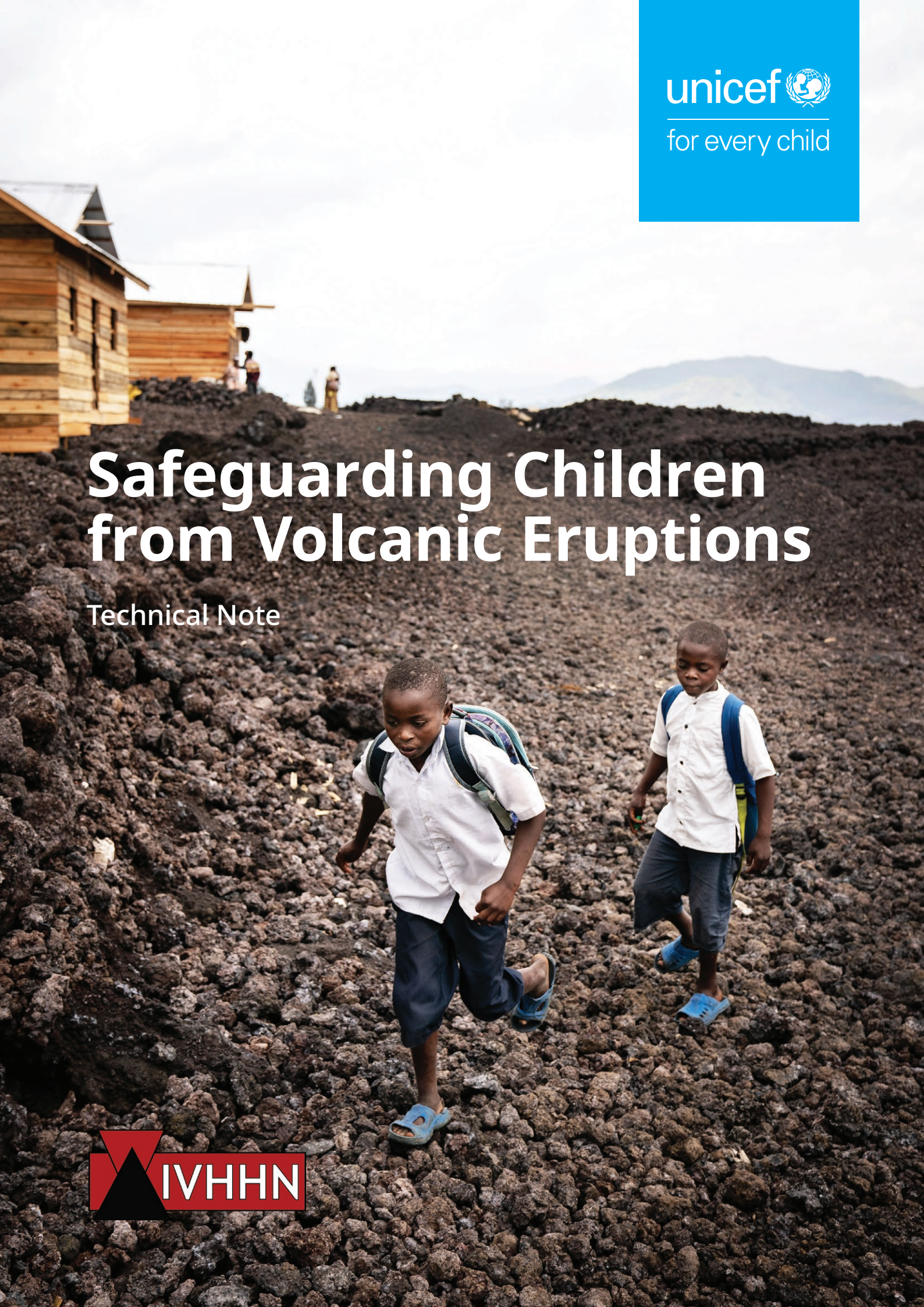
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Safeguarding Children from Volcanic Eruptions

