Reflection: Education and Pedagogical Insights

The Unpredictable Crater of Mount Bromo and Its Implications for Environmental Change and Educational Transformation

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ABSTRACT

This study examines the volcanic activity of Mount Bromo and its implications for environmental change and educational transformation. Using a qualitative descriptive design and a case study approach, the study analyzes secondary information from volcanic monitoring reports, scientific publications, environmental literature, and tourism-related sources. The analysis focuses on three interconnected dimensions: volcanic activity, environmental implications, and educational development. The findings indicate that Mount Bromo represents a dynamic geological environment in which changes in volcanic emissions, eruptive behavior, and monitoring observations require continuous scientific interpretation. Volcanic activity may influence air quality, ash deposition, ecosystems, tourism activities, and community interaction with the volcanic landscape. However, the available secondary data do not establish the magnitude or direct causal relationship of specific environmental changes. From an educational perspective, Mount Bromo offers an important contextual learning environment for integrating earth science, environmental education, disaster risk reduction, and sustainability. Volcanic monitoring data and historical eruption records can be used to strengthen scientific literacy, critical thinking, environmental awareness, and disaster preparedness. The study concludes that Mount Bromo should be understood not only as a tourism destination and geological phenomenon but also as a potential educational resource for transformative learning and community resilience. Further research is needed to combine environmental measurements with empirical assessments of educational outcomes.

Keywords: Mount Bromo; Volcanic Activity; Environmental Change; Educational Transformation; Contextual Learning; Disaster Education; Scientific Literacy; Sustainable Tourism; Community Resilience

Field: Education, Environmental Education, Disaster Risk Reduction, Earth Science Education

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SDG's: Quality Education (4); Sustainable Cities and Communities (11); Climate Action (13); Life on Land (15)

INTRODUCTION

Volcanic activity represents one of the most dynamic geological processes on Earth, continuously reshaping landscapes, influencing environmental conditions, and creating challenges for human communities living in volcanic regions (Bachri et al., 2026). In Indonesia, the interaction between volcanic processes, environmental sustainability, and public awareness is particularly important because of the country's extensive volcanic landscape and its exposure to geological hazards. Mount Bromo, an active volcano located in East Java, provides a compelling case for examining the relationship between volcanic activity, environmental change, and educational transformation. Rising to approximately 2,329 meters above sea level, Mount Bromo is situated within the Tengger volcanic complex and is recognized as one of Indonesia's prominent volcanic and tourism destinations. Its active crater, distinctive volcanic landscape, and cultural significance make it an important natural setting for scientific inquiry and educational development.

The activity of Mount Bromo's crater illustrates the continuing interaction between geological processes and human activities. Historical records indicate that Mount Bromo has experienced several significant eruptive episodes, including eruptions in 2004 and 2010, while volcanic activity has also been documented in subsequent years. The 2010 eruption episode was associated with increasing volcanic tremors and shallow volcanic earthquakes, resulting in restrictions on access to the caldera and concerns regarding public safety. More recently, the Global Volcanism Program reported increased activity at the Bromo cone in December 2023, including emissions of white, gray, and brown material. These observations demonstrate the importance of continuous volcanic monitoring and scientific interpretation in understanding the changing conditions of active craters. Rather than viewing the crater solely as a tourist attraction, its activity should be understood as a natural process that requires scientific awareness, environmental responsibility, and appropriate disaster preparedness.

The environmental implications of volcanic activity extend beyond the immediate crater area (Prayoga et al., 2026). Volcanic emissions, ash deposition, changes in air quality, and disturbances to surrounding ecosystems may affect the environmental conditions of volcanic landscapes and the activities of communities that depend on them. These issues become increasingly relevant in Mount Bromo because the volcano is located within Bromo Tengger Semeru National Park, an area recognized for its distinctive geological and ecological characteristics. The relationship between volcanic hazards and tourism is particularly important because Mount Bromo attracts substantial visitor interest. According to Antara News, the number of tourist visits to Mount Bromo reached 321,732 during the first half of 2025, increasing from 262,974 during the same period in 2024. This represents an increase of 58,758 visits, highlighting the continuing significance of Mount Bromo as a tourism destination and the importance of balancing visitor access with environmental protection and volcanic risk management (Antara News, 2025). Consequently, the sustainability of the Bromo environment requires not only effective monitoring and management but also greater public understanding of volcanic processes and their potential consequences.

Despite the scientific and environmental significance of volcanic activity, public understanding of active craters may remain limited when volcanic landscapes are primarily interpreted through tourism, visual attraction, and cultural experience (Vergara-Pinto et al., 2024) . The phrase "The Unpredictable Crater" reflects the need to reconsider how active volcanic environments are understood and communicated. In this context, education can play a transformative role by connecting scientific knowledge with real-world environmental challenges. Mount Bromo can serve as a contextual learning environment through which students and communities explore volcanic processes, environmental change, disaster preparedness, and sustainability. Previous research has also identified the potential of Mount Bromo's geological heritage as a resource for geography learning, suggesting that the area offers opportunities to strengthen educational engagement with geological phenomena. However, the educational value of volcanic environments depends on how scientific information is translated into meaningful learning experiences and public awareness.

Educational transformation in volcanic regions therefore requires a shift from conventional knowledge transmission toward contextual, interdisciplinary, and experiential learning (Tyas et al., 2025). The study of Mount Bromo's crater activity can support the integration of earth science, environmental education, disaster risk reduction, and sustainability awareness. Through this approach, learners are encouraged not only to understand volcanic activity as a geological phenomenon but also to recognize its implications for environmental conservation, community resilience, and responsible tourism. Such an educational perspective is relevant to the Sustainable Development Goals (SDGs), particularly SDG 4 on Quality Education, SDG 11 on Sustainable Cities and Communities, and SDG 13 on Climate Action, while recognizing that volcanic hazards are geological processes distinct from climate change.

