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A Systematic Review: Assessing Organ System-Specific Health Risks of Volcanic Eruptions Across Asia with their Corresponding Volcanic Hazard

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Abstract: Volcanic eruptions are complex natural phenomena that not only cause significant environmental and infrastructural damage but also present a myriad of public health challenges. This systematic review assesses the organ system-specific health risks associated with volcanic eruptions across Asia by synthesizing findings from studies published between 2015 and 2025. The review follows PRISMA guidelines to methodically evaluate the impact of volcanic hazards—such as ash, sulfur dioxide, and toxic metal particulates—on diverse organ systems including the respiratory, integumentary, ocular, cardiovascular, gastrointestinal, and reproductive systems. Data were extracted from studies investigating several prominent volcanoes in the region, including Sakurajima, Mt. Miyakejima, and Mt. Asama in Japan; Mt. Agung, Mt. Sinabung, Mt. Merapi, and Mt. Marapi in Indonesia; Taal and Mt. Mayon in the Philippines; and Mt. Shiveluch in Russia. Despite variations in the Volcanic Explosivity Index (VEI), even eruptions with relatively low explosivity have been linked to adverse health outcomes. Chronic exposure to fine volcanic ash and associated pollutants has been shown to exacerbate respiratory conditions such as asthma, bronchitis, and chronic obstructive pulmonary disease, while acute exposures during high-energy eruptions can result in thermal injuries, chemical burns, and inhalation trauma. Moreover, the toxic components of volcanic emissions have been implicated in systemic effects, including cardiovascular stress, gastrointestinal disturbances, and potential genetic damage, particularly in vulnerable populations with limited access to medical resources. The review emphasizes that the severity of health impacts is determined by a complex interplay between eruption dynamics, chemical composition of the emissions, and local environmental and socioeconomic factors. Ultimately, the findings underscore the need for comprehensive, volcano-specific risk assessments and the development of tailored emergency response strategies that integrate both short-term interventions and long-term public health planning. Such measures are essential to mitigate health risks, enhance community resilience, and guide policy decisions in regions frequently affected by volcanic activity.

Keywords: *Active Volcanoes, Exposure, Explosivity Index, Impacts, Public Health.*

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I. INTRODUCTION

Volcanic eruptions are among one of the most devastating natural phenomena, posing multiple serious threats to human health, ecosystem and infrastructure. Not only are such events devastating, the volcanic gas, ash, and other particulate matter injected into the atmosphere pose many health risks. Exposure to volcanic hazards can lead to a variety of health problems, but respiratory disorders are among the most common public health issues they may cause. Toxic particles like fine volcanic ash, containing silica and sulfur dioxide, can enter deep into the lungs and lead to

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diseases, including asthma, chronic bronchitis and other chronic pulmonary diseases [6]. Respiratory effects of volcanic eruptions have been extensively studied, especially in regions prone to volcanic activity [4]. Studies indicate that volcanic ash and gas exposure predispose individuals to increased risk of acute and chronic respiratory symptoms such as cough, wheeze, and exacerbation of chronic obstructive pulmonary disease (COPD) [5]. Add the ashfall that can compromise indoor air quality, a growing health risk, especially for vulnerable people such as children, the elderly and those with comorbidity. The physical problems are not limited to our lungs but also include skin irritations and irritation of the eyes from direct exposure to the ash and acid rains. Exposure to the harmful effects of volcanic pollutants for some time may cause systemic effects such as headaches and fatigue, suggesting that the toxicological consequences of inhaling small particles and gas are an explanation. These health challenges are compounded in resource-limited settings with limited access to healthcare and protective measures where effective risk communication and disaster(readiness) preparedness is key to public health response. These physical health effects are compounded by indirect effects from disruptions to critical services like contaminated water and decreased food security, which, in turn, cause secondary health problems. Volcanic ash often contaminates water supplies in ways that endanger people with gastrointestinal illnesses, adding even more strain on already overburdened healthcare systems. Additionally, chronic exposure to volcanic pollutants has been previously shown to increase cardiovascular risks, which prompts the importance of comprehensive approaches for assessing and mitigating health effects [3]. This paper intends to give a thorough investigation into how volcanic eruptions affect health, especially in terms of respiratory and general physical symptoms. By synthesizing the findings of the most pertinent studies, this work attempts to better understand these health risks, information that is critical for the protection of vulnerable populations and improving resilience to future eruptions.

