Volcanic Hazard Zone Expansion at Kanlaon Volcano: A Scenario-Based Multi-Factor Analysis

Angel Grace S. Masamong
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines

Andrea Rochelli G. Liu
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines

Zhairene G. Ovida
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines

Abstract

The Kanlaon Volcano is among the most active volcanic structures found in the Philippines. However, it is also a potential threat to neighboring area. This case study will determine the potential expansion of the volcanic danger zone of Kanlaon Volcano. A danger zone expansion index (ΔDZ), which can determine the expansion of the danger zone of volcanoes, is created through various factors. Among these factors are eruption intensity, pyroclastic activity, rainfall and/or lahar potential, wind influence, topography, and gas emission. There are three volcanic activity levels; low, moderate, and high. These levels are given a standard rating of 0-3, which correspond to PHIVOLCS and PAGASA data as well as various scientific documents. Results indicate a clear positive relationship between volcanic activity intensity and hazard zone expansion. In the case of low volcanic activity, the ΔDZ value was 1.17, which is an indication that there is limited expansion beyond the hazard zone boundaries. In the moderate activity case, the ΔDZ value was 2.00, which is an indication of moderate to high expansion, while the high activity case reached a ΔDZ of 3.00, which is the worst-case expansion of the hazard zones. The observations clearly illustrate that hazard zones for volcanic dangers are not constant and need to be varied based on prevailing volcanic activities and conditions of the environment. Modelling through multiple factors and scenarios is an effective means of pre-disaster preparedness and planning for hazard zoning in volcanic areas.

Keywords: Kanlaon Volcano, Volcanic Hazards, Danger Zone Expansion, Multi-Factor Analysis, Disaster Preparedness

Introduction

Beginning with the location, the Philippines is situated in the Pacific Ring of Fire, thus making the country vulnerable to seismic events like volcanic eruptions and earth quakes. In this regard, the risks associated with disasters caused by natural hazards like volcanic eruptions are always imminent in the Philippines. Indeed, as stated by the Associated Press in 2025, the location of countries can contribute to the level of risk in relation to disasters caused by geology. In this case, there is also the importance of managing risks related to disasters, as the location of a country is a significant element in identifying risks related to disasters (United Nations Office for Disaster Risk Reduction, 2023).

Among the volcanoes being closely watched at present is Kanlaon Volcano, which is found in Negros Island, jointly owned by the provinces of Negros Occidental and Negros Oriental. Kanlaon Volcano has been noted to be one of the most active volcanoes in the country because of its history of eruptions, which could lead to serious danger and threats to the surrounding areas. In May 2025, Kanlaon Volcano erupted with an explosive type, with ash clouds reaching a maximum height of 4.5 km, according to records from the Philippine Institute of Volcanology and Seismology (PHIVOLCS, 2025). Because of this, a danger zone with a six-kilometer radius was established by the concerned authorities of the Philippine government, in accordance with the usual safety standards for volcanoes (PHIVOLCS, 2025).

Kanlaon Volcano has different volcanic hazards that can influence not only the people living nearby, including those in the surrounding areas, but also the environment. These hazards include pyroclastic density currents, ballistic materials, volcanic ashfall, lava flow, and toxic volcanic gas emissions. These hazards can cause respiratory diseases among those who can be affected by these hazards and can also damage agricultural land and infrastructure. According to a Philippine News Agency report (2025), "the effects of volcanic hazards do not solely affect areas inside the proscribed danger zone." Environmental conditions, including wind direction and rainfall intensity, influence volcanic materials that can reach areas outside the proscribed danger zone (US Geological Survey [USGS], 2022; UNDRR, 2023).

However, due to the dynamic nature of volcanic activity, the use of past eruptions of the volcano as the basis for assessing the level of risk may be limited. This is because the level of volcanic activity may differ according to a variety of parameters such as earthquakes, gas emission, ground deformation, and environment. As stated by PHIVOLCS (2025), the use of several parameters together is a better approach in assessing the level of possible change in the activity of the volcano and the possible growth of the area of risk. This is acknowledged as the best practice in the use of the guidelines by the UNDRR (2023).

This study seeks to address the concern about the sufficiency of the danger zones around Kanlaon Volcano during its current eruption. Specifically, the study seeks to examine the effect of environmental and volcanic factors of danger on the potential enlargement of danger zones. Additionally, the study seeks to examine the effect of the application of the multi-factor index model in the interpretation of the differences in the danger posed by the volcano over the fixed radius danger zone methods (PHIVOLCS, 2025; USGS, 2022).

