig. 4. Elevation and temperature profile of mount Lewotobi Laki Laki

The findings of this investigation suggest that the environmental conditions surrounding Mount Lewotobi are not the only factors that are directly influenced by the volcanic dynamics, but also the geological structure. This discovery underscores the intricacy of the volcano's magmatic system, necessitating specialized attention in the mitigation of volcanic disaster risks. These findings suggest that temperatures are generally lower in higher elevations than in lowland regions. This phenomenon is in accordance with the principles of thermodynamics, which elucidate that air pressure and temperature decrease as altitude increases [21]. Nevertheless, volcanic activity results in a substantial rise in temperature in a variety of locations, such as the mountain's peak and slope areas. This suggests that the temperature patterns in the vicinity of Mount Lewotobi are significantly affected by the release of thermal energy from magma. Previous research has indicated that fluctuations in surface temperature can serve as an essential indicator for the monitoring of volcanic activity [9], [24].

This observation is pertinent to this context. Mount Lewotobi Laki-Laki is characterized by its stratovolcano shape and steep, rugged slopes. The flow pattern of volcanic material, including lava and lahar, is influenced by these characteristics during an eruption. The data indicates that the flow of volcanic material is inclined to follow the contour of steep slopes, particularly in the west and northwest. This phenomenon is consistent with the predictions made by the digital elevation model (DEM) employed in the investigation. The potential for substantial damage to settlements and agricultural land in the vicinity of the mountain is present due to the concentration of lahar flows in these regions. This investigation documented substantial temperature fluctuations throughout the eruption period. The data indicated a significant rise in temperature in early November 2024, which was concurrent with the eruption's high intensity. The eruptions were distinguished by the release of volcanic material, including hot gas and ash, as well as the potential for lava flows. This temperature increase was not restricted to the crater area; it also affected the slopes and lowlands. This analysis underscores the significance of ongoing temperature monitoring to identify potential increases in volcanic activity [9].

This study underscores the significance of managing volcanic disaster risks in the vicinity of Mount Lewotobi, in addition to its geological and environmental effects. This study offers valuable insights for local governments and communities in the development of mitigation strategies by employing an interdisciplinary approach that encompasses the analysis of elevation, temperature, and volcanic activity. The identification of high-risk areas is greatly facilitated by information on the distribution of temperature and the flow patterns of volcanic material, which enables the focus of preparedness measures in these regions. Additionally, the data that was gathered during the eruption period can be employed to simulate a variety of future eruption scenarios [25]. This modeling is crucial for comprehending the intricate dynamics of volcanic activity, particularly in predicting the likelihood of a significant eruption in the future [26].

In a global context, this study has substantial implications. The broader effects of climate change are reflected in the observed temperature increase at Mount Lewotobi during the eruption period. These results indicate that volcanic activity, particularly through greenhouse gas emissions and aerosol particles, has the potential to exacerbate the global warming trend. Consequently, this investigation is not only pertinent for comprehending local dynamics, but it also makes a significant contribution to the global discourse regarding the influence of volcanic activity on climate change. This study underscores the significance of education and community involvement in disaster risk management from a social perspective. Community participation in disaster mitigation initiatives is essential, particularly in the context of evacuation training and the promotion of awareness of volcanic hazards, as the region surrounding Mount Lewotobi is susceptible to volcanic activity. The data presented in this study has the potential to serve as educational material that will enhance the community's comprehension of the hazards they encounter.

E-ISSN 2961-8746
P-ISSN 2961-8932

Conclusion

The research results indicate that volcanic activity not only alters the geological structure but also influences the temperature distribution, which in turn affects the environment and the lives of the local community. The flow pattern of volcanic materials, including lava and lahars, is influenced by the steep elevation profile, which can present significant risks in specific regions. The ecosystem and local atmospheric conditions are influenced by the temperature increase that occurs during an eruption, which is not restricted to the crater but also extends to the slopes and lowlands. These results underscore the significance of utilizing contemporary technologies, including Digital Elevation Models (DEM) and satellite imagery, to effectively monitor these changes and to facilitate the development of more effective disaster risk mitigation strategies. This research provides valuable insights for the development of volcanology and the mitigation of volcanic disaster risk by employing an interdisciplinary approach. It is anticipated that the conclusions drawn will serve as guidelines for the enhancement of community preparedness and environmental management in regions that are susceptible to disasters.