Technical Note



IVHHN

Safeguarding Children from Volcanic Eruptions

Technical Note



Healthy Environments
for Healthy Children

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Abbreviations

CCRI-DRM	Children's Climate Risk Index – Disaster Risk Management (subnational guidance framework)
CO_2	Carbon dioxide
EWARS	Early Warning, Alert and Response System (WHO)
GIS	Geographic Information System
GVP	Global Volcanism Program (Smithsonian Institution)
H_2S	Hydrogen sulfide
H_2SO_4	Sulfuric acid
HCl	Hydrochloric acid
HEPA	High-efficiency particulate air (filter)
HVAC	Heating, ventilation and air-conditioning
IASC	Inter-Agency Standing Committee
IVHHN	International Volcanic Health Hazard Network
N95	A respirator classification denoting filtration of at least 95 per cent of airborne particles
PDC	Pyroclastic density current
PEI	Population Exposure Index
PFA	Psychological First Aid
$PM_{2.5}$/PM_{10}	Particulate matter with a diameter less than 2.5 / 10 micrometres, respectively
SO_2	Sulfur dioxide
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations Children's Fund
WASH	Water, sanitation and hygiene
WHO	World Health Organization



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Executive summary

Volcanic eruptions pose serious and often underestimated risks to children. **More than 166 million children under 18 years old live within 100 km of an active volcano, around 60 per cent of them in low- and middle-income countries where resources for preparedness and recovery are often most constrained.** Children experience volcanic hazards differently than adults because of physiological, behavioural and dependence-related factors. Their higher breathing rates, shorter stature, developing organ systems and reliance on caregivers all heighten their exposure and vulnerability, particularly to airborne ash and gases that settle near ground level.

This technical note, published by UNICEF and IVHHN, consolidates the evidence on how volcanic hazards affect children's health, safety and well-being, and sets out practical, action-oriented guidance for governments, health and nutrition planners, humanitarian responders, education and child protection actors, and other partners engaged in preparedness and response.

The report details the full range of hazards that volcanoes present, from acute life-safety threats such as pyroclastic flows, lahars[1] and ballistic projectiles to the widespread and long-lasting effects of ash and gas emissions on respiratory and ocular health. It also examines less visible impacts, from skin conditions to mental health consequences such as post-traumatic stress, anxiety and disrupted parental well-being, which can persist long after an eruption ends. Beyond direct health effects, eruptions disrupt the systems children depend on, damaging schools and health facilities, straining food security and degrading critical infrastructure such as water and power supplies.

This report offers a structured framework for action before, during and after eruptions to protect children from these risks. This includes critical investments that serve multiple needs such as strengthening early warning systems and developing household and school preparedness plans to hazard specific actions such as delivering clear, age-appropriate risk communication and protecting drinking water supplies. The report emphasizes prioritizing the needs of pregnant women and vulnerable children, including infants and children with disabilities.

Ultimately, protecting children from volcanic hazards requires deliberate, sustained planning across sectors, not only in the immediate aftermath of an eruption, but well in advance of one. By equipping decision-makers with the evidence and tools to act, this technical note aims to reduce preventable harm to some of the world's most at-risk children.



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1. Introduction

As with all natural hazards, children are more vulnerable to the effects of volcanic eruptions than adults. This is because of unique physiological, behavioural and dependence factors.

This technical note has been designed to provide information on the hazards, and associated impacts, of volcanic eruptions which may affect children. It is aimed at national and subnational government authorities, health and nutrition planners, humanitarian and emergency responders, education and child protection actors, and operational partners supporting preparedness and response in volcanic settings. While intended for responding agencies, this technical note may also be used by the public.

Following this introduction, an overview of volcanic hazards is given, and the impacts of those hazards to the health and well-being of children, as well as to the supporting systems which ensure their safety and well-being. The next section provides action-oriented recommendations on how to prepare for eruptions and protect children and their families during, and after volcanic eruptions. The annexes provide a detailed evidence review of the health, infrastructure and agricultural impacts, tables on risk management and multi-sectoral preparedness, and methods.