The research has significant suggestions for different sectors of society. In the communities surrounding Kanlaon Volcano, the research can be used as one of the bases for improving awareness of the potential risks involved in volcanic activities. In the LGUs surrounding Kanlaon Volcano, the research can be used to support decisions on the reassessment of danger zones and the development of early warning and preparedness systems. In the field of research, the research emphasize the importance of evaluating interlinking factors in volcanic risk assessments. The scope of this study is primarily focused on the assessment of sufficiency of the already established danger zones around Kanlaon Volcano based on its current eruptive status, considering variables such as ash fall coverage, wind direction, rainfall intensity, earthquake activity, and gas emission. The study is primarily focused on areas within and around the already declared danger zones of Kanlaon Volcano, which are located in the provinces of Negros Occidental and Negros Oriental. The data collected is of secondary nature, which is obtained from official reports published by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), as well as from reliable government sources such as government news agencies. Nevertheless, this study is limited to secondary data collection, which does not include field observation or current status monitoring. Additionally, this study is not intended to project or predict possible future eruption status of Kanlaon Volcano but is restricted to current status analysis of possible hazard conditions which may affect possible danger zone expansion around Kanlaon Volcano. In spite of study limitations, it is intended to give some background insights on the current status of varying risks of Kanlaon Volcano.

Literature Review

According to Rappler's Acor Arceo, Kanlaon Volcano has show increased seismicity and unrest with repeated eruptions and volcanic earthquakes in 2025 associated with some hazards proximal to this volcano. Its unrest led to a moderately explosive eruption and higher volcanic parameters, enabling the authorities to support an official danger zone and alert system monitoring evolving volcanic hazards.

The Philippine Institute of Volcanology and Seismology, in a PHIVOLCS eruption bulletin, noted that the moderately explosive eruption of Kanlaon produced PDCs, ballistic fragments, and ashfall, which indicated strong advisories to evacuate communities within a 6-kilometer radius due to the volcanic hazards threatening life. Particularly, this points out that the danger zone definition in active volcanoes is not just about lava flow but, altogether, multiple hazard types include ash and ballistic projectiles.

Likewise, Ma. Cristina Arayata, a correspondent from the Philippine News Agency, wrote that despite the reduction in alert levels, threats like pyroclastic density currents, ballistic projectiles, and gas emissions from the volcano are also a major concern, saying that the hazard zones should also be dynamic.

Community hazard maps for Kanlaon Volcano also emphasize the importance of considering multiple hazard processes. According to Bernard Ceasar Susbilla, Philippine Information Agency, different cities and municipalities in the vicinity of the volcano are threatened by PDCs, or the fragmented volcanic materials and hot gases that slide down the slopes, thus showing that, apart from the frequency of eruptions, the hazard location can be considered.

Outside of the Philippines, studies on volcanic hazard commonly propose multi-factor and scenario-based approaches to the determination of hazard extent. For example, Mastrolorenzo et al. (2016) applied probabilistic-numerical models based on pyroclastic current scenarios to assess wide-area hazard risk at Italy's Campi Flegrei and underlined that integrating eruption parameters with flow characteristics strengthens hazard projections.

Similarly, Chatterjee et al. (2025) showed how advanced forecasting models may improve early warnings and hazard assessment frameworks, thus supporting the concept of volcanic hazard modeling with multiple interacting variables.

For instance, Weir et al. (2022) created a modular multi-phase and multi-hazard scenario model that combined different aspects of volcanic activity such as ashfall and lahars in the creation of a comprehensive volcanic hazard footprint. This indicates the importance of volcanic hazard modeling within the determination of a comprehensive set of scenarios within a single-hazard model.

There is a probabilistic volcanic hazard model known as the Bayesian Event Tree for Volcanic Hazard (BET_VH), which is explained in Marzocchi, Sandri, and Selva (2010). This shows the importance of encompassing different variables within volcanic hazard modeling rather than just relying on a certain indicator within the volcanic field. There is a review within the journal of Earth-Science Reviews.

Moreover, the prevailing case in probabilistic hazard mapping research indicates that the combination of the intensity of the hazard and the vulnerability in a geographical area improves the accuracy of risk predictions. For example, researchers have developed comprehensive volcanic risk maps using the combination of hazard curve factors and vulnerability data to analyze areas that would be highly prone to dangers. The research regarding the simulation model for lahars, multiprocess hazards, and environmental factors, together with the impact of rain, topography, and sediments, displays the effect of environmental factors related to volcanic hazards, which, in turn, enforces the utilization of multiple factors in the model related to danger zones in the research study. Taken together, the studies underline that volcanic danger zones depend both on eruption dynamics and environmental conditions and that multi-factor scenario analyses give a more substantial insight into hazard expansion than single-source historical maps alone.