Although studies of Mount Bromo have examined its geological characteristics, tourism potential, and environmental challenges, there remains an opportunity to strengthen the connection between crater activity, environmental change, and educational transformation. This study addresses that opportunity by examining Mount Bromo's volcanic activity and its implications for environmental awareness and educational development. The study aims to explore how scientific understanding of the unpredictable crater can contribute to contextual learning, disaster education, and sustainable environmental awareness. By positioning Mount Bromo as both a geological phenomenon and an educational resource, this research seeks to contribute to the development of more relevant and transformative educational approaches for communities and learners living in or engaging with volcanic environments.

LITERATURE REVIEW

Volcanic Activity and the Geological Characteristics of Mount Bromo

Volcanic activity is a dynamic geological process involving the movement of magma, the release of volcanic gases, and the interaction between volcanic materials and the surrounding environment (Chouet & Matoza, 2013). Understanding volcanic activity requires an examination of eruptive behavior, crater conditions, volcanic emissions, and the geological characteristics of a volcanic system. Active volcanoes provide important opportunities for scientific research because their activity reflects ongoing geological processes that may influence environmental conditions and human activities.

Mount Bromo is an active volcano located within the Tengger volcanic complex in East Java, Indonesia. The volcano is situated in Bromo Tengger Semeru National Park and is recognized for its distinctive crater, volcanic landscape, and cultural significance. Its elevation of approximately 2,329 meters above sea level and its location within a complex volcanic environment make it an important subject for geological and environmental studies (Global Volcanism Program, n.d.). The existence of an active crater highlights the continuing interaction between geological processes and the surrounding landscape.

The concept of an unpredictable crater is particularly relevant to the interpretation of volcanic activity. Volcanic systems may experience fluctuations in emissions, seismic activity, and eruptive behavior, making continuous monitoring essential for understanding volcanic hazards. However, unpredictability does not imply that volcanic activity is entirely random. Scientific monitoring can identify changes in volcanic conditions and support the assessment of potential hazards. Therefore, understanding Mount Bromo requires the integration of geological knowledge, monitoring information, and environmental interpretation.

Previous documentation of Mount Bromo's eruptive history demonstrates the importance of studying volcanic activity over time. The Smithsonian Institution's Global Volcanism Program provides historical information concerning volcanic activity and eruptive episodes in the Tengger volcanic system. Such documentation is valuable for identifying patterns of volcanic behavior and establishing a scientific basis for disaster education and environmental awareness (Global Volcanism Program, n.d.). Nevertheless, historical activity should not automatically be interpreted as evidence of current volcanic conditions, because each eruptive episode requires separate scientific assessment.

Volcanic Activity and Environmental Change

Environmental change refers to alterations in physical, biological, and ecological conditions resulting from natural processes and human activities. Volcanic activity represents an important natural driver of environmental change because volcanic emissions, ash deposition, lava, and other eruptive materials can influence atmospheric conditions, soil characteristics, vegetation, and ecosystem processes. The effects of volcanic activity depend on the intensity, duration, composition, and geographical distribution of the emitted materials.

Volcanic ash is one of the most important environmental products associated with explosive eruptions (Wilson et al., 2012). Fine volcanic particles may be transported by wind and deposited across surrounding areas, potentially affecting vegetation, agricultural land, water resources, and human health. Volcanic gases, including sulfur dioxide and carbon dioxide, may also influence atmospheric conditions and create localized environmental risks. However, the magnitude of these effects varies according to the characteristics of the eruption and the environmental conditions of the affected area.

In the context of Mount Bromo, environmental change should be understood through the interaction between volcanic processes and the ecological characteristics of Bromo Tengger Semeru National Park. The area contains distinctive volcanic landscapes, vegetation, and natural resources that contribute to its ecological and tourism value. Volcanic activity may alter the appearance and condition of the landscape, while environmental management and tourism activities may influence the resilience of surrounding ecosystems. This relationship creates a need for integrated environmental research that considers both geological processes and human interactions with volcanic environments.

The environmental significance of Mount Bromo is also related to its role as a tourism destination. Tourism activities depend on the attractiveness and accessibility of the volcanic landscape, while volcanic hazards may influence visitor safety, access restrictions, and destination management. Data reported by Antara News indicate that Mount Bromo recorded 321,732 tourist visits during the first half of 2025, compared with 262,974 visits during the same period in 2024. The increase of 58,758 visits indicates the continuing importance of the destination for tourism and provides a relevant context for examining the relationship between volcanic hazards, environmental awareness, and sustainable tourism management (Antara News, 2025).

From an environmental education perspective, volcanic activity provides a meaningful context for understanding the relationship between natural processes and environmental sustainability. Students and communities can explore how volcanic activity affects ecosystems, how environmental risks are managed, and why scientific knowledge is important for responsible interaction with volcanic landscapes. Accordingly, environmental change should not be studied solely as a geological consequence but also as an educational opportunity to develop awareness, scientific reasoning, and sustainable behavior.

Disaster Education and Volcanic Risk Awareness

Disaster education is an important component of sustainable development because it helps individuals and communities understand hazards, recognize risks, and develop appropriate preparedness behaviors. The United Nations Office for Disaster Risk Reduction emphasizes the importance of disaster risk knowledge, education, and awareness in strengthening disaster resilience. The Sendai Framework for Disaster Risk Reduction 2015–2030 identifies the understanding of disaster risk as a fundamental priority for reducing disaster losses and improving resilience (United Nations Office for Disaster Risk Reduction, 2015).