II. METHODOLOGY

The research design of this research used a systematic review methodology. Publications discussing the health risks of volcanic hazards to specific organ systems were chosen using the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA System) as a framework.

➢ *Data Sources*

All published and scientific publications related to the aforementioned studies were meticulously selected and reviewed from two widely used search databases—Google Scholar, and ScienceDirect/Elsevier—following the PRISMA guidelines for performing this study.

➢ *Literature Search*

The aforementioned databases' search engines employed phrases and words to help choose a suitable and successful search approach. To find relevant references, a variety of keyword sets were employed and searched in online databases. Volcanic health risk-related terms including "Volcanic eruptions", "Health effects", "Health impact", "Volcanic Hazards," and "Asia" were included in the first batch of keywords. Terms pertaining to human exposure, such as "Volcanic exposure incidents" and "Volcanic exposure accidents," were utilized in the second group of keywords.

➢ *Inclusion and Eclusion Criteria*

The following criteria were used to categorize all relevant articles included in this review: (1) studies that mention the affected organ system; (2) studies that mention the health impacts of volcanic eruptions; (3) studies that mention the associated volcanic hazards; 4) studies that focus on human exposure to volcanic emissions (5) studies that mention the dosage of *Cordyceps sinensis* being used in the experiment; (7) original studies published as research articles or review articles; (7) original studies published in English or with an English translation; and (9) studies conducted in regions within Asia affected by volcanic eruptions.

Exclusion criteria for studies include if they are (1) case series, case reports, systematic reviews, or narrative reviews without new data; (2) studies that do not focus on human health impacts or exposure; (3) lack of related research data or outcome factors; (4) without full-text availability; or (5) not published in English or without an English translation.

➢ *Search Results*

Using combinations of keywords to search from the two research directories (26 from Elsevier and 35 from Google Scholar), 51 studies related to the related to the described study were first found. 36 studies were omitted from the initial findings because they only covered review and research articles written in English-language and had to be published between 2015 and 2025. After removing the duplicate studies, 17 review and research papers remained, and they are subjected to a final screening process based on the inclusion criteria. After additional screening and evaluation of the research and review papers' eligibility based on the titles, abstracts, and availability of research data, 10 studies were eventually included in the mixed-method analysis. The PRISMA flow diagram (see Fig. 1) displays the selection and outcome stages.

➢ *Data Extraction*

A comprehensive summary of the health impacts of volcanic eruptions and their associated hazards is presented in this review. The collected literature was evaluated, and pertinent information relevant to the review objectives was systematically recorded. The following information was extracted from each article for quantitative analysis: author and year of publication, affected organ system(s), target disease or health impact, effect(s) on the body, associated volcanic hazard, study type, and key findings.

➢ *Data Analysis*

The selected literature was evaluated for eligibility using qualitative and quantitative criteria. The studies were evaluated for their relevance to volcanic health risks, and quantitative results were extracted for analysis. The data gathered was used to identify patterns, severity, and trends in organ system-specific health effects of volcanic eruptions.