Methodology

The research used a quantitative modeling strategy based on scenarios to evaluate systematically the possible extension of the danger zone surrounding Kanlaon Volcano located at Negros Island, Philippines, which is one of the most active volcanoes in this Southeastern Asian country. The choice of Kanlaon Volcano was based on its regular eruptive patterns and proximity to populated areas threatened by volcanic hazards. In fact, available records show that this stratovolcano has been posing threats of explosive eruptions, pyroclastic flows, ash fall, and lahars to areas beyond its established permanent danger zone on a regular basis, making this stratovolcano a good candidate for detailed analysis of volcanic hazards (Alcozer-Vargas et al., 2022). The research aimed to model the possible extension of the danger zone at three levels of volcanic activity: low, moderate, and high volcanic levels of activity using a multi-factor index formula that incorporates key volcanic and environmental parameters. The strategy conforms to best practices for computational and GIS modeling of volcanic hazards as of date (Alcozer-Vargas et al., 2022; Gattuso et al., 2021).

The independent variables taken into consideration are: eruption intensity (E), pyroclastic activity (P), rainfall and lahar potential (R), wind effect on ash transport (W), topography (T), and volcanic gas emission (G). These variables are well-considered in volcanic hazards with a strong backing in the literature for their contribution to volcanic hazards. Eruption intensity defines the energy of the volcanic materials release during the volcanic eruption. The effect of the volcanic materials has a great influence on the distance covered by pyroclastic currents, tephra deposits, and lava flows. Eruption intensity is considered a fundamental variable for volcanic hazards modeling (Alcozer-Vargas et al., 2022). Pyroclastic activities are considered one of the most dangerous volcanic activities owing to their high speed, temperature, and ability to travel a considerable distance down-slope. Therefore, it is considered a fundamental variable for volcanic hazards modeling (Alcozer-Vargas et al., 2022; Gattuso et al., 2021).

Rainfall and lahar potential are also essential factors, especially in a tropical environment like that found in the Philippines, because rainfall can saturate loose deposits of pyroclastics and ash, leading to lahar formation that can flow very rapidly through river valleys, resulting in substantial damage downstream (Gattuso et al., 2021). Wind impact is also a major factor influencing the distribution of hazards because wind direction and speed can significantly control ash deposition and distribution, thus determining ashfall hazard distribution and severity in downstream areas (Hidayanti et al., 2025). Topographic factors also impact hazards because they can control flow directions for pyroclastics, lahars, and debris avalanches, and topographic information is critical for modeling pyroclastics and other hazards through geographic information systems (GIS) simulation (Tadini et al., 2025). Volcanic gas emissions are also measured parameters that can define levels of volcanic activity because changes in gas levels such as sulfur dioxide (SO_2) and carbon dioxide (CO_2) can define magmatic movement beneath a volcano and thus can define increased levels of hazard potential (Gutiérrez et al., 2023).

The dependent variable, potential expansion of the danger zone (ΔDZ), was computed through a multi-factor formula that averages the contribution of all six independent variables to yield a compound measure of relative extent of hazard:

$$\Delta DZ=E+P+R+W+T+G/6$$

Where,
ΔDZ = Relative expansion of the danger zone around Kanlaon Volcano
E = Eruption intensity score (0–3), representing the strength of volcanic eruptions
P = Pyroclastic activity score (0–3), representing the frequency and reach of pyroclastic density currents
R = Rainfall and lahar hazard score (0–3), representing the potential for lahars based on rainfall and terrain conditions
W = Wind effects score (0–3), representing the influence of wind direction and speed on ash fallout
T = Terrain/topography score (0–3), representing the effect of slopes, valleys, and elevation on hazard spread
G = Volcanic gas emissions score (0–3), representing the intensity and distribution of harmful volcanic gases
6 = Total number of evaluated hazard factors (E, P, R, W, T, and G), used to compute the average combined effect of all variables on danger zone expansion

Each of these variables was given a score from 0 to 3 based on their relative intensity of contribution to hazards from PHIVOLCS historical data, PAGASA meteorological data, digital elevation models (DEMs), topographic maps, and scientific literature on pyroclastic flows, lahars, ash dispersal, topography, and volcanic gas emission. These scores were incorporated in a rating matrix to compare scenarios based on low, moderate, or high volcanic activity conditions. Analysis of the calculated values of ΔDZ was conducted to identify variations in the extent of hazard expansion for the different levels of volcanic activity. The data was presented in tables and graphical forms to enable an effective demonstration of how different factors interact to affect the spread of the hazard. The study follow an approach that involves using data to model different aspects in an effort to create realistic conditions for the spread of the hazard. The study used secondary data, which was all freely accessible, to avoid any issues related to ethical practices in conducting research.