Volcanic disaster education is particularly important in communities located near active volcanoes. Unlike hazards that may occur without clear geological warning, volcanic eruptions may be preceded by changes in seismicity, gas emissions, deformation, or other observable indicators. However, the interpretation of these indicators requires scientific knowledge and access to reliable information. Education can help communities distinguish between ordinary volcanic activity and conditions that require increased vigilance, while encouraging them to follow official information from relevant authorities.

The educational value of Mount Bromo lies in its ability to connect abstract scientific concepts with a real-world volcanic environment. Conventional classroom instruction may introduce concepts such as magma, volcanic gases, eruption mechanisms, and hazard zones. However, the study of an actual active crater can provide a contextual framework for understanding these concepts in relation to environmental conditions and human activities. Such learning can be strengthened through field observations, scientific reports, geographical analysis, and disaster preparedness exercises.

Disaster education should also extend beyond the transmission of factual knowledge. Effective education should encourage learners to develop critical thinking, risk perception, decision-making skills, and a sense of responsibility toward their communities. In the case of Mount Bromo, students may examine how volcanic information is communicated, how tourism activities are affected by volcanic hazards, and how communities can respond to changes in environmental conditions. This approach positions disaster education as a process of developing both scientific understanding and practical resilience.

Contextual Learning and Educational Transformation

Contextual learning is an educational approach that connects academic knowledge with real-world situations, allowing learners to understand the relevance and application of concepts beyond the classroom (Perales & Bedoya Ulla, 2025). Contextual learning theory emphasizes that knowledge becomes more meaningful when learners relate new information to their experiences, environments, and social contexts. In science education, contextual learning can support the development of scientific reasoning by connecting theoretical concepts with observable natural phenomena.

Mount Bromo provides a relevant context for contextual learning because its volcanic activity involves interconnected geological, environmental, social, and economic dimensions. Students can examine volcanic activity through multiple disciplinary perspectives, including earth science, environmental studies, geography, disaster management, and sustainable development. This interdisciplinary approach can encourage learners to recognize that natural hazards are not isolated scientific events but phenomena with broader consequences for communities and society.

Educational transformation refers to changes in educational approaches, learning processes, and the development of competencies that enable individuals to respond to complex challenges. Transformative learning theory, developed by Mezirow, emphasizes the importance of critical reflection and the transformation of existing assumptions through meaningful learning experiences (Mezirow, 1991). In the context of volcanic education, transformative learning may occur when students reconsider their understanding of active volcanoes, environmental risks, and the relationship between tourism and disaster preparedness.

The study of Mount Bromo's crater activity can support educational transformation by shifting learning from passive observation toward active scientific inquiry. Learners may be encouraged to analyze volcanic monitoring data, interpret environmental changes, evaluate risk information, and formulate recommendations for sustainable tourism and community preparedness. Such activities can strengthen the connection between scientific knowledge and responsible decision-making.

Educational transformation is also relevant to the development of sustainability awareness. UNESCO's Education for Sustainable Development framework emphasizes the importance of knowledge, skills, values, and attitudes that enable learners to contribute to sustainable development (UNESCO, 2020). By integrating volcanic activity with environmental awareness and disaster education, Mount Bromo can serve as a learning environment for developing competencies related to sustainability, resilience, and environmental responsibility.

Volcanic Education, Sustainability, and Community Resilience

Sustainability education emphasizes the development of knowledge and competencies that enable individuals and communities to address environmental, social, and economic challenges (Xiao et al., 2025). The Sustainable Development Goals provide an international framework for connecting education with environmental protection, disaster resilience, and sustainable communities. In particular, SDG 4 focuses on quality education, SDG 11 addresses sustainable cities and communities, and SDG 13 emphasizes climate action and resilience. Although volcanic eruptions are geological hazards rather than direct consequences of climate change, disaster education and environmental sustainability are relevant to the development of resilient communities.

Community resilience refers to the capacity of individuals, organizations, and communities to anticipate, respond to, and recover from adverse events. In volcanic regions, resilience depends on several factors, including scientific knowledge, communication systems, institutional preparedness, social networks, and the ability to access and interpret risk information. Education contributes to resilience by strengthening knowledge and supporting the development of appropriate attitudes and behaviors.

Mount Bromo provides a useful context for examining the relationship between education and community resilience because of the interaction between volcanic hazards and tourism activities. Communities and tourism stakeholders may need to respond to changes in volcanic activity while maintaining environmental protection and economic sustainability. Education can support this process by increasing awareness of volcanic risks, encouraging responsible tourism behavior, and strengthening cooperation between scientific institutions, local authorities, educational institutions, and communities.

From this perspective, volcanic education should not be limited to emergency response. It should also promote long-term environmental awareness and responsible engagement with volcanic landscapes. Students and communities can learn how to interpret scientific information, understand the importance of official hazard assessments, and recognize the environmental responsibilities associated with tourism. Such an approach contributes to the development of sustainable communities that are better prepared to respond to natural hazards.

Research Gap

Existing literature provides important foundations for understanding volcanic activity, environmental change, disaster education, and contextual learning. Geological studies and volcanic monitoring reports provide information concerning the characteristics and behavior of active volcanoes. Environmental studies examine the consequences of volcanic processes for ecosystems and human activities. Meanwhile, educational research emphasizes the importance of contextual learning, scientific literacy, and transformative educational approaches.

However, the relationship between Mount Bromo's crater activity, environmental change, and educational transformation remains an important area for further investigation. Research that focuses primarily on geological characteristics may provide limited discussion of how volcanic information can be translated into educational practice. Similarly, studies of tourism and environmental management may not fully examine the role of education in strengthening scientific understanding and community awareness.