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III. RESULTS AND DISCUSSION

➢ *Overview of Volcanic Eruption Characteristics and Distribution in Asia*

Sakurajima, Mt. Miyakejima, and Mt. Asama in Japan offer compelling examples of how regional eruptive styles and underlying magma compositions influence both eruption dynamics and potential health impacts. Sakurajima, with its relatively low Volcanic Explosivity Index (VEI 2), is characterized as an explosive stratovolcano that, despite its lower explosivity, can intermittently release ash and gas, affecting local air quality and posing respiratory risks to nearby communities [18]. In contrast, Mt. Miyakejima, with a slightly higher VEI of 3 and an explosive basalt-andesite composition, not only increases the potential for more voluminous ash emissions but also introduces chemical constituents that can exacerbate ocular and respiratory irritations among exposed populations [17]. Mt. Asama, although registering a VEI of 2 and classified as a composite volcano with Vulcanian activity, has been observed to trigger acute respiratory responses, especially among individuals with pre-existing conditions, its moderate eruption style underscores the need for vigilant local monitoring despite its comparatively lower explosive output [11]. In Indonesia, a diverse group of volcanoes including Mt. Agung, Mt. Sinabung, Mt. Merapi, and Mt. Marapi demonstrates the wide-ranging hazards associated with explosive activity in volcanic regions. Mt. Agung, an explosive stratovolcano with a VEI of 3, has produced significant ash plumes and pyroclastic flows during its 2019 eruption, leading to widespread respiratory, integumentary, and ocular health concerns among the affected populations [16]. Similarly, Mt. Sinabung, with its Vulcanian to Plinian eruption style and a VEI of 3, is known for its intermittent yet vigorous eruptions that result in acute ash inhalation episodes and related respiratory complications [15]. Mt. Merapi, noted for its VEI of 4, exhibits more explosive behavior that significantly increases the volume of volcanic ash released, thereby heightening the risks of respiratory irritation and other health impacts [2]. In contrasting scenario, Mt. Marapi, despite a VEI of only 2, has been linked to severe localized effects such as extensive thermal injuries and inhalation trauma from ash exposure, illustrating that even lower VEI events can have disproportionately high health risks under certain conditions [12]. The volcanic systems in the Philippines, represented by Taal and Mt. Mayon, further underscore the intricate link between eruption style and public health outcomes. Taal volcano, with a high VEI of 4 and a phreatomagmatic eruption style, produces a potent mix of fine particulate matter (PM10 and PM2.5) and sulfur dioxide that has been associated with both acute and chronic respiratory and cardiovascular conditions among nearby residents. This combination of explosive energy and phreatomagmatic activity renders Taal one of the highest risk volcanoes in the region, necessitating strict air quality and emergency response protocols (Leung et al., 2020). Meanwhile, Mt. Mayon, also with a VEI of 4 but exhibiting a Strombolian eruption style, primarily produces episodic ash emissions that can trigger bronchitis, asthma, and other respiratory ailments. Although its eruptive style tends to be more rhythmic, the recurrent exposure to ash underscores a persistent medium-to-high risk profile for affected communities [10]. In Russia, Mt. Shiveluch stands as a striking example of extreme volcanic activity, recording the highest VEI of 5 among the discussed volcanoes. As an explosive stratovolcano, its eruptions are not only voluminous but also release a complex mixture of tephra, gases, and potentially toxic chemical elements that can have far-reaching impacts on public health. The intensity of Mt. Shiveluch's eruptions makes it a high-risk system, with the potential to affect respiratory, gastrointestinal, and reproductive systems over large geographic areas and extended time periods. This severity emphasizes the importance of integrating advanced monitoring techniques and robust emergency preparedness plans into regional disaster management strategies. Overall, the diverse characteristics and eruption styles of these volcanoes across Asia—from the relatively moderate, yet still hazardous, activity of Japan's Sakurajima, Mt. Miyakejima, and Mt. Asama to the more explosive and health-threatening eruptions of Indonesia's Mt. Agung, Mt. Sinabung, Mt. Merapi, and Mt. Marapi, as well as the high-risk dynamics of the Philippines' Taal and Mt. Mayon and Russia's formidable Mt. Shiveluch—highlight the critical need for tailored volcano-specific risk assessments and public health interventions [19].

Table 1 Volcanoes and their Eruption Characteristics

Volcano	Location	Last Major Eruption	Volcanic Explosivity Index (VEI)	Type of Eruption	Type of Volcano	Author/s
Sakurajima	Japan	2017	2	Explosive	Stratovolcano	Venzke, E. 2025
Mt. Miyakejima	Japan	2000	3	Explosive	Basalt-andesite stratovolcano	Venzke, E. 20205
Mt. Agung	Indonesia	2019	3	Explosive	Stratovolcano	Venzke, E. 2025
Mt. Sinabung	Indonesia	2016	3	Vulcanian	Stratovolcano	Syapitri et al., 2020
Taal	Philippines	2020	4	Phreatomagmatic	Stratovolcano	Leung et al., 2020
Mt. Shiveluch	Russia	2023	5	Explosive	Stratovolcano	Joint Institute for Nuclear Research, 2024
Mt. Merapi	Indonesia	2010	4	Explosive	Stratovolcano	Baxter et al., 2017
Mt. Mayon	Philippines	2018	4	Strombolian	Stratovolcano	Martinez-Villegas et al., 2021
Mt. Asama	Japan	2004	2	Vulcanian	Composite	Mueller et al., 2020