1.1 The unique vulnerability of children to volcanic eruptions

As with adults, volcanic eruptions can have a range of health impacts on children, ranging from immediate physical trauma (e.g., burns, crushing by debris) or even death, to short-term health symptoms (e.g., irritated skin, eyes and throat), and the development of respiratory conditions such as bronchitis, the exacerbation of asthma, and mental health impacts.

However, when compared to adults, children are uniquely vulnerable because of physiological, behavioural, and dependence factors. For instance, when it comes to exposure to airborne volcanic emissions (e.g., ash, gas and aerosol), newborns and young children breathe more rapidly and take in a larger volume of air per kilogram bodyweight than adults,[2] while their lungs, immune, neurological and cognitive systems are not fully developed. Those with specific disabilities or health conditions (e.g., asthma and other respiratory or cardiovascular conditions, cognitive or physical disabilities) will be additionally susceptible. Due to their shorter stature, children are more at risk of high exposure to airborne emissions as they accumulate and then resuspend near or on the ground. Children and adolescents also often spend more time outside, where exposure can be worse.

Children also have distinct physical, developmental and practical vulnerabilities that may increase their risk of injury or death during volcanic crises, particularly where rapid evacuation is required. Younger children and children with disabilities (or other additional needs) may be especially dependent on caregivers and emergency systems for their protection. Children's development can also be shaped by their mother's experiences during pregnancy (see **Figure 1**).

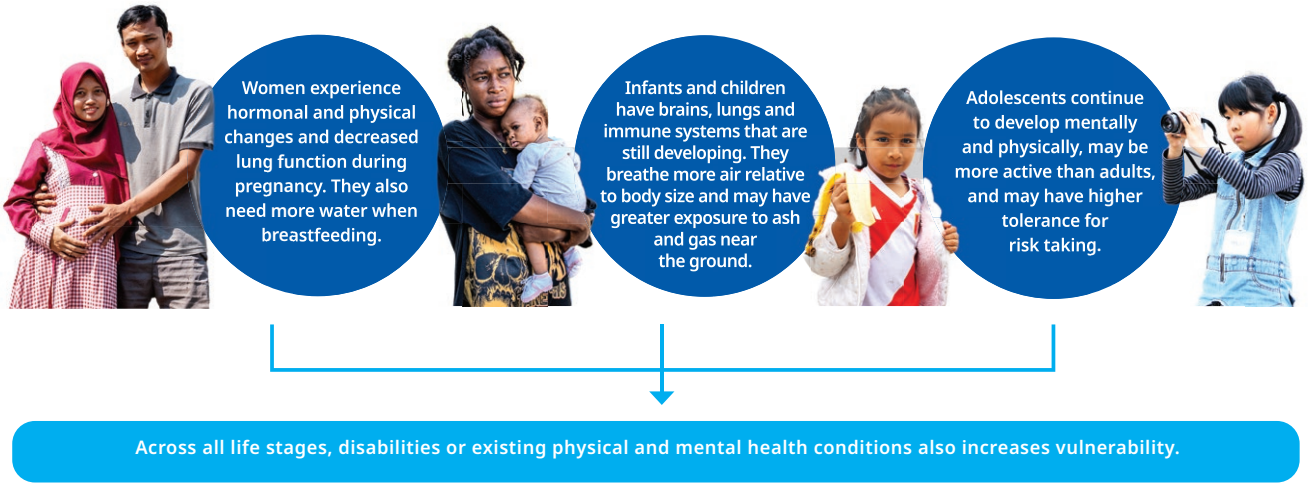
Children can be particularly vulnerable to mental health impacts following volcanic eruptions and should be considered a priority group for monitoring and psychosocial support, based on impacts documented from other disasters[3] (volcano-specific studies are limited). Interventions have been shown to lead to positive outcomes (see **Annex B**).