This study addresses the research gap by examining Mount Bromo's volcanic activity through an integrated environmental and educational perspective. It seeks to understand how information concerning volcanic activity can be used to support environmental awareness, disaster education, and educational transformation. The study positions Mount Bromo not only as an active volcanic system but also as a contextual learning environment that can support the development of scientific literacy, environmental responsibility, and community resilience.

The literature suggests that the educational significance of Mount Bromo depends on the ability to connect scientific evidence with meaningful learning outcomes. Therefore, this study emphasizes the importance of integrating volcanic knowledge, environmental interpretation, and educational development (Rustan et al., 2025). Through this approach, the research contributes to the broader discussion of how active volcanic environments can support transformative education and sustainable community development.

Theoretical Framework

Conceptual relationship

Mount Bromo crater activity

Volcanic emissions · Eruptive behavior · Monitoring data

↓

Environmental change

Ash deposition · Ecosystems · Tourism environment

↓

Educational transformation

Contextual learning · Scientific literacy · Disaster awareness

METHODOLOGY

Research Design

This study employs a qualitative descriptive research design using a case study approach to examine the volcanic activity of Mount Bromo and its implications for environmental change and educational transformation (Toulier et al., 2019). The research focuses on interpreting volcanic activity data, identifying potential environmental implications, and exploring how scientific information can support contextual learning and disaster education.

A case study approach is appropriate because Mount Bromo represents a specific active volcanic environment in which geological processes, environmental conditions, tourism activities, and educational opportunities are interconnected. Rather than attempting to predict volcanic eruptions, this study examines documented volcanic activity and its relevance to environmental awareness and educational development.

The research adopts an interdisciplinary perspective that combines volcanology, environmental education, disaster risk reduction, and contextual learning. This approach enables the study to interpret volcanic activity not only as a geological phenomenon but also as a potential source of meaningful educational experiences.

Research Location and Object

The research focuses on Mount Bromo, located within the Tengger volcanic complex in East Java, Indonesia. The primary research object is the volcanic crater and its documented activity, including changes in volcanic emissions, eruptive episodes, and other available indicators of volcanic unrest.

The geographical and environmental context of Mount Bromo is important because the volcano is located within Bromo Tengger Semeru National Park and is surrounded by areas with ecological, cultural, and tourism significance. The study considers the relationship between volcanic activity and the surrounding environment, particularly in relation to environmental awareness, disaster preparedness, and educational transformation.

Data Sources and Data Collection

The study uses secondary data obtained from reliable scientific and institutional sources. Secondary data are selected because they provide documented information concerning volcanic activity over time and allow the researcher to examine the relationship between volcanic processes and educational implications.

The primary data sources include:

1. Volcanic activity data

Volcanic activity data are obtained from the Global Volcanism Program of the Smithsonian Institution and official volcanic monitoring information where available. These data include historical eruption records, observations of volcanic emissions, and documented changes in volcanic activity.

The Global Volcanism Program provides eruption information and volcanic activity records for the Tengger volcanic system. For example, its documentation includes increased activity at the Bromo cone reported in December 2023, with emissions described as white, gray, and brown. Such information provides a basis for examining volcanic activity as a dynamic environmental phenomenon (Global Volcanism Program, n.d.).

2. Environmental information

Environmental information is collected from scientific publications, institutional reports, and relevant studies concerning volcanic emissions, ash deposition, environmental conditions, and the ecological context of Mount Bromo. These data are used to interpret the possible environmental implications of volcanic activity.

The study does not assume that every documented volcanic emission produces measurable environmental damage. Instead, environmental implications are identified based on scientific evidence and the characteristics of the documented activity.

3. Educational literature

Educational data are obtained from peer-reviewed research concerning contextual learning, scientific literacy, disaster education, environmental education, and transformative learning. These sources provide the theoretical basis for interpreting how volcanic activity may be used as a learning resource.

4. Tourism and community context

Tourism-related information is obtained from institutional reports and credible publications concerning Mount Bromo's tourism activities. These data provide contextual information regarding the interaction between volcanic hazards, visitor activities, environmental awareness, and sustainable tourism.

Data Analysis

The collected data are analyzed using qualitative descriptive analysis and thematic analysis. The analysis is organized into three main stages.

Stage 1. Identification of volcanic activity

The first stage involves identifying documented volcanic activity at Mount Bromo. The analysis focuses on the type of volcanic activity, the period of occurrence, the characteristics of emissions, and the available information concerning eruptive behavior.

The data are organized chronologically to identify changes in volcanic activity over time. Historical eruption records and monitoring reports are compared to establish a descriptive understanding of the volcanic system.

Stage 2. Interpretation of environmental implications

The second stage examines the relationship between documented volcanic activity and environmental conditions. The analysis considers the potential implications of volcanic emissions, ash deposition, and other volcanic materials for the surrounding environment.

Environmental implications are interpreted using scientific literature and available environmental information. The analysis distinguishes between documented environmental impacts and potential impacts that require further investigation.

This distinction is important because the existence of volcanic activity does not automatically establish that a specific environmental change has occurred. Claims concerning environmental impacts must be supported by appropriate measurements or scientific evidence.

Stage 3. Educational interpretation

The third stage interprets the educational implications of Mount Bromo's volcanic activity. The analysis connects volcanic information with concepts of contextual learning, scientific literacy, disaster education, and environmental awareness.

The educational interpretation focuses on how volcanic activity can be transformed into meaningful learning experiences. The study examines opportunities for learners to analyze volcanic data, understand environmental risks, interpret scientific information, and develop awareness of sustainable interaction with volcanic environments.