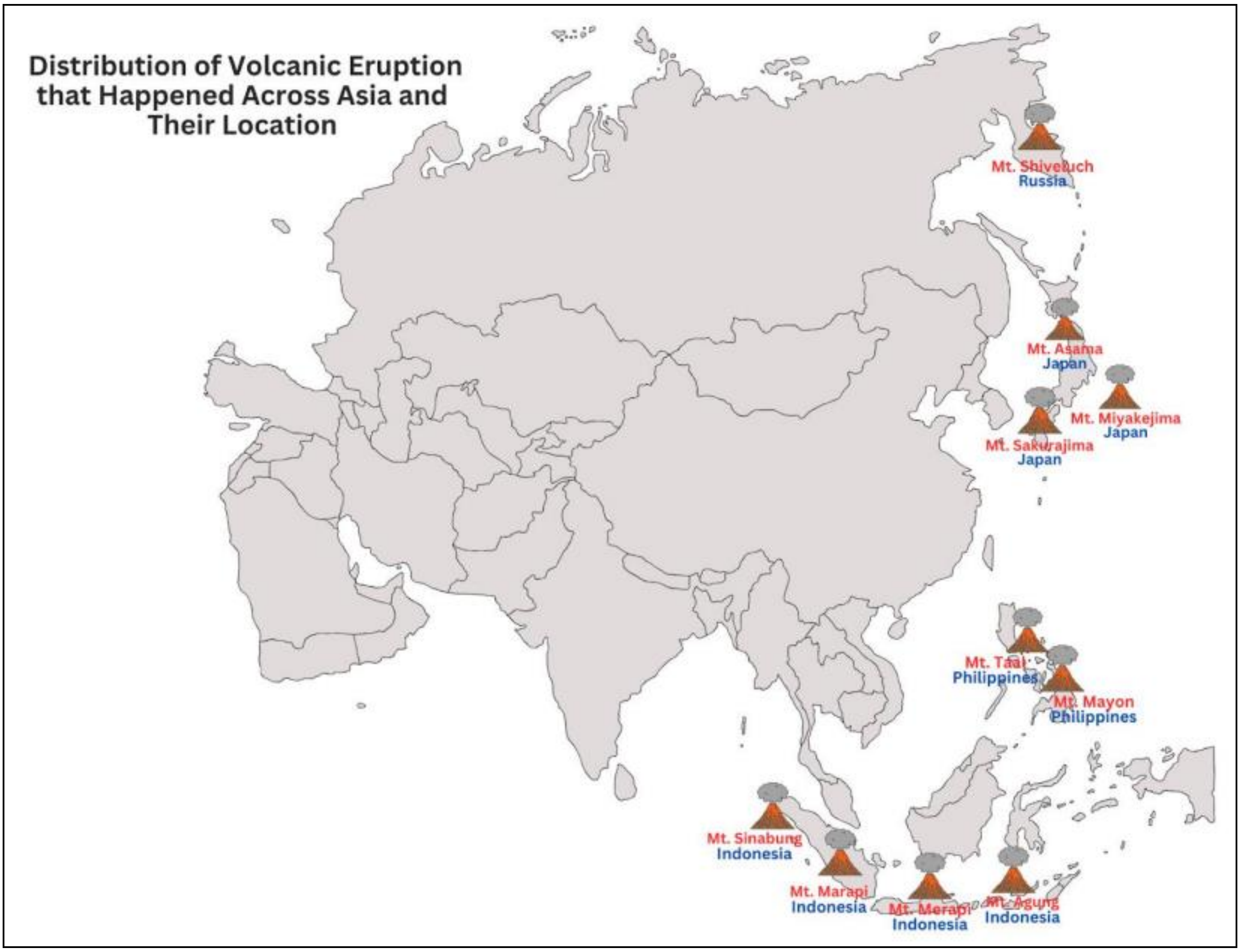

Fig 1 Distribution of Volcanic Eruption Across Asia

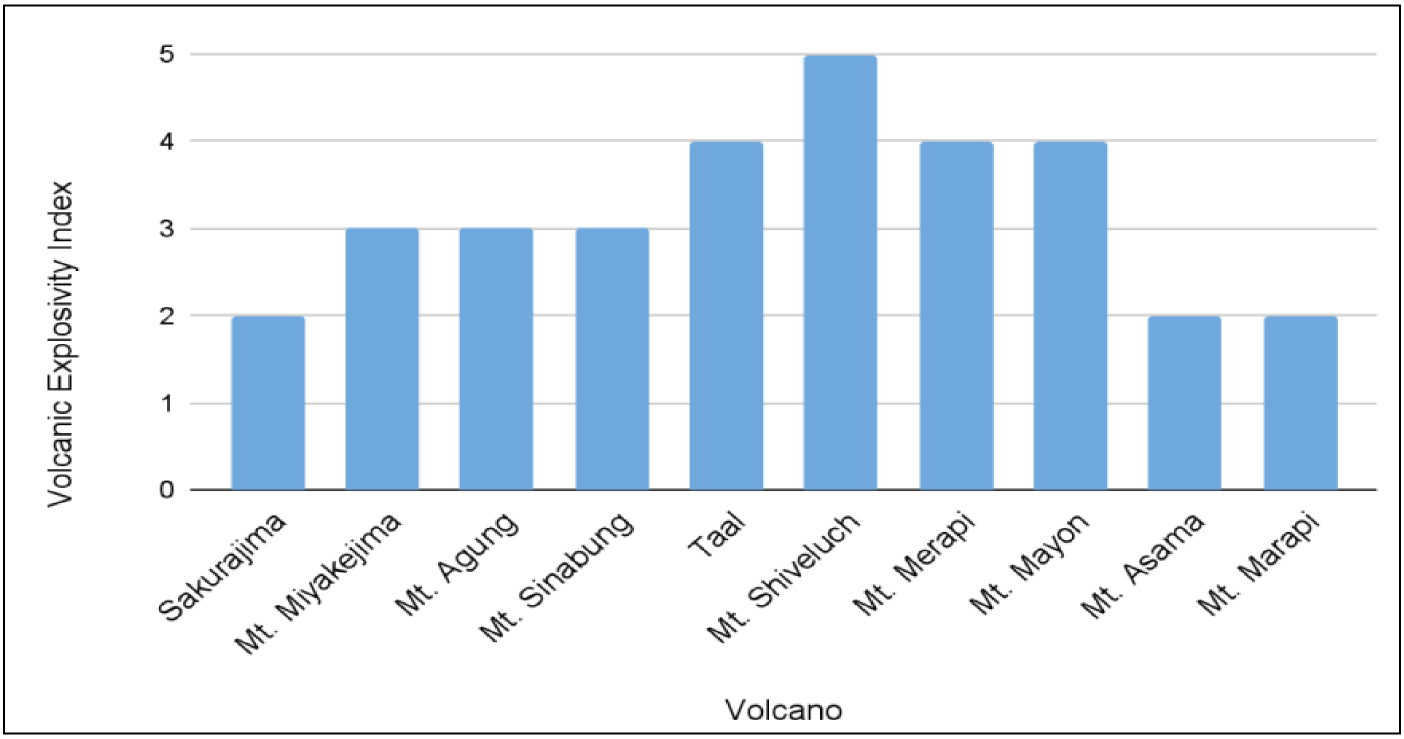

Fig 2 Comparison of Volcanic Explosivity Index for Selected Volcanoes

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➢ *Integrated Overview of Organ-Specific Health Impacts and Volcanic Hazard Risk Assessments*

Health hazards from volcanic eruptions are substantial and can impact many different organ systems, depending on the hazard involved. One is Sakurajima, one of the most active volcanoes in Japan, which releases fine volcanic ash that affects the respiratory system and contributes to conditions like asthma, bronchitis and lung cancer. Long-term exposure to these particles increases the risks of respiratory diseases, particularly among susceptible groups [11]. The same goes for Mt. Miyakejima, a sulfur dioxide spewer that carries major respiratory risks. Long-term exposure to the gas could induce and worsen chronic bronchitis-like symptoms and asthma, highlighting the importance of proper air quality management in volcanically active areas [8]. Mt. Agung eruptions affect respiratory, integumentary, and ophthalmic systems, requiring multi-organ system management. Acute respiratory tract infections, skin irritation and eye damage have all been linked to explosive eruptions, pyroclastic flows and lahars. Health effects were reported in various communities due to the eruption in 2017, highlighting the need for disaster preparedness and health response