It should also be noted that breastfeeding women face extreme vulnerabilities following volcanic eruptions due to disrupted water supplies and psychological stress, which can compromise maternal milk supply. Children with specific disabilities or health conditions (e.g., asthma and other respiratory or cardiovascular conditions, cognitive or physical disabilities) may be at particular risk during volcanic emergencies. Adolescents may also require targeted mental health and sexual and reproductive health support. Young children who are 'closer to the ground', due to their height or playing at ground level, are at risk of high exposures from deposited (and remobilized) volcanic ash, and gases which are heavier than air.

For information on children's physical and mental health responses to volcanic eruptions, see **Section 2** and **Annex B**.

Figure 1. The vulnerabilities of pregnant women and children at different developmental stages to volcanic eruptions



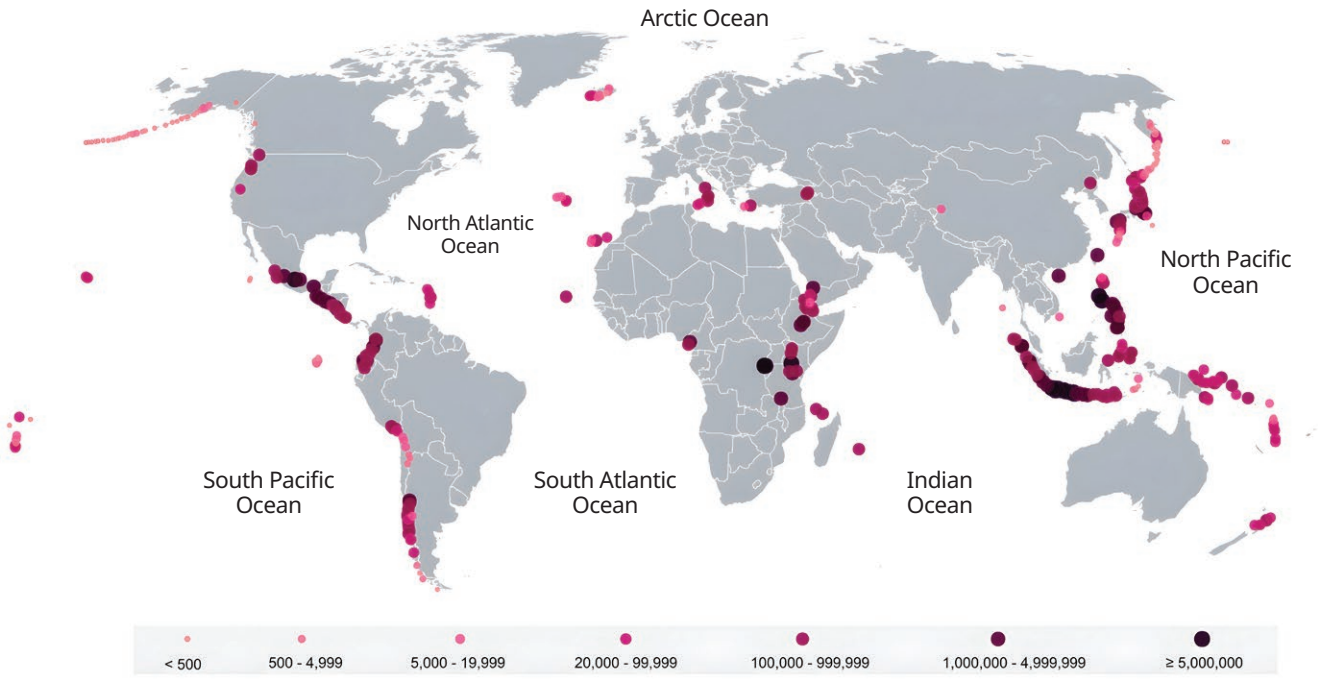
Source: Adapted from UNICEF, Safe from Wildfire Smoke, 2024 (based on Lein et al., UC Davis Environmental Health Sciences Center, 2023).

1.2 What and where are volcanoes?

Volcanoes are landforms created where molten rock, called magma, erupts at the Earth's surface. There are many types of volcanoes. Each is different and the composition of the magma varies among volcanoes and individual eruptions, so it can be challenging to define the hazard in advance of a new eruption. Usually, around 50 volcanoes are erupting at any one time.[4] Many others are considered active (having had an eruption within the Holocene epoch – the last 11,700 years)[5] but are currently dormant (not showing any signs of eruption or unrest). However, volcanoes can also be hazardous even when they are not erupting.