Data Analysis Framework

The study uses the following analytical framework:

Analytical dimension → Data examined → Educational implication

Volcanic activity → Eruptive episodes, emissions, monitoring observations → Understanding geological processes

Environmental change → Ash, emissions, ecological context → Environmental awareness

Disaster risk → Hazard information, safety restrictions, preparedness → Disaster education

Contextual learning → Scientific data and real-world case → Scientific literacy

Educational transformation → Critical reflection and interdisciplinary learning → Sustainable and responsible behavior

This framework supports the integration of geological evidence and educational interpretation while maintaining a clear distinction between scientific observations and educational implications.

Data Validity and Reliability

To improve the validity and reliability of the findings, the study applies source triangulation. Information concerning volcanic activity is compared across scientific and institutional sources where possible. Geological information is prioritized from recognized volcanological institutions, while educational interpretations are grounded in established educational theories and peer-reviewed literature.

The study also applies a clear distinction between primary observations, secondary interpretations, and educational recommendations. Historical volcanic activity is not treated as evidence of current volcanic conditions. Likewise, potential environmental impacts are not presented as confirmed impacts unless supported by relevant data.

The reliability of the study depends on the completeness and quality of available secondary data. Therefore, the research acknowledges that conclusions concerning environmental change and educational transformation are limited by the scope of the available evidence.

Ethical Considerations

The study uses publicly available secondary data and does not involve direct experimentation on volcanic systems or activities that may expose researchers to volcanic hazards. Scientific information is interpreted responsibly, and the research avoids making unsupported predictions concerning future eruptions.

Information concerning volcanic activity is presented as documented scientific evidence rather than as a warning or forecast. The study emphasizes the importance of relying on official volcanic monitoring information for safety-related decisions.

Research Limitations

This study has several methodological limitations. First, it relies primarily on secondary data and does not conduct direct field measurements of volcanic emissions, seismic activity, or environmental conditions. Second, the study does not establish causal relationships between volcanic activity and environmental change. Third, the educational implications are developed through theoretical interpretation rather than direct measurement of student learning outcomes.

Future research may address these limitations through field-based environmental measurements, longitudinal volcanic activity analysis, classroom interventions, and empirical evaluation of contextual learning models based on Mount Bromo.

RESULTS AND DISCUSSION

Results

Overview of Mount Bromo Volcanic Activity

The analysis of documented volcanic information indicates that Mount Bromo represents an active volcanic environment characterized by continuing geological processes and the potential for changes in volcanic activity. Historical eruption records and volcanic monitoring information provide an important basis for understanding the behavior of the Bromo crater. The Global Volcanism Program documents the Tengger volcanic system and provides information concerning historical eruptive activity and subsequent volcanic observations.

One important observation is that volcanic activity should not be interpreted solely through the occurrence of major eruptions. Changes in volcanic emissions, the appearance of ash or other volcanic materials, and variations in monitoring observations are also relevant to understanding the condition of an active crater. Consequently, the study of Mount Bromo requires a broader interpretation of volcanic activity that includes both eruptive episodes and ongoing volcanic processes.

The historical record of Mount Bromo demonstrates the importance of monitoring and scientific interpretation. Previous eruptive episodes, including the activity documented during 2010, illustrate that volcanic conditions may create challenges for communities and tourism activities. More recent observations of activity at the Bromo cone also highlight the continuing relevance of volcanic monitoring (Suhardjo et al., 2023).

However, historical records alone cannot establish the current status of the crater. The findings therefore emphasize that the interpretation of Mount Bromo's volcanic activity must be based on dated observations and official monitoring information. This distinction is particularly important for educational purposes because students need to understand the difference between historical volcanic events, observed volcanic activity, and scientific forecasts.

The Unpredictable Crater and the Importance of Scientific Understanding

The concept of the "unpredictable crater" provides a useful perspective for interpreting Mount Bromo as a dynamic geological environment. The term does not suggest that volcanic activity is completely random or impossible to monitor. Rather, it highlights the importance of recognizing that active volcanic systems may change over time and that scientific observations are necessary to understand these changes.

Volcanic activity involves complex interactions between magma, volcanic gases, geological structures, and environmental conditions. These processes create challenges for predicting the timing, intensity, and consequences of volcanic events. Scientific monitoring can provide information about changes in volcanic conditions, but monitoring information must be interpreted carefully and should not be confused with certainty about future eruptions.

The findings suggest that the study of Mount Bromo should move beyond a simplified understanding of volcanic activity as a spectacular natural event. The crater can be understood as a dynamic system that requires continuous observation, scientific interpretation, and responsible public communication. This perspective is relevant to education because it encourages learners to examine evidence rather than rely exclusively on visual impressions or popular descriptions of volcanic activity (Renaldo et al., 2022).

From an educational standpoint, volcanic monitoring data can be used to introduce students to scientific inquiry. Students may examine how observations are collected, how scientific information is communicated, and how changes in volcanic conditions are interpreted. Such learning activities can support the development of scientific reasoning and improve understanding of the relationship between geological processes and environmental risks.

Environmental Implications of Volcanic Activity

The analysis indicates that Mount Bromo's volcanic activity has important implications for understanding the relationship between geological processes and environmental conditions. Volcanic emissions and ash deposition may influence the surrounding environment, depending on the characteristics and intensity of volcanic activity. The environmental implications of an eruption may include changes in air quality, the deposition of volcanic materials, and disturbances to surrounding ecosystems.

However, the available secondary information does not establish the magnitude of specific environmental changes during the study period. Therefore, the findings are interpreted as environmental implications rather than direct measurements of environmental damage. This distinction is necessary to avoid overstating the relationship between volcanic activity and environmental change.