plans [1]. Like Mt. Sinabung, its regular ash ejections pose serious respiratory hazards. Novo and contemporary acute respiratory tract infections have been observed in nearby populations because of inhalation of the ash, evidence that it might be a threat for the communities nearby the active volcanoes for its protection [15]. The 2020 eruption of Taal Volcano showed the detrimental effects of ashfall, especially fine particulate matter (PM10 and PM2. 5). Those airborne particles irritated the eyes, skin and lungs, making it difficult for those who were exposed to breathing [9]. Unique challenges arise from these factors for Mt. Shiveluch, leading to atypical quirks involving the integumentary and reproductive systems. This volcano's ashfall and volcanic gases have been associated with skin damage, reproductive disorders, and genetic damage, indicating long-term effects that go beyond immediate respiratory problems [19]. Mt. Merapi and Mt. Mayon are both volcanoes with considerable respiratory effects from ash eruptions. Characteristics of volcanic ash include cough, wheezing, and shortness of breath after exposed to volcanic ash [2] from Mt. Merapi. Likewise, exposure to volcanic ash from Mt. Mayon also increases the prevalence of pneumonia, asthma, cardiovascular stress, and dermatitis [10]. The cases highlight the need for respiratory protection and public health measures during eruptions. Finally, ash emissions from Mt. Asama are likely to result in respiratory problems, especially asthma.