UNICEF has calculated that, worldwide, more than 166 million children under 18 years old live within a 100 km radius of an active volcano (Figure 2). Of these volcanoes, around 60 per cent are in low- and middle-income countries.

Figure 2. Children living within 100 km of an active volcano, worldwide



Source: Global Volcanism Program, Smithsonian Institution (https://volcano.si.edu/ - Accessed April 2025), WorldPop 0-17 1km grid Population Estimates (2025)

Note: Only areas within a 100 km radius of volcanic activity after 1800 were included in the exposure analysis. Methodology in Annex F.

Figure 3. Children living within 100 km of an active volcano, Latin America

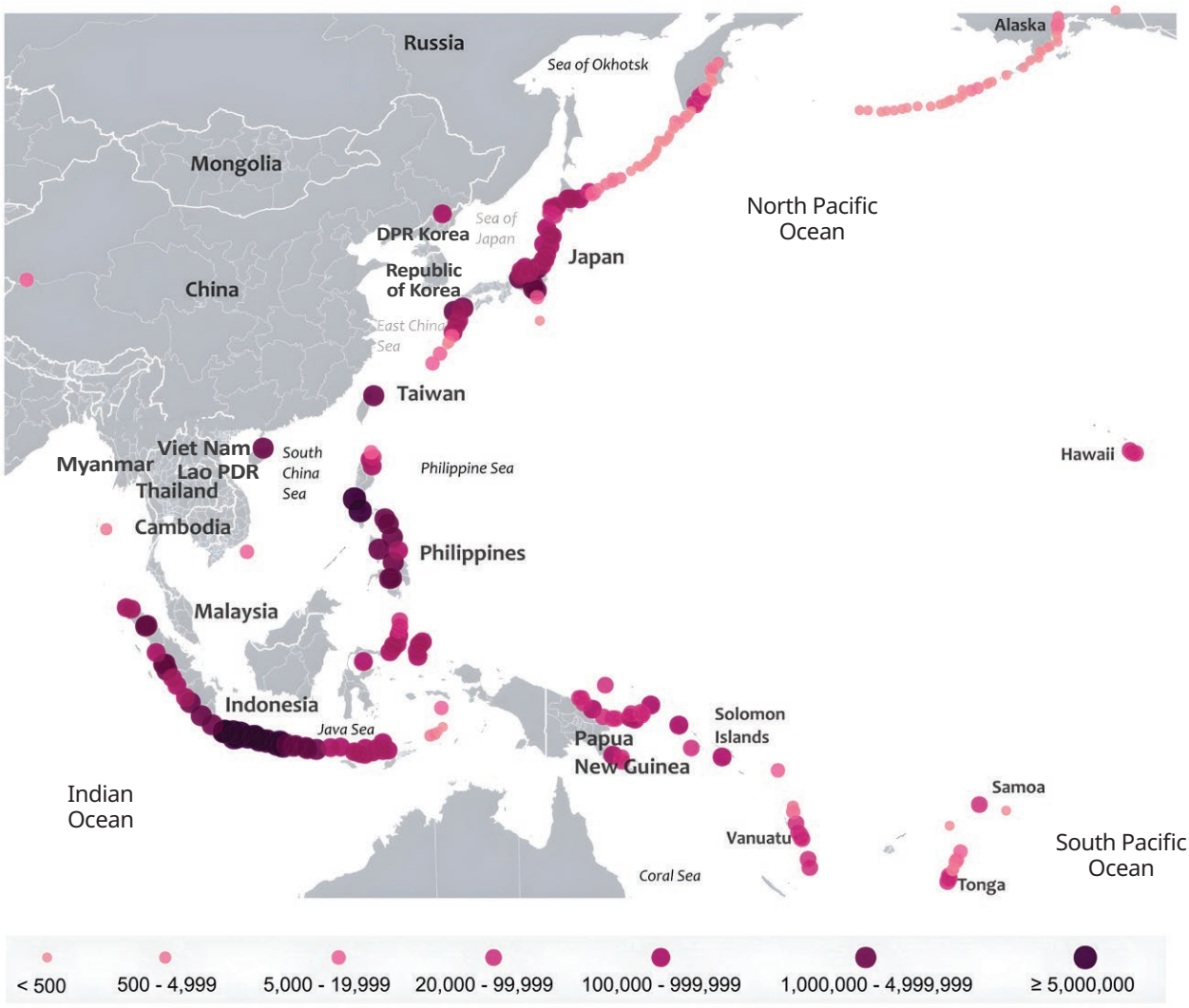


Source: Global Volcanism Program, Smithsonian Institution (https://volcano.si.edu/ - Accessed April 2025), WorldPop 0-17 1km grid Population Estimates (2025)

Note: Only areas within a 100 km radius of volcanic activity after 1800 were included in the exposure analysis. Methodology in Annex F.



Figure 4. Children living within 100 km of an active volcano, East Asia and the Pacific



Source: Global Volcanism Program, Smithsonian Institution (https://volcano.si.edu/ - Accessed April 2025), WorldPop 0-17 1km grid Population Estimates (2025)

Note: Only land within radius of volcanic activity after 1800 were included in the exposure analysis. Methodology in Annex F.

Volcanoes are found mainly on the tectonic plate boundaries of the Earth, where the plates are pulling apart or colliding. Many active volcanoes are located along subduction zones, where tectonic plates converge, such as the horseshoe-shaped 'Ring of Fire' around the Pacific Ocean. Volcanoes also form along rift zones where tectonic plates are splitting apart (for example, in the East African Rift and in Iceland). However, there are some volcanoes which form when magma rises in a plume from deep in the Earth, which are found in the middle of a plate, such as the Hawaiian Islands on the Pacific Plate.