The environmental significance of Mount Bromo is also influenced by its location within Bromo Tengger Semeru National Park. The volcanic landscape contributes to the ecological and tourism value of the area, while volcanic hazards may create challenges for environmental management and visitor safety. The interaction between volcanic activity and tourism demonstrates that environmental sustainability requires consideration of both natural processes and human activities (Renaldo et al., 2021) .

The tourism context provides an additional dimension to the environmental discussion. Antara News reported that Mount Bromo recorded 321,732 tourist visits during the first half of 2025, compared with 262,974 visits during the same period in 2024. The increase of 58,758 visits represents approximately 22.3% growth. This tourism context illustrates the importance of environmental awareness and responsible destination management in a volcanic landscape.

Nevertheless, tourism growth should not be interpreted as evidence that volcanic activity directly caused environmental degradation. A reliable assessment of environmental change would require data concerning air quality, ash deposition, vegetation conditions, soil characteristics, or other relevant environmental

indicators. Future research should therefore integrate volcanic monitoring data with environmental measurements to establish a more accurate understanding of the consequences of volcanic activity.

Mount Bromo as a Contextual Learning Environment

One of the principal educational implications of the study is the potential of Mount Bromo to serve as a contextual learning environment. Contextual learning connects academic knowledge with real-world situations and enables students to understand how scientific concepts apply to their surrounding environment. In this case, volcanic activity provides a meaningful context for examining geological processes, environmental change, and disaster risk.

The findings suggest that Mount Bromo can support interdisciplinary learning activities. In geography education, students may examine volcanic landforms, crater characteristics, and the relationship between geological processes and landscapes. In science education, learners may explore magma, volcanic gases, ash, and monitoring indicators. In environmental education, students may investigate the relationship between volcanic activity, ecosystems, and sustainability.

The use of volcanic activity data can also strengthen the connection between theoretical knowledge and scientific evidence. Rather than learning about volcanoes only through textbooks, students can examine historical eruption records, interpret monitoring reports, and analyze documented observations. This approach may encourage learners to ask questions, compare information, and develop evidence-based explanations (Sudarmanto et al., 2025).

The educational value of Mount Bromo therefore extends beyond its role as a natural attraction. The crater can function as a learning resource that supports scientific inquiry and environmental awareness. However, the educational benefits depend on the quality of learning design, the reliability of scientific information, and the ability of educators to translate complex volcanic processes into appropriate learning activities.

Volcanic Activity and Disaster Education

The results indicate that volcanic activity can provide a meaningful foundation for disaster education. Active volcanic environments require individuals and communities to understand hazards, recognize the importance of scientific information, and develop appropriate preparedness behaviors. In the context of Mount Bromo, disaster education can connect volcanic observations with practical discussions of risk, safety, and community resilience.

The Sendai Framework for Disaster Risk Reduction emphasizes the importance of understanding disaster risk as a foundation for reducing disaster losses and strengthening resilience (United Nations Office for Disaster Risk Reduction, 2015). This perspective is relevant to Mount Bromo because scientific knowledge concerning volcanic activity can support the development of public awareness and responsible behavior.

Educational activities based on Mount Bromo may include the interpretation of volcanic monitoring information, the identification of potential volcanic hazards, and the analysis of appropriate preparedness measures. Students can also examine the relationship between volcanic activity and tourism management, including the importance of following official access restrictions and safety guidance.

The study emphasizes that disaster education should not be limited to memorizing information about volcanic eruptions. Instead, it should encourage learners to understand how scientific evidence informs decisions. This includes recognizing the limitations of volcanic forecasts, distinguishing between official information and unsupported claims, and understanding why safety recommendations may change as volcanic conditions evolve.

Such an approach can contribute to the development of scientific literacy and disaster awareness. However, the present study does not measure actual changes in student preparedness or disaster-related behavior. The educational implications are therefore conceptual and should be tested through empirical research.

Educational Transformation through Scientific and Environmental Learning

The findings suggest that the study of Mount Bromo's volcanic activity can contribute to educational transformation by connecting scientific knowledge with environmental and social challenges. Educational transformation involves more than introducing new learning materials. It requires the development of learning experiences that encourage critical thinking, reflection, and the application of knowledge to real-world situations.

Mount Bromo offers an opportunity to develop learning activities that integrate geology, environmental science, disaster education, and sustainability. Students may analyze volcanic data and reflect on how natural

processes influence communities and tourism activities. Through this process, learners can develop a more comprehensive understanding of the relationship between natural hazards and human responsibility.

Transformative learning theory emphasizes the importance of critical reflection in the development of new perspectives (Mezirow, 1991). Applied to volcanic education, this perspective suggests that students may reconsider assumptions about volcanoes as merely dangerous or visually attractive natural features. Instead, they may develop a more balanced understanding of volcanoes as geological systems that require scientific observation, environmental management, and responsible human interaction.

The educational transformation associated with Mount Bromo can also be connected to sustainability education. UNESCO (2020) emphasizes the importance of developing knowledge, skills, values, and attitudes that support sustainable development. In this context, volcanic activity can be used to develop awareness of environmental responsibility, disaster resilience, and sustainable tourism (Renaldo et al., 2023).

Nevertheless, the study does not claim that educational transformation has already occurred among students or communities. Demonstrating such transformation would require empirical evidence, such as changes in scientific literacy, environmental attitudes, critical thinking, or disaster preparedness. The present findings identify the potential of Mount Bromo as a foundation for developing and evaluating such educational interventions.

Implications for Sustainable Tourism and Community Awareness

Mount Bromo's volcanic activity has implications for the relationship between tourism, environmental management, and community awareness. The destination's tourism significance creates opportunities for economic development but also requires responsible management of visitors and the surrounding environment. The coexistence of tourism activities and an active volcanic system highlight the importance of integrating scientific information into public awareness and destination management (Delyana Rahmawany Pulungan et al., 2025).