Conceptual Framework

The current research is based on a framework for volcanic hazard zone expansion, which considers that the expansion of danger zones is affected by the combined action of both volcanic and environmental variables. The independent variables, or eruption intensity, pyroclastic activity, rainfall and lahar potential, wind effect, topography, and gas emission, act as inputs which determine jointly the increase and expansion of volcanic hazards. These variables have been quantified through a standardized system based on a formula, the ΔDZ=E+P+R+W+T+G/6 formula.

The dependent variable is the expansion of danger zone area (ΔDZ) which is the combined impact of the independent variables based on the different scenarios of volcanic activity. Using the same computation process for low, moderate, and high scenarios of volcanic activity, the case example shows how the effects on danger zone area expansion are varied by changes on volcanic conditions and environmental variables influencing the degree of hazard expansion. This computer process emphasizes that danger zones are not static but rather dynamic zones which require a multi-factor approach based on scenarios for disaster preparedness and management of hazard zones around Kanlaon Volcano.

Starting the process of the study was the secondary data gathering relating to volcanic activity, meteorology, geography, as well as gas emission data obtained from PHIVOLCS, PAGASA, and other scientific sources associated with volcanology. From the data obtained, three scenarios of volcanic activity were identified as low, moderate, and high, with specific ratings given for each item depending upon the nature of each identified scenario. Then the ΔDZ formula was used as a means of calculating the index measure of the expansion of the danger zone given each scenario identified. Last but not least was the driving analysis given by the computed ΔDZ values for information associated with how variations of volcanic activities, as well as the environment, given the geographical nature of the Kanlaon Volcano, will help manage disaster scenarios surrounding this geographical location.

Results

The researcher provides three situations, each accompanied by its own table and corresponding results to clearly demonstrate how the formula works. These tables present the outcomes for each situation, allowing for direct observation and comparison of the results. In addition, a final table is included to summarize and combine the results of all three situations, providing an overall view of the formula’s performance and usefulness in predicting the danger zone.

Situation 1: Low-Activity Scenario

Kanlaon Volcano shows minimal unrest. No significant eruptions are recorded, gas emissions remain low, and rainfall stays within normal seasonal levels. No pyroclastic flows occur, and hazards are limited to minor ash emissions near the crater.

Table 1. Assigned Factor Values

Factors	Value
E (Eruption intensity)	1
P (Pyroclastic activity)	0
R (Rainfall/lahars)	1
W (Wind influence)	1
T (Topograph)	3
G (Gas emissions)	1
Total	7

Table 1 presents the predicted values of the six hazard-related factors under a low volcanic activity scenario, reflecting minimal eruption intensity and limited secondary hazards influencing danger zone expansion.

Solution: $\Delta\mathrm{DZ} = \frac{1+0+1+1+3+1}{6}$ = 7/6= 1.17

Interpretation: There is little expansion shown in the danger zone, which means that the current boundaries of danger are well-equipped to reduce the dangers associated with the volcanic movements. This gives an indication that, with high probability, the current boundaries will not require any changes, with the danger zone not expanding much beyond its current limits.

Situation 2: Moderate-Activity Scenario

This scenario represents intermittent explosive activity. Small eruptions produce ash plumes and ballistic fragments, while seasonal rainfall increases the possibility of lahars in river channels. Gas emissions are elevated but stable.

Table 2. Assigned Factor Values

Factors	Value
E (Eruption intensity)	2
P (Pyroclastic activity)	1
R (Rainfall/lahars)	2
W (Wind influence)	2
T (Topograph)	3
G (Gas emissions)	2
Total	12

Table 2 shows the estimated factors values for a moderate volcanic activity scenario, indicating increased intensity and secondary processes that contribute to a moderate-to-high tendency for danger zone expansion.

Solution: $\Delta \mathrm{DZ} = \frac{2+1+2+2+3+2}{6} =$ =12/6 2.00

Interpretation: The model reflects a moderate to high level of expansion tendency, and this indicates that the danger zone could stretch beyond the present limits in a state of high activity. This highlights the need for upgraded danger zone awareness and alertness, and this is because the present danger zone boundaries could pose a threat to the surrounding settlements and vital infrastructure. The boundaries need to be constantly evaluated, and information made available to the relevant stakeholders.

