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Mathematical Modeling and Calculation of Volcanic Ash Dispersion from Mount Lewotobi Using the Gaussian Plume Approach

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Abstract

The eruption of Mount Lewotobi at the end of 2024 and throughout 2025 caused widespread volcanic ash dispersion and had a significant impact on the socio-economic aspects of the community, including mass evacuations, damage to settlements, transportation disruptions, and airport closures. These problems required scientific modeling that could accurately describe the pattern of ash dispersion. This study uses a quantitative approach through mathematical modeling based on advection equations, the law of mass conservation, and the Gaussian Plume model simulated using MATLAB software. The purpose of this study is to develop a mathematical model to map the direction and pattern of volcanic ash dispersion as a basis for disaster mitigation planning. The simulation results show that volcanic ash tends to spread westward and northwestward following the dominant wind patterns, forming an asymmetrical plume. These findings confirm that mathematical modeling and computer simulation can improve the accuracy of predictions and support the effectiveness of technology-based disaster mitigation strategies.

Keywords: Volcanic ash dispersion, Mount Lewotobi, Disaster mitigation, Gaussian plume model, Mathematical modeling.

INTRODUCTION

Mount Lewotobi, located in Eas Flores Regency, East Nusa Tenggara, Indonesia, has erpted more than 23 times throughout its history, with the frist recorded eruption occurring in 1861 (Nartini, 2024). The mountain's volcanic activity occurs periodically, with significant eruptions in 1932, 1939, 1999, and most recently in November 2024, which caused at least 10 fatalities and severe damage to settlements and public facilities(Yanuarto, 2024).

The last eruption spewed volcanic ash as high as 9 kilometers, affecting the surrounding islands, where thousands of residents had to be evacuated and causing significant economic damage. Throughout 2025, Mount Lewotobi showed continuous eruption activity with a Level IV (Alert) status, such as on August 18, 2025, when the ash column reached a height of 8,000 meters above the summit, accompanied by rain of gravel and thick ash that disrupted community activities in several villages on the slopes of the mountain (Sekertariat Badan Geologi, 2024). Mitigation measures included the construction of a lava control system, although social, educational, economic, and transportation impacts were unavoidable, including airport closures and the diversion of sea transportatio (Dikson & Angelia Tugu, 2025).

In order to mitigate and manage disasters and minimize risks, important research is being conducted to develop mathematical models of volcanic ash dispersion. These models are usually based on simulations of ash column dynamics, the direction and distance of ash dispersion influenced by wind speed, ash column height, and ash particle characteristics (Irfan et al., 2024). This method is useful for estimating the impact of ash, assisting in evacuation and determining mitigation policies to reduce risks to the surrounding community. The objective of this study is to use the development of a mathematical model of volcanic ash dispersion from Mount

Lewotobi using an advection approach, the law of mass conservation, and the Gaussian Plume model as a basis for mapping the directional pattern of ash dispersion to support disaster mitigation strategies (Mahardhika et al., 2025).