The tourism data reported by Antara News demonstrate the continuing relevance of Mount Bromo as a destination. However, tourism growth should be accompanied by awareness of volcanic hazards and environmental responsibilities. Educational initiatives may support this process by providing visitors, local communities, and students with information concerning volcanic processes, environmental protection, and appropriate behavior in volcanic areas (Nyoto et al., 2025).

From a community education perspective, volcanic activity can be used to develop learning materials that are relevant to local experiences. Community members may benefit from information concerning volcanic hazards, environmental conditions, and the importance of official monitoring. Educational institutions can contribute by developing programs that connect scientific knowledge with local environmental challenges (Renaldo et al., 2026).

The findings also suggest that sustainable tourism education should emphasize the balance between visitor experience and environmental responsibility. The attractiveness of Mount Bromo's crater should not reduce awareness of its active geological nature. Instead, tourism education can encourage visitors to respect safety restrictions, protect the environment, and recognize the scientific significance of the volcanic landscape.

Research Contributions and Limitations of the Findings

This study contributes to the discussion of volcanic education by integrating volcanic activity, environmental implications, and educational transformation within a single conceptual framework. The research positions Mount Bromo as both an active volcanic system and a potential learning environment for developing scientific literacy, disaster awareness, and environmental responsibility.

The main contribution lies in connecting geological observations with educational relevance. While volcanic activity is commonly examined through geological and environmental perspectives, this study emphasizes the importance of translating scientific information into meaningful educational experiences. This approach is particularly relevant to education journals that seek to connect learning with real-world environmental challenges.

However, several limitations should be recognized. First, the study relies on secondary data and does not conduct direct field measurements of volcanic activity or environmental conditions. Second, the available information does not establish a causal relationship between volcanic activity and specific environmental changes. Third, the educational implications are based on theoretical interpretation rather than direct measurement of learning outcomes.

These limitations indicate that the findings should be understood as an exploratory contribution rather than a definitive assessment of environmental change or educational transformation. Future studies should combine scientific monitoring data with environmental measurements and empirical educational research to strengthen the evidence base.

Discussion Summary

The results and discussion demonstrate that Mount Bromo's volcanic activity provides a valuable context for examining the relationship between geological processes, environmental change, and education. The concept of the unpredictable crater highlights the importance of continuous monitoring, scientific interpretation, and responsible public communication.

The environmental implications of volcanic activity are relevant to the ecological and tourism context of Mount Bromo, although the magnitude of environmental change requires further empirical investigation (Utomo et al., 2026). The educational implications are particularly significant because volcanic activity can be transformed into contextual learning experiences that support scientific literacy, disaster education, and environmental awareness.

Overall, the study suggests that Mount Bromo can serve as a meaningful educational resource for connecting scientific knowledge with sustainability and community resilience. The findings support the development of interdisciplinary learning approaches that encourage learners to understand volcanic activity, interpret environmental risks, and recognize the importance of responsible interaction with active volcanic environments.

CONCLUSION

Conclusion

This study examined the volcanic activity of Mount Bromo and its implications for environmental change and educational transformation. Based on the analysis of documented volcanic information and relevant educational literature, Mount Bromo represents an important natural environment for understanding the relationship between geological processes, environmental awareness, disaster preparedness, and contextual learning. The concept of the unpredictable crater emphasizes the importance of continuous scientific monitoring and responsible interpretation of volcanic activity.

The findings indicate that volcanic activity has important implications for the environmental conditions surrounding Mount Bromo. Volcanic emissions, ash deposition, and other volcanic processes may influence ecosystems, tourism activities, and community interactions with the volcanic landscape. However, the extent of these environmental changes requires further investigation through direct measurements and reliable environmental data.

From an educational perspective, Mount Bromo provides a meaningful context for developing scientific literacy, environmental awareness, and disaster education. Volcanic monitoring information can be incorporated into contextual and interdisciplinary learning activities, enabling students to connect scientific concepts with real-world environmental challenges. Such an approach can support educational transformation by encouraging critical thinking, scientific inquiry, and responsible environmental behavior.

Overall, this study highlights the potential of Mount Bromo as both a geological phenomenon and an educational resource. The integration of volcanic science, environmental education, and disaster risk reduction may contribute to the development of more relevant and transformative learning approaches. Nevertheless, further empirical research is necessary to evaluate the actual environmental impacts and educational outcomes associated with Mount Bromo's volcanic activity.

Implications

Educational Implications

The study has important implications for the development of contextual and interdisciplinary education. Mount Bromo's volcanic activity can be incorporated into learning activities that connect geological science with environmental education and disaster preparedness. Educators may use volcanic monitoring reports, historical eruption records, and environmental information as learning materials to strengthen students' understanding of scientific processes.

The integration of real-world volcanic data can encourage students to develop analytical thinking and evidence-based reasoning. Rather than learning about volcanic activity solely through theoretical explanations,

students can examine actual scientific observations and consider their implications for environmental conditions and community safety.

The study also highlights the importance of educational approaches that promote scientific literacy and environmental responsibility. By connecting volcanic phenomena with sustainability and disaster risk reduction, educational institutions can support the development of learners who are better prepared to understand and respond to environmental challenges.

Environmental and Community Implications

The findings suggest that environmental awareness should be an important component of education in volcanic regions. Communities and tourism stakeholders around Mount Bromo may benefit from educational initiatives that explain volcanic hazards, environmental conservation, and responsible interaction with the volcanic landscape.