Despite volcanoes being hazardous, populations have always chosen to live near them due to the fertility of the soil, mineral and geothermal resources and, more recently, leisure and tourism opportunities. However, volcanic risk is not socially neutral. Lower-income households systematically occupy more at-risk land, have less access to resilient housing, and have fewer financial resources for recovery. They also have fewer options for relocation and may be strongly attached to their land.

Of populations living near active volcanoes, those in South-East Asia are the largest and fastest-growing anywhere in the world. The density of both populations and volcanoes in Indonesia and the Philippines makes them the most threatening volcanic locations in the world, in terms of potential harm to communities (Figure 4).[6]



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2. Overview of volcanic hazards and impacts

Where to find volcano information

The Smithsonian Institution's Global Volcanism Program documents and archives eruption information to "better understand worldwide volcanic activity". The database can be utilized to learn about each volcano's type, eruptive activity and any associated observations. Learn more: https://volcano.si.edu

2.1 What hazards do volcanoes present?

Volcanic eruptions can last for hours, days, weeks, months, years or even decades. They can produce many near and far-reaching hazards, some of which co-occur or trigger each other (known as compound or cascading hazards). Some volcanoes erupt explosively, generating towering plumes of ash (fragmented magma and rock), gases and aerosols, which can travel long distances in the atmosphere, as well as various flows along the ground e.g., pyroclastic flows, lava flows or mudflows (see **Annex A**) which can travel for several kilometres. Other volcanoes may erupt less explosively, emitting flows and fountains of lava as well as gases (**Figure 5**). The most widespread and disruptive hazard is usually volcanic ash, but hazards close to the volcano, such as various types of flows and gas, may pose a risk of destruction, injury and fatality.