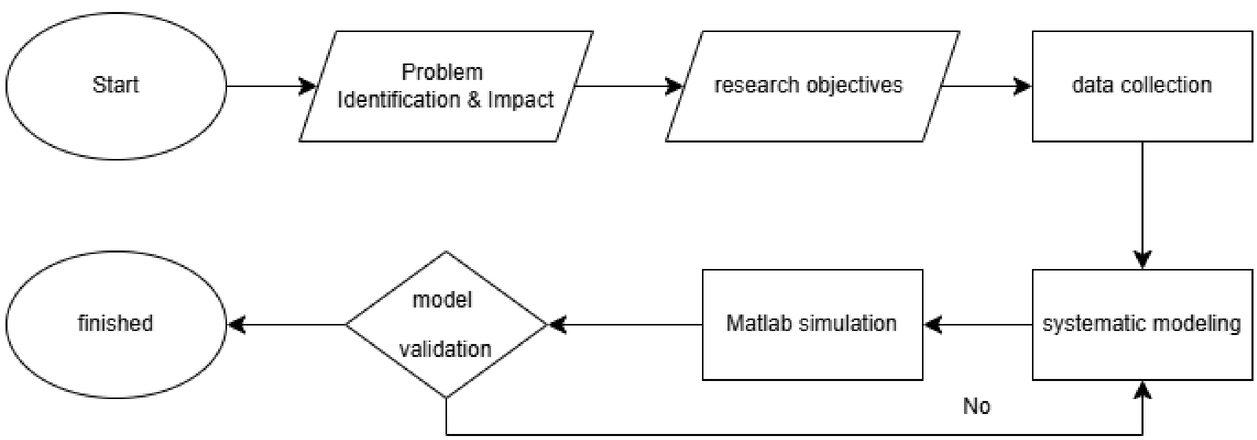
METHODS

This study uses a quantitative approach with mathematical modeling and computer simulation methods. Modeling was carried out to describe the process of volcanic ash dispersion after the eruption of Mount Lewotobi Laki-laki in 2025. This model was summarized using Matlab software to obtain an overview of the pattern and direction of volcanic ash dispersion. The simulation is expected to provide representative results as a basis for analyzing the impact and mitigation of volcanic disasters.

This simulation test will examine the validity of the ash modeling by looking at the suitability of the distribution pattern against observational data or historical data on volcanic ash distribution, as well as a means of prediction in volcanic disaster risk mitigation. This method is in line with studies on volcanic ash dispersion simulation that use the diffusion advection model and Lagrangian method in related literature. Thus, this test is crucial as part of efforts to understand and anticipate volcanic ash dispersion patterns for the safety of communities in affected areas.

The data used is secondary data obtained from:

1. PMVBG (Center for Volcanology and Geological Disaster Mitigation) Eruption column, ash volume, eruption geological parameters.
2. BMKG (Meteorology, Climatology, and Geophysics Agency) Wind Direction Data, Wind Speed, and Atmospheric Conditions at certain altitudes.



Picture 1. research flowchart

This study describes a systematic process for modeling the spread of volcanic ash from Mount Lewotobi using the Gaussian Plume approach. The research began with identifying problems arising from the 2024–2025 eruptions, particularly those related to the risk of volcanic ash spreading and impacting communities and infrastructure. After the problem was defined, the research set out to develop a mathematical model to map the ash distribution pattern. The next step was to collect secondary data obtained from PVMBG (eruption column data, ash volume, geological parameters) and BMKG (wind direction and speed data). This data became the main input for the modeling process.

In the mathematical modeling stage, several equations are used, namely the advection equation, the mass conservation law (Reynolds), particle precipitation velocity, and the Gaussian Plume model. All of these parameters are then simulated using MATLAB software to produce a visualization of the ash distribution pattern. The simulation results are then validated by comparing them with observational data or historical eruption data. If the model is not yet accurate, it is refined until it is valid. After that, the results are analyzed to determine the direction of ash dispersion, the plume pattern formed, and its impact on the surrounding area.

The analysis was conducted through mathematical modeling and MATLAB simulation.

1. Mathematical Modeling
   Based on:
   1.1 Advection Equation
   Modeling ash dispersion using the advection equation for mass transfer:

$$J = Q.C.U.A$$

   with :
   - J = mass transfer rate,
     Q = mass flow rate,
   - C = cross-sectional area,
   - U = Volcanic ash concentration.

   This equation was developed using the law of mass conservation in control volume and Reynolds' transport theory. This equation was developed using the law of mass conservation in control volume and Reynolds' transport theory.

   1.2 Mass Conservation Equation (Continuum)

   According to Reynolds' theory, we obtain:

$$\frac{\partial C}{\partial t} + \frac{\partial(\mu C)}{\partial x} + \frac{\partial(uC)}{\partial y} + \frac{\partial(wC)}{\partial z} = 0$$

   Where u, v, w are the wind speed components on the x, y, z axes.

2. Model Gaussian (*Gaussian Plume Model*)

   The Gaussian model is used to describe the distribution of volcanic ash concentration. In general, the equation is:

$$C(x, y, z) = \frac{Q}{2\pi U \sigma_x \sigma_y \sigma_z} \exp\left(-\left(\frac{x^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{(z - H^2)}{2\sigma_z^2}\right)\right)$$

   with:

   - Q = source emission rate,
   - U = wind speed in the x direction,
   - $\sigma_x, \sigma_y, \sigma_z$ = standard deviation of ash dispersion in the x, y, z directions,
   - H = eruption column height.