References

[1] N. A. Pambudi and D. K. Ulfa, "The geothermal energy landscape in Indonesia: A comprehensive 2023 update on power generation, policies, risks, phase and the role of education," *Renewable and Sustainable Energy Reviews*, vol. 189, p. 114008, Jan. 2024, doi: 10.1016/j.rser.2023.114008.

[2] V. Ariyanti, T. Gaafar, S. De La Sala, J. Edelenbos, and P. Scholten, "Towards liveable volcanic cities: A look at the governance of lahars in Yogyakarta, Indonesia, and Latacunga, Ecuador," *Cities*, vol. 107, p. 102893, Dec. 2020, doi: 10.1016/j.cities.2020.102893.

[3] U. Sumotarto *et al.*, "Geothermal Well Targeting in Consideration To Geological Structures of Mataloko Field, Flores," *IOP Conf Ser Earth Environ Sci*, vol. 819, no. 1, p. 012019, Jul. 2021, doi: 10.1088/1755-1315/819/1/012019.

[4] P. Cui *et al.*, "Scientific challenges in disaster risk reduction for the Sichuan–Tibet Railway," *Eng Geol*, vol. 309, p. 106837, Nov. 2022, doi: 10.1016/j.enggeo.2022.106837.

[5] P. Zhang, M. S. Miller, and C. M. Eakin, "Unraveling an enigmatic boundary along the Sunda-Banda volcanic arc," *Earth Planet Sci Lett*, vol. 599, p. 117860, Dec. 2022, doi: 10.1016/j.epsl.2022.117860.

[6] L. Hu *et al.*, "Land subsidence in Beijing and its relationship with geological faults revealed by Sentinel-1 InSAR observations," *International Journal of Applied Earth Observation and Geoinformation*, vol. 82, p. 101886, Oct. 2019, doi: 10.1016/j.jag.2019.05.019.

[7] J. R. C. Voigt *et al.*, "Geomorphological characterization of the 2014–2015 Holuhraun lava flow-field in Iceland," *Journal of Volcanology and Geothermal Research*, vol. 419, p. 107278, Nov. 2021, doi: 10.1016/j.jvolgeores.2021.107278.

[8] H.-P. Chan, K. I. Konstantinou, and M. Blackett, "Spatio-temporal surface temperature variations detected by satellite thermal infrared images at Merapi volcano, Indonesia," *Journal of Volcanology and Geothermal Research*, vol. 420, p. 107405, Dec. 2021, doi: 10.1016/j.jvolgeores.2021.107405.

[9] D. Coppola *et al.*, "Thermal Remote Sensing for Global Volcano Monitoring: Experiences From the MIROVA System," *Front Earth Sci (Lausanne)*, vol. 7, Jan. 2020, doi: 10.3389/feart.2019.00362.

[10] R. B. Astro, "Overview of the Potential and Utilization of Geothermal Energy on Flores Island," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 12, pp. 1377–1384, Dec. 2023, doi: 10.29303/jppipa.v9i12.5616.

[11] H. D. Tjia, "Volcanic lineaments in the Indonesian island arcs," *Bulletin Volcanologique*, vol. 31, no. 1, pp. 85–96, Dec. 1967, doi: 10.1007/BF02597007.