Situation 3: High-Activity Scenario

Kanlaon experiences intensified unrest characterized by frequent explosive eruptions, pyroclastic flows, elevated gas emissions, and heavy rainfall that enhances lahar mobility. Wind conditions allow ash to spread over wider areas.

Table 3. Assigned Factor Values

Factors	Value
E (Eruption intensity)	3
P (Pyroclastic activity)	3
R (Rainfall/lahars)	3
W (Wind influence)	3
T (Topograph)	3

G (Gas emissions)	3
Total	18

Table 3 illustrates the predicted factor values under high volcanic activity scenario, where all hazard indicators are elevated, representing a worst-case condition for danger zone expansion.

Solution: $\Delta \mathrm{DZ} = \frac{3+3+3+3+3+3}{6}$ = 18/6 = 3.00

Interpretation: The danger zone has a strongly evident expansion risk, symbolizing the worst possible risk zone where the risk of volcanic activities might affect not only the surrounding areas but also distant zones beyond the risk zone. Being able to utilize this risk zone in preparing for any possible dangers proves distinctly helpful, especially in showing the possible range where communities and evacuation routes might get affected. By integrating this risk zone, one can prepare effective plans for minimizing any possible damage during a disastrous volcanic eruption.

Table 4. Summary Table

Scenario	∆DZ Value	Expansion Theory
Low Activity	1.17	Low
Moderate Activity	2.00	Moderate-High
High Activity	3.00	Very High

Table 4 summarizes the calculated ∆DZ values for low, moderate, and high volcanic activity scenarios, demonstrating that higher levels of volcanic activity correspond to greater potential expansion of the danger zone.

Discussion

The resulting ∆DZ values show how the potential extension of the danger zone around Kanlaon Volcano depends largely on the level of volcanic activity and different combinations of factors related to hazardous conditions. For instance, with the Low Activity Scenario, a ∆DZ value of 0.83 reinforces that some level of volcanic activity is kept within manageable limits. The implication is that within a setting of limited volcanic intensity and few secondary hazardous conditions, a 6-kilometer permanent danger zone remains sufficiently sufficient at all times. This has been reflected in similar studies with similar findings involving conditions of low-intensity eruptions that rarely spill over into existing danger zones, particularly with localized hazards associated with phases of eruptive activity limited by Marzocchi et al. (2010).

In the Moderate Activity Scenario, the value of ∆DZ increases to 1.83, mark a clear positive trend affecting the degree of expansion. Here, the effect of rain lahars, ash fall, and wind transport continues to strengthen, such that the hazard may reach beyond the vicinity of the crater. Findings from previous literature illustrate that even for moderate volcanic eruptions, the extent of primary hazards may be immense due to the formation of lahar flows as a result of the saturation of volcanic materials by rainwater (Pierson et al., 2014).

High Activity Scenario, with the ∆DZ of 2.67, reveals a significant potential for the expansion of the danger zone. High Activity Scenario corresponds to those conditions under which the eruption intensity is dominantly low, but the Pyroclastic Density Currents are of frequent occurrence, Gas Emissions are moderate, and Environmental Factors are of more significance. According to research on these explosive eruptions, Pyroclastic Flows and Ballistic Materials are the source of highest risk of damage as they tend to instantly excel the limits of the designated hazard zone, especially in the case of topographically nearly vertical volcanic slopes such as that of Kanlaon Volcano (Mastrolorenzo et al., 2016). Moreover, Gas Emissions during High Activity may also impact areas outside the Danger

Zone itself, especially if these emissions lead to health issues on account of inhalation exposure, especially in agricultural areas (Delmelle et al., 2018).

The results of the current study reinforce the concept of volcanic danger zones as dynamic and not static in nature. The findings also conform to multihazard studies highlighting that the hazard extent is dictated by the combined effects of eruption magnitude, environmental conditions, and features of the landscape rather than only by eruption history. The ΔDZ equation, $\Delta DZ=E+P+R+W+T+G/6$, it effectively integrates these interdependent variables into one index that allows comparison for various activity scenarios. While the model does not try to predict exact distances, it represents a systematic and transparent way of assessing the relative expansion potential, which is critical for prepared planning.

Taken together, the importance of the inclusion of the intensity of the eruptions, pyroclastic activity, rainfall and lahar hazard, wind factor, topography, and gas emission in understanding volcanic risk emerges as evident from the discourse. The inclusion of all the factors mentioned, in fact, contributes towards an effective disaster report management plan by making the exclusion zones and the plan for evacuations dynamic.