   This equation shows that ash concentration is normally distributed (Gaussian) following the wind direction and spreading in the form of a plume.

3. Particle Precipitation Velocity

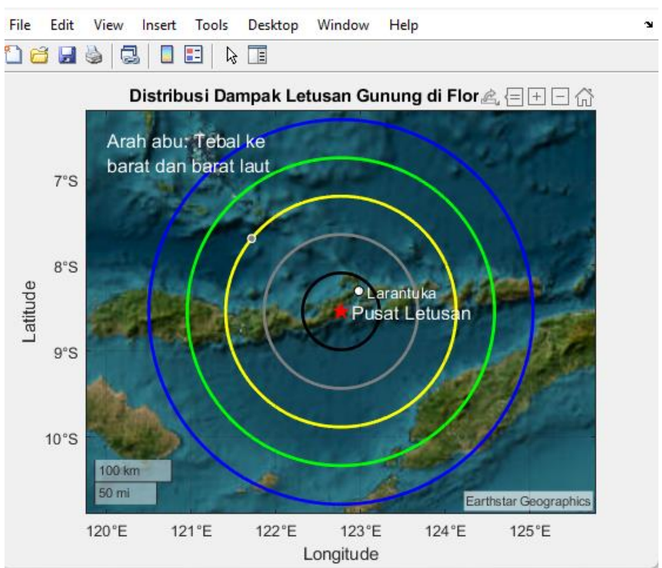
The downward movement of ash is influenced by the precipitation velocity of particles, which is determined by:

$$v_p = \frac{g d_p^2 (p_p - p)}{18\mu}$$

with:

- v_p = precipitation rate (m/s),
- g = gravitational acceleration (m/s^2),
- d_p = particle diameter m,
- p_p = particle density (gr/cm^3),
- μ = air viscosity.

Results and Discussion



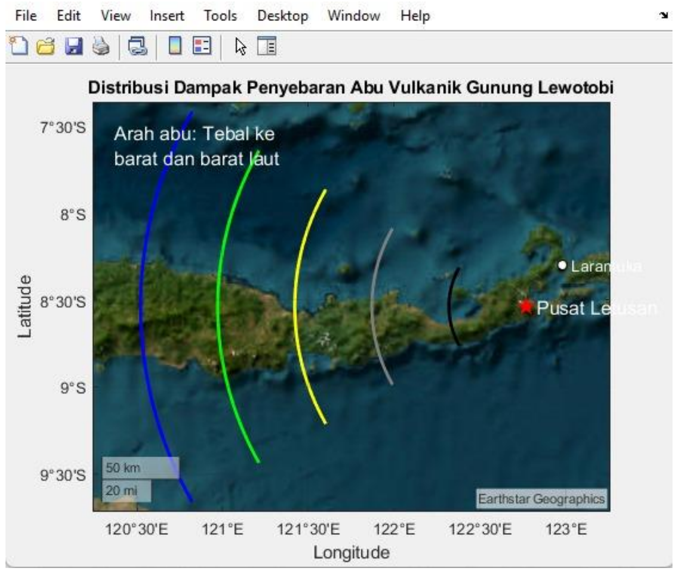
Picture 2. Distribution of the Impact of Volcanic Ash Spread from Mount Lewotobi

The first image shows the distribution of ash in the form of concentric circles from the center of the Lewotobi eruption. Each circle represents an ash impact zone with a specific radius, for example 50 km, 100 km, 150 km, 200 km, and 250 km. The spread is assumed to be uniform in all directions from the center of the eruption. This is a simple approach to see the potential affected area without considering the prevailing wind direction.

A simple approach to see the potential affected area without considering the prevailing wind direction. Explanation:

- Thick ash fallout only occurred in the western and northwestern sectors towards the sea and western land, according to satellite image analysis and BMKG observations during the actual event.

- The city of Larantuka is outside the thick ash fallout sector, so the risk is much lower than if a concentric assumption were used.
- This model is highly suitable for disaster response and mitigation, as it accounts for wind patterns and facilitates the mapping of evacuation zones as well as airport and shipping coordination.



