Review

Respiratory Disorders Due to Volcanic Ash Exposure from Volcanic Eruptions: Short-Term and Long Term Risks: A Literature Review

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ABSTRACT

Volcanic eruptions release respirable ash containing crystalline silica, heavy metals, and adsorbed gases, posing both acute and chronic respiratory hazards to exposed populations. This literature review aimed to synthesise evidence on the short-term and long-term respiratory health effects of volcanic ash exposure and to evaluate mitigation strategies, including respiratory protection and interdisciplinary preparedness. A literature review was conducted following PRISMA-informed reporting. PubMed, Google Scholar, and Scopus were searched for publications between 2018 and 2025 using terms related to volcanic ash, respiratory disorders, lung disease, and mitigation. Fifteen studies met the eligibility criteria and were synthesised narratively. Acute effects consistently reported across studies included cough, wheeze, dyspnoea, and exacerbation of pre-existing asthma and bronchitis, with symptom reporting reaching 68.4% of exposed children and the highest rates in Indonesian cohorts (95.1%). Exposure–response gradients were documented, with residents near the Tajogaite eruption twice as likely to report respiratory symptoms as those with minimal exposure. Long-term concerns included COPD, chronic bronchitis, and silicosis, although documented silicosis attributable to volcanic ash remains absent. Physicochemical analyses identified crystalline silica content, sub-10 μm particle size, high surface reactivity, and heavy metal leaching (As, Cd, Ni) as determinants of toxicity, and murine and in vitro models demonstrated silica-driven IL-33-mediated airway inflammation. Psychiatric sequelae including anxiety, depression, and insomnia were reported in evacuees. Respiratory protection use was high (93%) in one Indonesian community, but only 9% received guidance on correct use. Volcanic ash exposure is associated with acute respiratory morbidity and plausible long-term risk, with vulnerable groups disproportionately affected. Evidence for

chronic disease remains limited by exposure heterogeneity and the predominance of short follow-up. Standardised respiratory protection guidance, exposure surveillance, and longitudinal cohort studies are required.

Keyword : Lung diseases; mitigation; public health; respiratory disorders; volcanic ash

Introduction

Volcanic eruptions are geological phenomena that affect not only the environment but also human health, particularly the respiratory system. A primary health concern is exposure to volcanic ash, which comprises fine respirable particles including crystalline silica, heavy metals such as arsenic, nickel, and cadmium, and adsorbed toxic gases.[1] These particles are sufficiently small to penetrate deep into the respiratory tract, and their high surface reactivity permits sustained generation of reactive oxygen species within the lung.[2]

Immediate health effects include acute respiratory symptoms such as cough, wheeze, and dyspnoea, which are of particular concern in vulnerable groups including children and individuals with pre-existing respiratory disease.[3],[4] Acute inflammatory responses, together with high rates of ocular and skin irritation, further compound the health burden during eruptions.[4] Long-term exposure to volcanic ash has been associated with chronic respiratory disease, including chronic obstructive pulmonary disease (COPD) and silicosis, and may increase susceptibility to respiratory infection.[3],[5] The psychological impact of eruptions, including elevated rates of anxiety, depression, and insomnia among evacuees, indicates that the health consequences extend beyond pulmonary pathology.[6]

The complexity of volcanic eruptions necessitates an interdisciplinary approach to disaster management that integrates medical, ecological, and political responses.[6],[7] Governments and international organisations have a central role in establishing clear safety protocols, strengthening early warning systems, and ensuring the availability of protective measures such as respiratory masks. Public education campaigns are also essential to minimise health impacts and strengthen community resilience.[7]

The chemical composition of volcanic ash is a further determinant of risk. Heavy metals and crystalline silica can provoke chronic inflammatory responses and bioaccumulate in vital organs, with potential for systemic disorders beyond the respiratory tract.[8] Radionuclides present in some ash deposits may additionally induce inflammation and oxidative stress in the lung even after short-term exposure, adding a further dimension to the hazard profile.[9] Given the recurring nature of volcanic hazards in Indonesia and the region, this review aimed to analyse the respiratory health impacts of volcanic ash exposure and to assess the effectiveness of interdisciplinary approaches in mitigating these risks.