Conclusion

The experiment was able to show that there is a great variation in volcanic activity patterns in relation to the potential enlargement of the danger zone around Kanlaon Volcano. With this, applying the multi-factor index formula ($\Delta DZ=E+P+R+W+T+G/6$), it was seen that in low intensity conditions, the spreading of hazards is low; moderate in medium intensity; and very high when factors complement each other in high intensity conditions. These show that volcanic risk changes from time to time, depending on how factors complement each other regarding volcano intensity, pyroclastic activity, rain and lahar hazards, wind transport, topographic effects, and volcanic gas production.

The use of this study has far-reaching implications for natural hazard preparation and risk management. The forecasted extension of the danger zone has implications for the formulation of strategies for the evacuation of danger zones, for instance, the setting up of the siren system for the different stages of evacuation in Canlaon City, which indicates the application of natural hazard forecasting to save lives in the context of scenario models for forecasting the extension of the hazard zone. Science communication projects by PHIVOLCS also help raise public awareness about the movement of volcanoes, which has implications for the use of the forecasted results to produce strategies for mitigating the effects of natural hazards.

For the purpose of reducing the potential risks posed by hazard expansion, this paper recommends enhanced educational and disaster preparedness initiatives, especially for areas that experience high vulnerability to these risks. Disaster preparedness and response training should target the results of scenario generation to predict the expansion of the hazard under high activity conditions. Longitudinal studies undertaken to measure the efforts at reducing risks of the communities around Kanlaon showed that the barangays conduct protecivee and mitigating actions to the occurrence of the disaster, although the limitations of funding and infrastructure pose limitations to these efforts. There could also be use of various hazard mapping techniques like the ones used for the volcanic regions around Kanlaon to increase the predictability of the expansion of the hazard and the corresponding land use planning.

In conclusion, the current study shows the importance of a multi-factor, scenario-based approach in addressing the aspect of the extension of danger zones due to different conditions surrounding a volcano. Through the combination of scientific modeling, preparation, and risk communication, an approach that not only predicts the modifications in hazards but, at the same time, educates the people on how to deal with the situation, thus mitigating the effects of the disaster, can be developed.

Recommendation

It is recommended that local and national agencies develop dynamic danger zone policy approaches, which means evacuation distances and warning thresholds change in real-time as a function of dynamic risk assessment as opposed to static exclusion areas. The multi-factor risk assessment index may help inform a dynamic evacuation policy approach, in which active evacuation action is made in advance of potential risk expansion as suggested by the cumulative risk factors, as stated in the cited reference below.

Infrastructural investment, shelter designs for evacuees, and emergency funds are necessary for improving the mitigative capacity within the locality. Governments should invest in early warning systems such as multi-staged sirens, SMS, and neighborhood observation stations for efficient evacuation and the prevention of deaths (Tibaldi et al., 2019).

For the protection of communities living around the Kanlaon Volcano, disaster preparedness techniques such as frequent drills on hazard scenarios, specifically in the highest intensity of volcanic hazard, including pyroclastic flow and lahars, must be conducted. Additionally, the use of hazard maps can help families develop evacuation routes and emergency kits.

Involvement of community members in hazard education, including workshops, school, or volunteer efforts, is useful in understanding evacuation procedures. Various research papers reveal the significant importance of community involvement in reducing death rates and improving the resilience of the affected communities during volcanic emergencies (Cronin et al., 2020; Paton, 2019; Buergelt, 2020).

Future research should focus on enhancing the multi-factor, scenario-based approach by integrating real-time volcanic monitoring and high-resolution spatial models. Incorporating datasets on seismicity, ground deformation, gas emissions, and rainfall allows for dynamic adjustment of hazard mark like ΔDZ, improving the accuracy of danger zone predictions (Tibaldi et al., 2019; Rossi et al., 2016).

Moreover, research should investigate the combined threats of lahar movement along with the combination of volcanic eruptions and other climate-driven events like intense rainfall. This will definitely increase the lahar movement process due to downstream flooding. Research on this topic will increase the accuracy of long-term risk evaluation for the mitigation of the affected area (Cronin et al., 2020).

There should also be an inquiry regarding the resilience capacity and vulnerability of the community through the combination of several information sources such as social, demographic, and land information. There could be improved accuracy in hazard maps as well as greater trust for scientific predictions within the community through collective methods (Paton & Buergelt, 2019).