Table 2 Organ System-Specific Health Risk and Their Association with Volcanic Hazards

Volcano	**Affected Organ System**	**Health Impacts**	**Associated Volcanic Hazards**	**Author/s**
Sakurajima	Respiratory System	Asthma, bronchitis, lung cancer	Ash	Mueller et al., 2020
Mt. Miyakejima	Respiratory System	chronic bronchitis-like symptoms, asthma	Sulfur Dioxide	Kochi et al., 2017
Mt. Agung	Respiratory, Integumentary, and Ophthalmic Systems	Acute respiratory tract infection, skin and eye irritations	Explosive eruption, pyroclastic flows, lahars, slow-moving lava flows	Adventist Development and Relief Agency Indonesia, 2017
Mt. Sinabung	Respiratory System	Acute respiratory tract infection	Volcanic ash	Syapitri et al., 2020
Taal	Respiratory, Integumentary, and Ophthalmic Systems	Irritation to the eyes, skin, nose, and lungs	Volcanic ash (PM10 & PM2.5)	Leung et al., 2020
Mt. Shiveluch	Integumentary and Reproductive systems	Skin damage, reproductive system disorders, and genetic damage	Ashfall, volcanic gases	Joint Institute for Nuclear Research, 2024
Mt. Merapi	Respiratory System	Acute Laryngeal Edema, Tracheobronchial Thermal Injury, Acute Respiratory Distress Syndrome (ARDS), and Severe Burns	Pyroclastic Flow and Ashfall	Baxter et al., 2017
Mt. Mayon	Respiratory, Integumentary, and Cardiovascular Systems	Irritation of the respiratory tract, Pneumonia, Asthma, Dermatitis, and Cardiovascular Stress	Volcanic Ash, Sulfur Dioxide, and Hydrogen Sulfide	Martinez-Villegas et al., 2021
Mt. Asama	Respiratory	Asthma	Volcanic Ash	Mueller et al., 2020
Mt. Marapi	Respiratory and Integumentary System	Skin burns, skin necrosis, inhalation trauma, sepsis, multiple organ failures, deep tissue damage, metabolic changes	Volcanic ash, tephra	Saputra, D. et al., 2024

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Table 3 Heatmap of Organ-Specific Health Risks

Volcano	Organ System					
	Respiratory	Integumentary	Ophthalmic	Reproductive	Cardiovascular	Gastrointestinal
Sakurajima	Yellow	Black	Black	Black	Black	Black
Mt. Miyakejima	Red	Black	Black	Black	Black	Black
Mt. Agung	Red	Red	Red	Black	Black	Black
Mt. Sinabung	Red	Black	Black	Black	Black	Black
Taal	Red	Orange	Orange	Black	Red	Black
Mt. Shiveluch	Yellow	Yellow	Black	Orange	Black	Red
Mt. Merapi	Red	Black	Black	Black	Black	Black
Mt. Mayon	Red	Black	Black	Black	Black	Black
Mt. Asama	Red	Black	Black	Black	Black	Black
Mt. Marapi	Red	Red	Black	Black	Black	Black

*High (Red), Medium (Orange), Low (Yellow), None (Black)