Material and Methods

This study employed a literature review design. Reporting was structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework to ensure transparency of study identification and selection. PubMed, Google Scholar, and Scopus were searched for English-language publications. Search terms combined the following concepts using Boolean operators: ("volcanic ash" OR "volcanic eruption" OR "tephra") AND ("respiratory" OR "lung" OR "pulmonary" OR "respiratory disorder") AND ("mitigation" OR "public health" OR "respiratory protection"). Reference lists of included studies were hand-searched to identify additional relevant sources. Inclusion criteria: (1) original research, including cohort, survey, experimental, in vitro, and analytical studies; (2) publication between 2018 and 2025; (3) human participants, animal models, or physicochemical analysis with direct relevance to human respiratory health; (4) volcanic ash or volcanic emissions as the primary exposure; (5) report of respiratory outcomes, exposure characterisation, or mitigation effectiveness. Exclusion criteria: (1) reviews, editorials, and conference abstracts; (2) studies restricted to technical or geochemical aspects without a stated health relevance; (3) studies of non-volcanic particulate exposure; (4) studies without extractable data relevant to the review questions.

Results

Fifteen studies met the eligibility criteria and were included in the synthesis (Table 1). Designs comprised ambispective cohort and quasi-experimental studies of the ASHES and ISVOLCAN cohorts (n=4), a comparative survey of caregivers (n=1), a rapid questionnaire survey with agency interviews (n=1), experimental murine and in vitro models (n=2), atmospheric dispersion modelling with health risk assessment (n=1), and physicochemical characterisation studies with or without bioreactivity assessment (n=6). Studies were conducted in Spain (La Palma, Canary Islands) (n=6), Italy (Etna, Somma-Vesuvius) (n=2), Indonesia (n=1), Japan and Mexico as part of a multi-country study (n=1), Russia (Kamchatka) (n=1), and the United Kingdom (n=1).

Table 1. Characteristics and principal findings of included studies

No	Author (Year)	Design	Setting / Population	Principal findings
1	Barone et al. (2021)[1]	Analytical (ICP-OES, ICP-MS, ion chromatography)	Etna volcanic ash	Leaching released As, Cd, and Ni above legal limits; low BET surface area indicated limited environmental reactivity
2	Tomašek et al. (2025)[2]	Analytical with bioreactivity assessment	Sub-10 μm volcanic ash versus desert dust	Volcanic ash showed higher oxidative potential than desert dust due to iron content; pro-inflammatory cytokine release in lung cells; low cytotoxicity across samples
3	Ruano-Ravina et al. (2022)[3]	Ambispective cohort with quasi-experimental before–after design	General population, highly exposed individuals, and those with pre-existing respiratory disease; La Palma	Acute cough, wheeze, and dyspnoea in exposed groups, particularly children and those with pre-existing conditions; increased emergency visits anticipated
4	Covey et al. (2021)[4]	Comparative survey	411 caregivers and 657 children; Indonesia, Japan, Mexico	68.4% of children had ash-related symptoms; highest reporting in Indonesia (95.1%); eye irritation 47.9%, cough 46.5%
5	Candal-Pedreira et al. (2024)[5]	Ambispective cohort (ASHES first follow-up)	474 adults; La Palma	Significant increase in respiratory symptoms with higher exposure; women in the moderate-exposure group reported more symptoms; obstructive changes on spirometry did not reach statistical significance
6	Rodríguez-Pérez et al.	Prospective cohort (ISVOLCAN)	First 1,002 participants;	High rates of ocular irritation and upper respiratory symptoms