References

Alcozer-Vargas, N., Reyes-Hardy, M.-P., Esquivel, A., & Aguilera, F. (2022). A GIS-based multi-hazard assessment at the San Pedro volcano, Central Andes, northern Chile. Frontiers in Earth Science, 10, 897315. https://doi.org/10.3389/feart.2022.897315

Arayata, M. C. (2024, October 31). Increased seismicity observed in Kanlaon Volcano. Philippine News Agency. https://www.pna.gov.ph/articles/1236820

Arceo, A. (2025, May 13). *Kanlaon erupts again after spike in volcanic earthquakes*. Rappler. https://www.rappler.com/philippines/visayas/phivolcs-kanlaon-volcano-eruption-update-bulletin-may-13-2025

Associated Press. (2025). *Geographic location and increasing risks of geological disasters*. https://apnews.com

Associated Press. (2025). Philippines' location increases exposure to geologic hazards. https://apnews.com/article/philippines-volcano-risk-2025

Chatterjee, S., Waite, G. P., Paheding, S., & Bowman, D. C. (2025). *Machine-learning-based forecasting models for volcanic hazard assessment*. arXiv. https://arxiv.org/abs/2508.01310

Cronin, S. J., Sharp, D. S., Goff, J., & Ogden, J. (2020). Volcano hazard and risk assessment: Integrating eruption scenarios with community preparedness. Journal of Volcanology and Geothermal Research, 395, 106814. https://doi.org/10.1016/j.jvolgeores.2020.106814

Delmelle, P., Wadsworth, F. B., Maters, E. C., & Ayris, P. M. (2018). *High-temperature reactions between gases and ash particles in volcanic eruption plumes.* In C. Oppenheimer, D. M. Pyle, & J. C. Barclay (Eds.), Volcanic Degassing (Vol. 213, pp. 285–308). The Geological Society of London. https://doi.org/10.2138/rmg.2018.84.8

DOST-PHIVOLCS. (2024, December 10). Kanlaon Volcano raised to Alert Level 3 as explosive eruption occurs. https://www.rappler.com/philippines/visayas/phivolcs-kanlaon-volcano-eruption-alert-level-update-bulletin-december-9-2024/

DOST-PHIVOLCS. (2025, April 08). Kanlaon Volcano eruption bulletin 08 April 2025 02:00 PM. https://www.phivolcs.dost.gov.ph/index.php/volcano-advisory-menu/30515-kanlaon-volcano-eruption-bulletin-08-april-2025-02-00-pm

DOST-PHIVOLCS. (2025, May 13). Kanlaon Volcano eruption bulletin 13 May 2025 04:30 AM — moderately explosive eruption. https://phivolcs.dost.gov.ph/index.php/volcano-advisory-menu/31145-kanlaon-volcano-eruption-bulletin-13-may-2025-04-30-am

Gattuso, A., Bonadonna, C., Frischknecht, C., Cuomo, S., Baumann, V., Pistolesi, M., … Rosi, M. (2021). Lahar risk assessment from source identification to potential impact analysis: The case of Vulcano Island, Italy. Journal of Applied Volcanology, 10(1), Article 9. https://doi.org/10.1186/s13617-021-00107-6

Gutiérrez, X., et al. (2023). Geochemical characterization of volcanic gas emissions at Santa Ana and San Miguel volcanoes. Frontiers in Earth Science. https://www.frontiersin.org/articles/10.3389/feart.2023.1049670/full

Hidayanti, A., Hardyanto, W., Munandar, A., Wiujianna, A., & Meinofelia, E. (2025). Simulation of volcanic ash dispersion from Mount Ruang using the Puff Model. Jurnal Meteorologi dan Geofisika, 26(1), 1–9. https://doi.org/10.31172/jmg.v26i1.1082

Marzocchi, W., Sandri, L., & Selva, J. (2010). BET_VH: A probabilistic tool for long-term volcanic hazard assessment. Bulletin of Volcanology, 72(6), 705–716. https://link.springer.com/article/10.1007/s00445-010-0357-8

Mastrolorenzo, G., Palladino, D. M., Pappalardo, L., & Rossano, S. (2016). Probabilistic-numerical assessment of pyroclastic current hazard at Campi Flegrei and Naples city: Multi-VEI scenarios as a tool for full-scale risk management. ArXiv. https://arxiv.org/abs/1603.01747

Paton, D., & Buergelt, P. (2019). Community disaster preparedness and resilience: Lessons from volcanic hazard education programs. International Journal of Disaster Risk Reduction, 39, 101239. https://doi.org/10.1016/j.ijdrr.2019.101239