E-ISSN 2961-8746
P-ISSN 2961-8932

[12] S. Brune *et al.*, "Geodynamics of continental rift initiation and evolution," *Nat Rev Earth Environ*, vol. 4, no. 4, pp. 235–253, Mar. 2023, doi: 10.1038/s43017-023-00391-3.
[13] C. Zhang *et al.*, "Magmatism and hydrocarbon accumulation in sedimentary basins: A review," *Earth Sci Rev*, vol. 244, p. 104531, Sep. 2023, doi: 10.1016/j.earscirev.2023.104531.
[14] L. Caricchi, M. Townsend, E. Rivalta, and A. Namiki, "The build-up and triggers of volcanic eruptions," *Nat Rev Earth Environ*, vol. 2, no. 7, pp. 458–476, Jun. 2021, doi: 10.1038/s43017-021-00174-8.
[15] M. Edmonds, E. J. Liu, and K. V. Cashman, "Open-vent volcanoes fuelled by depth-integrated magma degassing," *Bull Volcanol*, vol. 84, no. 3, p. 28, Mar. 2022, doi: 10.1007/s00445-021-01522-8.
[16] E. V. Sharkov, "Catastrophic Volcanic Eruptions: Causes and Mechanisms," *Journal of Volcanology and Seismology*, vol. 14, no. 6, pp. 373–378, Nov. 2020, doi: 10.1134/S0742046320040041.
[17] A. Wildani, S. Maryanto, D. Rahadi Santoso, and H. Triastuty, "The Duration Amplitude Distribution of Volcanic Tremor Recorded at Ijen Volcano, Indonesia," *Malaysian Journal of Fundamental and Applied Sciences*, vol. 19, no. 4, pp. 635–644, Aug. 2023, doi: 10.11113/mjfas.v19n4.2934.
[18] G. Jay, "Volcanic Eruption," in *Ciottone's Disaster Medicine*, Elsevier, 2024, pp. 631–636. doi: 10.1016/B978-0-323-80932-0.00102-6.
[19] A. Donovan and C. Oppenheimer, "Volcanoes on borders: a scientific and (geo)political challenge," *Bull Volcanol*, vol. 81, no. 5, p. 31, May 2019, doi: 10.1007/s00445-019-1291-z.
[20] D. B. Kattel, H. A. M. Salih, T. Yao, and K. Ullah, "Near-Surface Air Temperature Dependence on Elevation and Geographical Coordinates Over Tropical Desert Land Surfaces," *Front Earth Sci (Lausanne)*, vol. 9, Feb. 2022, doi: 10.3389/feart.2021.777381.
[21] N. C. Pepin *et al.*, "Climate Changes and Their Elevational Patterns in the Mountains of the World," *Reviews of Geophysics*, vol. 60, no. 1, Mar. 2022, doi: 10.1029/2020RG000730.
[22] M. R. Raupach and J. J. Finnigan, "The influence of topography on meteorological variables and surface-atmosphere interactions," *J Hydrol (Amst)*, vol. 190, no. 3–4, pp. 182–213, Mar. 1997, doi: 10.1016/S0022-1694(96)03127-7.
[23] C. D. Whiteman, "Observations of Thermally Developed Wind Systems in Mountainous Terrain," in *Atmospheric Processes over Complex Terrain*, Boston, MA: American Meteorological Society, 1990, pp. 5–42. doi: 10.1007/978-1-935704-25-6_2.
[24] E. Pavlidou, C. Hecker, H. van der Werff, and M. van der Meijde, "Study of Volcanic Activity at Different Time Scales Using Hypertemporal Land Surface Temperature Data," *J Geophys Res Solid Earth*, vol. 122, no. 10, pp. 7613–7625, Oct. 2017, doi: 10.1002/2017JB014317.
[25] M. P. Poland and K. R. Anderson, "Partly Cloudy With a Chance of Lava Flows: Forecasting Volcanic Eruptions in the Twenty-First Century," *J Geophys Res Solid Earth*, vol. 125, no. 1, Jan. 2020, doi: 10.1029/2018JB016974.
[26] T. J. Aubry *et al.*, "Impact of climate change on volcanic processes: current understanding and future challenges," *Bull Volcanol*, vol. 84, no. 6, p. 58, Jun. 2022, doi: 10.1007/s00445-022-01562-8.