	(2024)[6]		La Palma	during eruption; higher long-term prevalence of anxiety, depression, and insomnia; higher odds of adverse outcomes among western residents
7	Ruano-Ravina et al. (2023)[7]	Ambispective cohort with pre–post quasi-experimental design (protocol)	Adults 18–70 years and children 6–17 years; La Palma	Protocol for five-year follow-up; exposure stratified by proximity and air quality metrics; outcomes include respiratory health, quality of life, and mental health
8	Sauzéat et al. (2022)[8]	Experimental (C57BL/6 mice)	Recent volcanic ash deposits	Acute pulmonary inflammation; long-term metallome deregulation with heavy metal accumulation in liver and testis, and isotopic divergence in copper and zinc
9	Zinicovscaia et al. (2024)[9]	Analytical (ICP-MS, gamma spectrometry)	Shiveluch ash, Kamchatka	Silica content 59%; As, Cr, and Sb posed potential long-term concerns including carcinogenicity; radiation levels low with K-40 the most abundant radionuclide
10	Fernandez et al. (2023)[10]	Analytical with surface reactivity assessment	Pomici di Avellino ash, Somma-Vesuvius	Mean particle diameter 6.33 μm; high surface area (7.4–14.9 m^2/g); sustained hydroxyl radical production and higher iron release over time; potential for silicosis where cristobalite content is high
11	Tomašek et al. (2018)[11]	In vitro multicellular human lung model at air–liquid interface	Volcanic ash with and without gasoline exhaust	Acute pro-inflammatory cytokine elevation and oxidative stress markers; potential for chronic structural change with prolonged exposure
12	Horwell et al. (2019)[12]	Rapid questionnaire survey with agency and NGO interviews	125 respondents; Yogyakarta,	93% used respiratory protection, predominantly disposable surgical masks (65%); only 9%

			Kelud 2014 eruption	received guidance on correct use; 42% doubted full protection
13	Heaviside et al. (2021)[13]	Atmospheric dispersion modelling with health risk assessment	Hypothetical five-month Icelandic effusive eruption affecting the UK	Median 772 excess deaths (worst case 3,350); 1,354 respiratory and 896 cardiovascular hospitalisations projected; six-fold rise in emergency respiratory visits documented after the Kilauea eruption
14	Unno et al. (2020)[14]	Experimental (murine)	Silica crystal exposure	IL-33 critical for silica-induced allergic airway eosinophilia via innate lymphoid cells and IL-5/IL-13; IL-25 and TSLP played lesser roles
15	Ruggieri et al. (2023)[15]	Analytical with leaching tests	Tajogaite 2021 ash and water, La Palma	Fluoride levels exceeded the safe limit for children; As and Ba presented lower risk; chronic bronchitis associated with long-term exposure in adults and children

All human studies reporting acute outcomes documented increased respiratory symptoms following ash exposure. Acute cough, wheeze, and dyspnoea were consistently reported among exposed populations, with exacerbation of pre-existing asthma and bronchitis.[3],[5] In the ASHES cohort, individuals living near the Tajogaite eruption were twice as likely to develop respiratory symptoms as those with minimal exposure, and symptom severity was dose-dependent.[5] Among children, 68.4% of caregivers reported ash-related symptoms, with the highest rate in the Indonesian cohort (95.1%) and the most common complaints being eye irritation (47.9%) and cough (46.5%).[4] Modelling of a hypothetical Icelandic eruption projected 1,354 respiratory hospitalisations over a five-month period, with a documented six-fold rise in emergency respiratory visits after the Kilauea eruption.[13]

Evidence for chronic respiratory disease was consistent in direction but more limited in strength. COPD and silicosis were identified as principal long-term concerns for populations with prolonged exposure,[10] and chronic bronchitis was associated with long-term exposure in both adults and children.[15] However, no case of silicosis attributable to volcanic ash has been documented to date, despite plausible risk in areas with high cristobalite

content.[10] In the ASHES follow-up, spirometric evidence of obstructive impairment did not reach statistical significance despite a significant symptom increase, which the authors attributed to the short follow-up interval and the need for longer observation.[5]

Experimental evidence supports biological plausibility for chronic effects. Murine exposure produced acute pulmonary inflammation followed by long-term metallome deregulation and heavy metal accumulation in the liver and testis.[8] Silica crystal exposure induced IL-33-mediated allergic airway eosinophilia through innate lymphoid cell activation and IL-5/IL-13 production, providing a mechanistic pathway by which ash-borne silica may exacerbate asthma.[14] In vitro exposure to ash combined with gasoline exhaust produced acute pro-inflammatory cytokine elevation and oxidative stress, with potential for structural change in lung tissue under chronic exposure.[11]