➢ *Comprehensive Synthesis of Volcanic Hazard Risks and Health Impacts*

The severity of health consequences varies depending on the nature of the eruptions, ash composition, and proximity of human populations. Each volcano presents unique health hazards, ranging from respiratory illnesses to severe thermal injuries. Based on the findings, each volcano is classified into a low, medium, or high-risk category. Several volcanoes in the study pose high health risks due to their frequent activity, high concentrations of hazardous volcanic emissions, and the severe medical conditions observed among affected populations. Sakurajima in Japan, for instance, has been associated with long-term respiratory effects, including an increased mortality rate among populations exposed to chronic volcanic emissions [11]. This prolonged exposure to fine particulate matter (PM2.5, PM10) and sulfur dioxide (SO_2) can lead to conditions such as chronic obstructive pulmonary disease (COPD) and cardiovascular complications. Similarly, Mt. Agung in Indonesia caused acute respiratory and skin conditions due to the inhalation of volcanic gases and ash, particularly during its 2017 eruption [1]. The presence of SO_2 and other toxic gases heightened the risks for asthma, bronchitis, and eye irritation. Another high-risk case is Mt. Sinabung, which caused mucous membrane irritation, respiratory distress, and persistent coughing among exposed populations [15]. The fine ash particles led to upper respiratory tract inflammation, affecting not only those with pre-existing conditions but also healthy individuals. Additionally, Mt. Merapi in Indonesia and Mt. Marapi in Sumatra pose severe health threats due to their high-energy eruptions, which cause widespread burns, respiratory damage, and fatal injuries. Victims of Mt. Merapi's eruptions suffered from inhalation trauma, lung injuries, and full-thickness burns, with fatalities linked to extensive burn coverage and exposure to extreme heat [2]. Similarly, a reported case from Mt. Marapi involved a victim suffering from burns covering over 40% of their body, leading to metabolic complications and multiple organ failure (Saputra et al., 2024). These volcanoes exhibit explosive eruptions and pyroclastic flows, making them among the most dangerous in the study. While not as extreme as the previously mentioned cases, several volcanoes still pose moderate health risks due to their episodic emissions of harmful gases and ash. Mt. Miyakejima, for example, has shown a correlation between volcanic emissions and respiratory illnesses, such as asthma exacerbation, bronchitis, and other irritation-related conditions [8]. Although these effects are generally short-term and reversible with treatment, repeated exposure can worsen underlying health conditions. Similarly, Taal Volcano in the Philippines was found to have caused both acute and chronic respiratory problems, as well as cardiovascular issues and skin irritation due to its release of high concentrations of PM2.5, PM10, and SO_2 [9]. While Taal's eruptions are less frequent than high-risk volcanoes like Mt. Merapi, its hazardous emissions have long-lasting effects on nearby communities. Mt. Mayon, another Philippine volcano, has been associated with respiratory issues, skin irritation, and eye discomfort caused by ashfall exposure [10]. Common treatments such as bronchodilators, corticosteroids, and saline eye washes help alleviate symptoms, but prolonged exposure remains a concern. Lastly, Mt. Asama in Japan was found to worsen symptoms in 43% of asthma patients, with SO_2 and fine ash contributing to increased respiratory distress [11]. However, the effects were less severe in individuals without pre-existing conditions, making it a medium-risk volcano. Mt. Shiveluch in Russia is classified as a low-risk volcano, primarily due to its indirect health effects. Unlike high-risk volcanoes, which cause immediate respiratory or thermal injuries, Mt. Shiveluch's impact stems from long-term exposure to toxic metals in volcanic ash, such as chromium, arsenic, and antimony [19]. These metals pose a significant risk to children, as they are more likely to ingest contaminated materials, leading to potential oncological diseases, reproductive disorders, and chromosomal damage. While these health threats are serious, they do not cause the immediate, life-threatening conditions seen in high-risk volcanoes. Instead, they represent a long-term environmental and public health concern, making Mt. Shiveluch a low-to-medium risk depending on exposure levels. These findings emphasize the importance of health preparedness, protective measures, and environmental monitoring for populations living near active volcanoes. For high-risk areas, evacuation plans, respiratory protection, and emergency medical care are crucial to minimizing fatalities. Meanwhile, for long-term hazards like Mt. Shiveluch, public health interventions should focus on mitigating heavy metal exposure and promoting environmental clean-up efforts.

IV. CONCLUSION

The approach of volcanic hazards in Asia shows diverse health impacts, varying with eruption dynamics, volcanic explosivity index, and type of emitted material. Mt. Agung, Taal, Mt. Shiveluch, Mt. Miyakejima, and Mt. Marapi are among more than 130 high-risk volcanoes, known for their explosive eruption and release of ash, gases, and toxic particulates that can threaten public safety. These pollutants lead to significant health risks such as respiratory, ocular, integumentary and systemic effects, highlighting the pressing need for advanced monitoring systems and integrated emergency response plans. Medium-risk volcanoes such as Mt. Sinabung, Mt. Merapi, Mt. Mayon, Sakurajima, and Mt. Asama tend to produce mainly short-term health effects, such as respiratory irritation and asthma exacerbations. Over decades and centuries, they still need to be closely monitored and necessarily planned and faced public health intervention, and community preparedness in order to minimize health impact from eruptions.