Authors

Azmi Khusnani holds a Physics Education degree (S.Pd.) at Universitas Ahmad Dahlan and a master's in physics education (M.Pd.) at Universitas Ahmad Dahlan. She is a member of the Physical Society of Indonesia and the Association of Educational Institutions of Muhammadiyah-Aisyiyah Universities (ALPTK-PTMA). Her areas of research interest include Disaster Physics, Experimental Physics, and Artificial Intelligence. (email: husnaniazmi@gmail.com).

Adi Jufriansah holds a Bachelor of Education (S.Pd) in Mathematics Education and a Master of Education (M.Pd) in Physics Education, in addition to several certificates and professional skills. Currently, he teaches Physics Education at Universitas Muhammadiyah Maumere. He is a member of the Physical Society of Indonesia (PSI) and a member of the Association of Educational Institutions of Muhammadiyah-Aisyiyah Universities (ALPTK-PTMA). His research areas are image/signal processing, biometrics, pattern recognition

DOI: 10.56741/bst.v4i01.873
E-ISSN 2961-8746
P-ISSN 2961-8932

image analysis, machine learning, deep learning, Blockchain, Internet of Things (IoT), Astrophysics, and mathematical models. Several grants have been obtained at national and international levels from the International Astronomical Union (IAU). (email: saompu@gmail.com).

Yudhiakto Pramudya holds a Doctoral degree (Ph.D) in Physics from Wesleyan University, United States. He works as a lecturer and researcher in Physics and Astronomy in the Master of Physics Education Study Program at Ahmad Dahlan University. He is a member of the Physical Society of Indonesia (PSI). He successfully received the 75 Inspirational and Influential Figures in Indonesia Award in 2020 and the IVLP Impact Awards 2024. In addition, he also has a certificate in disaster management in the Incident Command System (ICS). His research fields include wave and fluid physics, disaster physics, image/signal processing, Internet of Things (IoT), Astronomy, and physics education for the disabled. (email: yudhiakto.pramudya@pfis.uad.ac.id).

Dedi Suwandi Wahab is a student in the Physics Education Study Program at Muhammadiyah University, Maumere. He has participated in a national-level student creativity program organized by the Ministry of Education, Culture, Research and Technology. He is also an active student in organizations including the Study Program Student Association, and is a member of computing research. (email: dediwahab04@gmail.com).

Isma Alip is a student in the Physics Education Study Program at Muhammadiyah University, Maumere. He has participated in a national-level student creativity program organized by the Ministry of Education, Culture, Research and Technology. He is also an active student in organizations including the Study Program Student Association, and is a member of computing research. (email: ismaa824@gmail.com).

Fazaki Ramadhani Anwar Samana is a professional in meteorology and climatology who works at the Agency for Meteorology, Climatology, and Geophysics (BMKG) at Fransiskus Xaverius Seda Station. With a high dedication to atmospheric science, Fazaki plays a role in monitoring and analyzing weather and climate, helping to provide accurate data that supports disaster mitigation and environmental planning. (email: fazaki.samana@bmkg.go.id).

Tuti Asmianti Sina is a student of the Physics Education Study Program of Universitas Muhammadiyah Maumere. He is also an active student in organizations including the Study Program Student Association, and is a member of computational research. (email: tutiasmitanti14@gmail.com).

Servia is a student of the Physics Education Study Program of Universitas Muhammadiyah Maumere. He is also an active student in organizations including the Study Program Student Association, and is a member of computational research. (email: vhiya18@gmail.com).

Maria Deti is a student of the Physics Education Study Program of Universitas Muhammadiyah Maumere. He is also an active student in organizations including the Study Program Student Association, and is a member of computational research. (email: mariadeshy86@gmail.com).