Vulnerable groups were consistently identified as experiencing disproportionate burden. Children showed higher symptom reporting and greater susceptibility to exacerbation of pre-existing conditions,[3],[4] and caregivers with children who had pre-existing respiratory disease were significantly more likely to report worsening symptoms.[4] Individuals with occupational exposure and those with pre-existing respiratory disease were identified as requiring targeted health strategies.[5]

Physicochemical analyses identified several determinants of ash toxicity. Particle size was consistently identified as critical: mean diameters of approximately 6.33 μm permit deep lung penetration,[10] and sub-10 μm fractions exhibit the greatest bioreactivity.[2] Surface reactivity and iron content drove hydroxyl radical production, with volcanic ash showing higher oxidative potential than desert dust.[2],[10] Leaching studies identified arsenic, cadmium, and nickel at concentrations above legal limits,[1] and fluoride in ash-contaminated water exceeded the safe limit for children.[15] Silica content reached 59% in Shiveluch ash,[9] and radionuclide levels were low, with K-40 the most abundant.[9]

Evidence on mitigation was limited but identified a clear gap between protection use and correct use. In Yogyakarta during the 2014 Kelud eruption, 93% of respondents used respiratory protection, predominantly disposable surgical masks (65%), but only 9% received guidance on correct use and 42% doubted the effectiveness of their protection.[12] Modelling studies indicated that volcanic emissions pose significant health risks even to distant populations, with meteorological conditions playing a crucial role in pollutant dispersion.[13]

Psychiatric sequelae were documented in evacuees, with higher prevalence of anxiety, depression, and insomnia, and significant disruption to daily routines contributing

to these outcomes.[6] Ocular irritation and skin complaints were reported across multiple studies,[4],[6] and systemic effects including hepatic and testicular accumulation of heavy metals were observed in animal models.[8]

Discussion

Acute Effects and Exposure–Response Relationships

The consistency of acute respiratory findings across geographically and methodologically diverse studies provides strong support for a causal relationship between ash exposure and acute respiratory morbidity. The dose-dependence reported in the ASHES cohort,[5] together with the high symptom prevalence in the Indonesian cohort,[4] indicates that exposure intensity is a modifiable determinant of outcome. The finding that women in the moderate-exposure group reported more symptoms than men[5] suggests possible sex differences in symptom perception or reporting, although this requires confirmation in larger samples.

Long-Term Effects and the Problem of Uncertainty

The evidence for chronic respiratory disease is best characterised as biologically plausible but not yet established. The principal limitation is temporal: the ASHES cohort had not accumulated sufficient follow-up to detect chronic disease, and the absence of documented silicosis attributable to volcanic ash[10] means that the long-term risk remains theoretical rather than demonstrated. This does not justify complacency. The mechanistic evidence is substantial: silica-driven IL-33-mediated eosinophilia provides a specific pathway for asthma exacerbation,[14] and the demonstration of sustained hydroxyl radical production with high surface area ash indicates that oxidative injury may persist beyond the eruption period.[10]

An important consideration is the variability of ash characteristics between eruptions. Ash from different volcanoes, and even from different phases of the same eruption, differs in silica polymorph content, particle size distribution, surface area, and adsorbed gas composition.[1],[2],[10] This heterogeneity complicates the extrapolation of risk estimates from one setting to another and has been identified as a barrier to assessing long-term health impacts. The observation that populations living in volcanically active regions may experience less severe effects than expected could reflect adaptation, but could equally reflect under-reporting, survivor bias, or lower cumulative exposure in long-resident

populations; the available evidence does not permit these explanations to be distinguished.

Vulnerable Populations

The consistent identification of children as a high-risk group[4] has direct implications for disaster planning. Caregivers prioritised protecting their children over their own health across all three countries studied, with Indonesian caregivers reporting the highest levels of concern.[4] This suggests that risk communication targeted at caregivers may be a particularly effective channel. Individuals with pre-existing respiratory disease should be prioritised in evacuation planning and respiratory protection distribution.[3],[5]

Mitigation: The Gap Between Use and Correct Use

The finding that 93% of respondents used respiratory protection but only 9% received guidance on correct use[12] represents the single most actionable finding of this review. Disposable surgical masks, used by 65% of respondents, provide limited protection against respirable particles in the sub-10 μm range, which are precisely the fraction of greatest concern.[2] This indicates that distribution of respiratory protection without accompanying fit-testing and education may produce a false sense of security and limited actual risk reduction.