This emphasizes the need to conduct volcano-specific risk assessments and develop site-specific disaster-management plans. These measures contribute to strengthening public awareness, improving healthcare responses, and incorporating research findings into mitigation strategies towards reducing the health impacts of volcanic activity and building resilience in vulnerable populations.

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APPENDICES

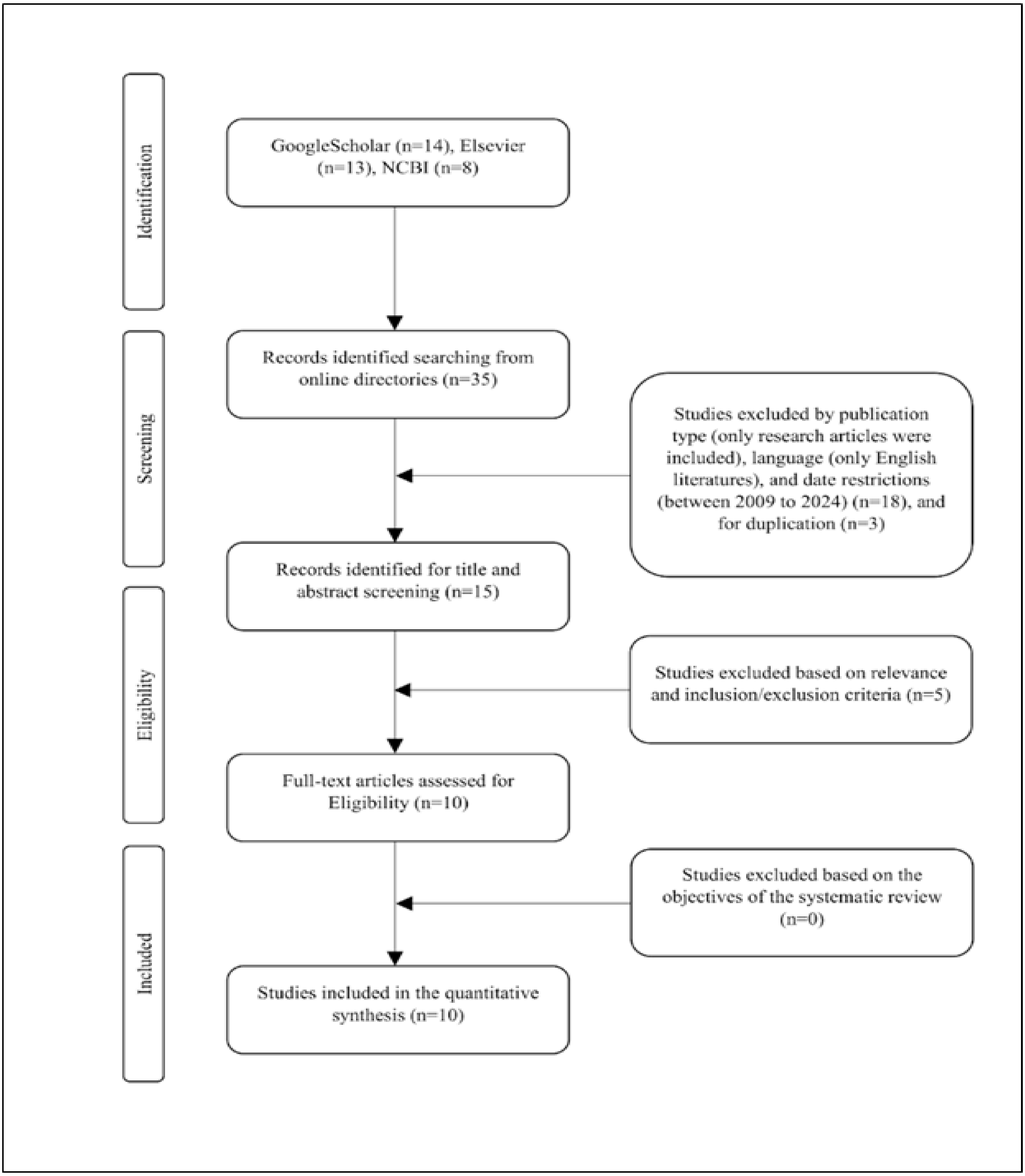

Fig 3 PRISMA Study Selection Stages Flow Diagram for Related Studies