Picture 3. Distribution of the Impact of Volcanic Ash Spread from Mount Lewotobi to the West and Northwest

Figure 3 illustrates the distribution of volcanic ash from the eruption of Mount Lewotobi, emphasizing the thick ash spread towards the west and northwest. The visualization uses color sectors on the map to show the ash distribution zone based on the radius from the center of the eruption, rather than full circle symmetry. The blue, green, yellow, gray, and black ash zones represent graduated distances (50 km to 250 km) from the center of the eruption, where the density of ash decreases with distance and the role of wind direction.

CONCLUSION

The eruption of Mount Lewotobi had a significant impact, both physically and socio-economically, on East Flores and the surrounding area. Research shows that the major eruption at the end of 2024 and the series of eruptions in 2025 produced a volcanic ash column reaching a height of 8–9 kilometers, forcing thousands of residents to evacuate and causing damage to settlements, public facilities, and transportation. The mathematical models used in this study, including advection equations, mass conservation, and Gaussian Plume, clarify the distribution pattern of ash according to wind conditions and geophysical parameters, where the spread of thick ash is greatly influenced by the direction and speed of the wind during the eruption. Computer simulation results show that the most extensive ash-affected zone is in the west and northwest sectors of the eruption center, not in a concentric circle but following a plume pattern. The effectiveness of disaster mitigation, including the construction of a lava control system and adjustments to modes of transportation, is key to minimizing further losses. Thus, disaster management based on mathematical modeling and simulation can be a strategic foundation for the implementation of mitigation, evacuation, and socio-economic recovery of communities affected by the eruption of Mount Lewotobi in the future.

References

Dikson, M., & Angelia Tugu, M. T. (2025). *Sosialisai Penggunaan asker Dampak Erupsi Gunung Lewotobi Laki-Laki Di Desa Lewomada Kecamatan Talibura Kabupaten Sikka*. *5*, 77–81. https://doi.org/10.36082/gemakes.v5i1.1871

Irfan, Wawomeo, A., Cahyani, S. L., Gonsalves, D., Tokan, P. K., Blasius, G., Wuan, A. O., Budiana, I., Kesehatan, P., & Kupang, K. (2024). *Tanggap Darurat Bencana Erupsi Gunung Lewotobi Laki-Laki di Kabupaten Flores Timur*. 83–90. https://doi.org/https://doi.org/10.58222/pakdemas.v4i1.303

Mahardhika, V., Hidayat, F. O., & Arifudin, M. (2025). *Analisis Sebaran Gas SO 2 Menggunakan Citra Satelit Himawari-9 Studi Kasus : Gunung Lewotobi Laki Laki 3 - 4 November 2024*. *6*(November 2024), 4–7. https://doi.org/https://doi.org/10.29303/Goescienceed.v6i2.766

Nartini, N. K. (2024). *Sejarah Letusan Gunung Lewotobi Laki-laki dari Masa ke Masa Baca artikel detikbali, "Sejarah Letusan Gunung Lewotobi Laki-laki dari Masa ke Masa."* Detikbali. https://www.detik.com/bali/nusra/d-7625316/sejarah-letusan-gunung-lewotobi-laki-laki-dari-masa-ke-masa

Sekertariat Badan Geologi, H. (n.d.). *Kenaikkan Status Gunung Lewotobi Laki-laki Menjadi "AWAS" Akibat Peningkatan Aktivitas Vulkanik*. Retrieved September 30, 2025, from https://geologi.esdm.go.id/media-center/kenaikkan-status-gunung-lewotobi-laki-laki-menjadi-awas-akibat-peningkatan-aktivitas-vulkanik

Sekertariat Badan Geologi, H. (2024). *Kenaikan Status Gunung Lewotobi Laki-Laki Menjadi "AWAS" Akibat Peningkatan Aktivitas Vulkanik*. https://geologi.esdm.go.id/media-center/kenaikkan-status-gunung-lewotobi-laki-laki-menjadi-awas-akibat-peningkatan-aktivitas-vulkanik

Yanuarto, T. (2024). *10 Meninggal Dunia Akibat Erupsi Gunung Lewotobi Laki-laki*. BNPB. https://bnpb.go.id/berita/update-10-meninggal-dunia-akibat-erupsi-gunung-lewotobi-laki-laki