The integration of scientific knowledge into community education can support better understanding of volcanic risks and encourage responsible behavior. However, educational initiatives should be based on reliable scientific information and should complement, rather than replace, official volcanic monitoring and safety guidance.

Implications for Sustainable Tourism

Mount Bromo's tourism significance creates opportunities for integrating environmental education into sustainable tourism management. Educational materials for visitors may explain the geological significance of the crater, potential volcanic hazards, and the importance of respecting access restrictions and environmental protection measures.

Such initiatives may help promote responsible tourism behavior and strengthen awareness of the relationship between tourism activities and volcanic environmental conditions. The educational value of the destination can therefore extend beyond recreation to include scientific learning and environmental responsibility.

Implications for Policy and Institutional Collaboration

The study highlights the importance of collaboration among educational institutions, volcanological authorities, environmental managers, local governments, and communities. Such collaboration may support the development of educational materials based on scientific monitoring information and local environmental conditions. Educational institutions can contribute by incorporating volcanic science and disaster preparedness into relevant learning programs. Meanwhile, scientific and environmental institutions can support education through the provision of accessible and reliable information concerning volcanic activity and environmental risks.

Limitations

This study has several limitations that should be considered when interpreting its findings. First, the research relies primarily on secondary data and documented scientific information. It does not involve direct field measurements of volcanic emissions, seismic activity, ash deposition, or environmental conditions around Mount Bromo. Consequently, the study cannot establish the magnitude of specific environmental changes during the study period.

Second, the study does not establish a causal relationship between volcanic activity and environmental change. Although volcanic processes may influence environmental conditions, the actual effects depend on factors such as eruption intensity, duration, atmospheric conditions, and the characteristics of the surrounding ecosystem. Additional environmental measurements are required to establish these relationships more accurately. Third, the educational implications are based on theoretical interpretation rather than direct assessment of student learning outcomes. The study does not measure changes in scientific literacy, environmental awareness, disaster preparedness, or critical thinking among students or community members.

Fourth, the interpretation of volcanic activity is limited by the availability and completeness of historical and monitoring information. Different periods may contain different levels of documentation, and historical activity should not be interpreted as a direct indicator of current volcanic conditions. Finally, the study does not conduct a comparative analysis with other active volcanoes or educational settings. Therefore, the transferability of its findings to other volcanic regions may be limited.

Recommendations

Recommendations for Educational Institutions

Educational institutions are encouraged to develop contextual learning activities based on volcanic phenomena such as Mount Bromo. Learning materials may integrate volcanic monitoring reports, geological information, environmental observations, and disaster preparedness concepts. Teachers and lecturers should consider using interdisciplinary approaches that connect science, geography, environmental education, and disaster risk reduction. Such approaches may improve the relevance of learning and encourage students to apply scientific knowledge to real-world challenges.

Recommendations for Environmental and Disaster Education

Disaster education programs should emphasize the importance of scientific information, risk awareness, and responsible decision-making. Students and communities should be encouraged to understand the difference between historical eruption records, current volcanic observations, and official hazard assessments. Educational materials should also emphasize that volcanic activity may change over time and that safety decisions must rely on updated information from authorized monitoring institutions.

Recommendations for Sustainable Tourism Management

Tourism stakeholders around Mount Bromo are encouraged to strengthen environmental and disaster awareness initiatives. Visitor education may include information about volcanic hazards, environmental conservation, waste management, and responsible behavior within volcanic areas. Tourism management should continue to prioritize public safety and environmental protection while maintaining opportunities for scientific and educational engagement with the volcanic landscape.

Recommendations for Scientific and Institutional Collaboration

Collaboration among volcanological institutions, universities, schools, environmental agencies, and local communities should be strengthened. Such collaboration may support the development of scientifically accurate educational materials and learning programs based on volcanic activity data. The integration of scientific monitoring information into educational programs should be conducted carefully, ensuring that the information is current, appropriately interpreted, and suitable for the intended learners.

Future Research

Future research should expand the investigation of Mount Bromo's volcanic activity through empirical, interdisciplinary, and longitudinal approaches. First, future studies should integrate long-term volcanic monitoring data with environmental measurements. Data concerning seismic activity, volcanic emissions, ash deposition, air quality, and vegetation conditions may provide a stronger basis for understanding environmental change associated with volcanic activity.

Second, researchers should conduct field-based environmental studies around Mount Bromo. Such research may examine the effects of volcanic materials on soil characteristics, water quality, vegetation, and local ecosystems. These studies would strengthen the empirical foundation of environmental impact assessments. Third, future research should investigate the effectiveness of contextual learning based on Mount Bromo's volcanic activity. Experimental or quasi-experimental studies may compare learning outcomes between conventional instruction and volcanic activity-based learning. Relevant outcomes may include scientific literacy, critical thinking, environmental awareness, and disaster preparedness.

Fourth, future studies should examine the role of digital technology in volcanic education. Digital learning platforms, interactive volcanic monitoring visualizations, virtual field trips, and geospatial learning tools may provide opportunities for students to explore volcanic phenomena without requiring direct access to hazardous environments. Fifth, comparative studies involving Mount Bromo and other active volcanoes may provide broader insights into the development of volcanic education and community resilience. Such research may examine differences in educational practices, environmental conditions, scientific communication, and disaster preparedness across volcanic regions.

Finally, future research should investigate the relationship between volcanic activity, sustainable tourism, and community education. This may include examining how educational interventions influence visitor awareness, environmental behavior, and community participation in volcanic risk management. Future research in these areas may contribute to the development of evidence-based educational strategies that integrate scientific knowledge, environmental sustainability, and disaster resilience. By positioning active volcanic environments as meaningful learning resources, researchers can support the development of transformative educational approaches for communities and learners in volcanic regions.

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