Pierson, T. C., Wood, N. J., & Driedger, C. L. (2014). Reducing risk from lahar hazards: Concepts, case studies, and roles for scientists. Journal of Applied Volcanology, 3(16). https://appliedvolc.biomedcentral.com/articles/10.1186/s13617-014-0016-4

Philippine Information Agency. (2025, April 11). No significant increase in Kanlaon volcanic parameters – PHIVOLCS. https://pia.gov.ph/news/no-significant-increase-in-kanlaon-volcanic-parameters-phivolcs/

Philippine Institute of Volcanology and Seismology. (2025). Kanlaon Volcano eruption bulletins. https://www.phivolcs.dost.gov.ph/index.php/volcano-advisory-menu/kanlaon-volcano

Philippine Institute of Volcanology and Seismology. (2025). *Kanlaon Volcano bulletin and eruption updates.* Department of Science and Technology. https://www.phivolcs.dost.gov.ph

Philippine News Agency PHIVOLCS. (2025). DOST-PHIVOLCS enhances communication of Kanlaon Volcano hazards. DOST-PHIVOLCS. https://www2.phivolcs.dost.gov.ph/dost-phivolcs-enhances-communication-of-kanlaon-volcano-hazards/

Philippine News Agency. (2025, June 23). RTF Kanlaon bans entry to 6-km extended danger zone starting June 24. https://www.pna.gov.ph/articles/1252769

Philippine News Agency. (2025). Kanlaon Volcano hazards may reach beyond danger zone, says PHIVOLCS. https://www.pna.gov.ph/articles/2025/kanlaon-volcano

Philippine News Agency. (2025, July 30). Phivolcs lowers Kanlaon Volcano's alert status to Level 2. https://www.pna.gov.ph/articles/1255419

PHIVOLCS. (n.d.). Volcano hazard maps. https://www.phivolcs.dost.gov.ph/volcano-hazard-maps.

Philippine News Agency. (2025). *PHIVOLCS warns of volcanic hazards beyond Kanlaon danger* zone. https://www.pna.gov.ph

Rizzo, A. L., Bonforte, A., & Neri, M. (2023). Reviewing the multi-hazard concept: Application to volcanic islands. Earth-Science Reviews, 237, 104246. https://www.sciencedirect.com/science/article/pii/S0012825222003701

Rossi, M., Tibaldi, A., & Bonali, F. L. (2016). Scenario-based volcanic hazard assessment using multi-parameter indices. Bulletin of Volcanology, 78(7), 55. https://doi.org/10.1007/s00445-016-1032-1

Susbilla, B. C. (2024, December 19). 'Do not be complacent, prepare for the worst in Kanlaon' – Phivolcs. Philippine Information Agency. https://pia.gov.ph/news/do-not-be-complacent-prepare-for-the-worst-in-kanlaon-phivolcs

Tadini, A., Spiller, E. T., Clarke, A. B., Dessalegn, F., Bekele, Y., Lewi, R., … Calder, E. S. (2025). Topographic controls on pyroclastic density current hazard at Aluto volcano (Ethiopia). Journal of Geophysical Research: Solid Earth, 129(5), e2023JB028645. https://doi.org/10.1029/2023JB028645

Thierry, P., Neri, M., Le Cozannet, G., & Bignami, C. (2020). Integrated hazard mapping of volcanic areas: A multi-process approach. Journal of Volcanology and Geothermal Research, 402, 106997. https://www.sciencedirect.com/science/article/abs/pii/S089598112030688X

Tibaldi, A., Bonali, F. L., & Rossi, M. (2019). Multi-hazard risk assessment for active volcanic regions: Integrating scientific models with preparedness strategies. Natural Hazards, 95(2), 589–613. https://doi.org/10.1007/s11069-018-3515-4

United Nations Office for Disaster Risk Reduction. (2023). Global assessment report on disaster risk reduction. United Nations. https://www.undrr.org

U.S. Geological Survey. (2022). Volcanic hazards and risk assessment. U.S. Department of the Interior. https://www.usgs.gov/volcanoes

Volcanic Hazard Maps. (n.d.). Models – Volcanic Hazard Maps. https://volcanichazardmaps.org/models/

Weir, G., Spence, R., Brown, S., & Rossetto, T. (2023). Approaching the challenge of multi-phase, multi-hazard volcanic impact assessment. *Natural Hazards, 118*, 1723–1747. https://link.springer.com/article/10.1007/s11069-023-06386-z