At population level, modelling studies indicate that even distant populations may experience measurable mortality and morbidity from volcanic emissions.[13] This supports the case for early warning systems and proactive public health planning rather than reactive response.

The complexity of volcanic hazards requires coordination across health, environmental science, and disaster management sectors.[6],[7] The ASHES and ISVOLCAN cohorts represent models of integrated epidemiological surveillance that could be adapted to other volcanically active regions, including Indonesia.[5–7] Key elements include exposure stratification by proximity and air quality metrics, biological sampling for contaminant exposure, standardised respiratory assessment, and long-term follow-up.

This review has several limitations. First, the evidence base is dominated by studies of two eruptions (Tajogaite 2021 and Kelud 2014), which limits generalisability to other volcanic settings with differing ash composition. Second, several studies were protocols or preliminary reports rather than completed outcome studies,[7] and the ASHES follow-up had not accumulated sufficient duration to detect chronic disease.[5] Third, the included analytical and experimental studies provide mechanistic insight but cannot establish human dose–response relationships. Fourth, outcome definitions and exposure metrics were not standardised across studies, precluding quantitative synthesis. Fifth, one included study reported country-specific symptom rates that appear internally inconsistent across reporting

metrics (overall symptom prevalence versus respiratory-specific prevalence), and the available data do not permit this discrepancy to be resolved; this has been noted rather than reconciled.[4] Sixth, the search was restricted to English-language publications, which may have excluded relevant Indonesian-language reports. Seventh, the review did not include a formal risk-of-bias assessment. Finally, the search did not include grey literature from national disaster management agencies, which may hold relevant surveillance data.

Three priorities emerge. First, longitudinal cohort studies with standardised exposure metrics and respiratory outcome measures are required to establish whether acute ash-related morbidity translates into chronic disease. The ASHES and ISVOLCAN cohorts provide templates that should be replicated in other high-risk regions. Second, research should address the effectiveness of specific respiratory protection types against volcanic ash in field conditions, since current evidence indicates that the most commonly used protection is likely to be inadequate. Third, risk communication strategies should be evaluated for effectiveness in promoting correct use of protection, with particular attention to caregivers of children and to individuals with pre-existing respiratory disease.

For practice, the findings support integration of respiratory protection distribution with mandatory education on correct use, prioritisation of children and individuals with pre-existing respiratory disease in evacuation planning, and inclusion of psychiatric screening in post-eruption health assessment given the documented burden of anxiety, depression, and insomnia.[6]

Conclusion

Volcanic ash exposure is associated with acute respiratory morbidity including cough, wheeze, dyspnoea, and exacerbation of pre-existing asthma and bronchitis, with symptom prevalence reaching 68.4% of exposed children and the highest rates documented in Indonesian cohorts. Exposure–response gradients have been demonstrated, and vulnerable groups including children and individuals with pre-existing respiratory disease experience disproportionate burden. Long-term risks including COPD and silicosis are biologically plausible and supported by mechanistic evidence of silica-driven airway inflammation, but remain unconfirmed in human populations owing to limited follow-up duration and the absence of documented silicosis attributable to volcanic ash. Psychiatric sequelae including anxiety, depression, and insomnia represent an additional and under-recognised component of the health burden. Mitigation efforts are currently undermined by a gap between the use of respiratory protection and its correct use, with only 9% of one surveyed community receiving guidance. Addressing this gap, alongside strengthened early warning systems,

interdisciplinary preparedness, and longitudinal surveillance, represents the most immediate opportunity to reduce the respiratory health burden of volcanic eruptions. Public education and ongoing health monitoring remain essential, particularly for vulnerable populations.

Declaration of Generative AI in Scientific Writing

The authors affirm that the usage of generative artificial intelligence tools, including Copilot Microsoft. These tools were not used for generating content, data analysis, or interpretation. The authors are fully responsiblefor the accuracy and integrity of the content as well as the conclusions presented in this study

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