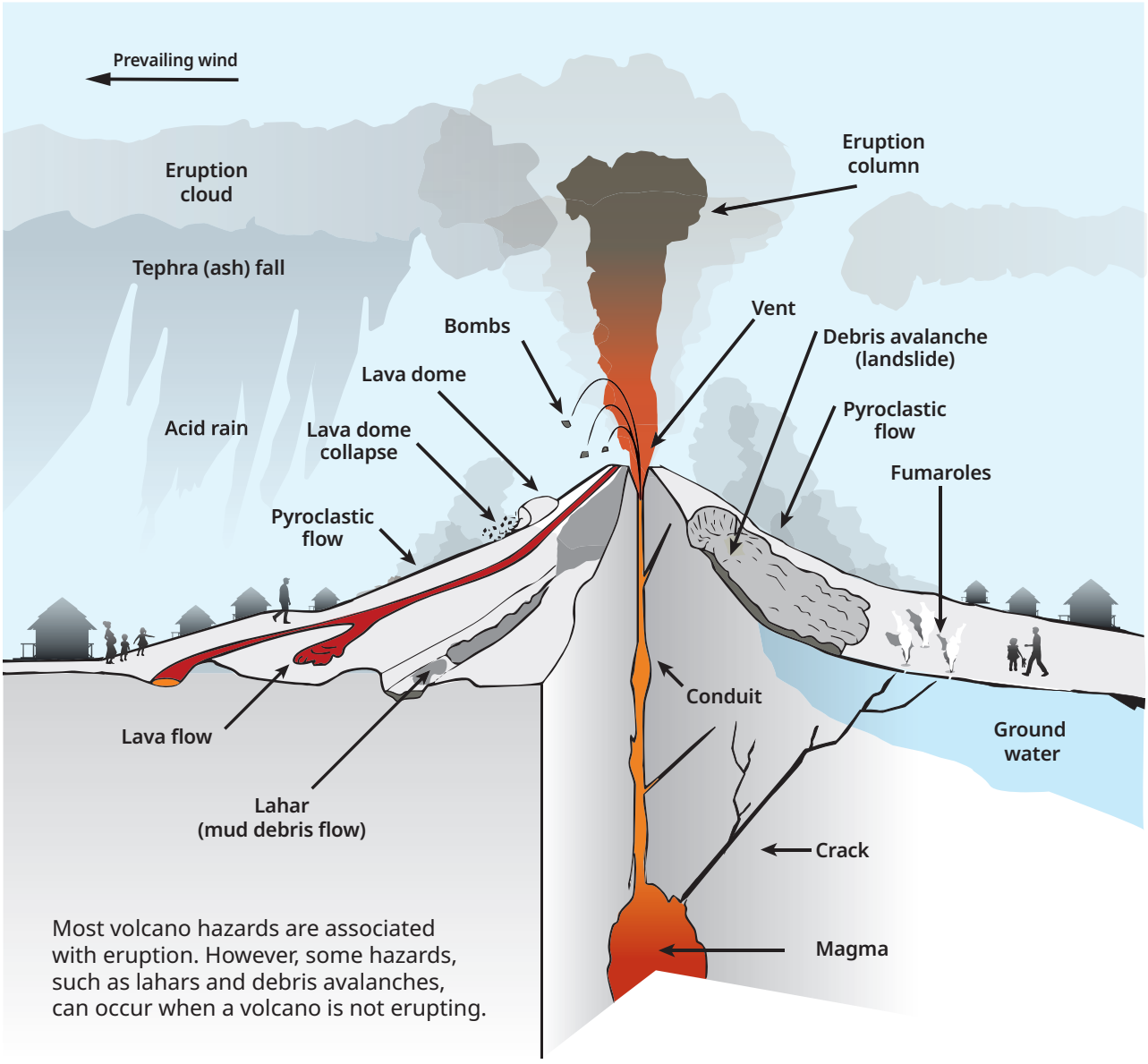
Before an eruption, a volcano may show signs that it is becoming more active than usual. This is known as volcanic unrest. Unrest does not always lead to an eruption. During this period, people living on or near the volcano may experience hazards such as earthquakes, increased gas emissions and changes in the shape of the ground. There may also be small volcanic explosions caused by groundwater being superheated, called phreatic eruptions. All of these hazards can occur as magma moves underground. Volcanic unrest may last from hours to years. It can be very challenging for local communities and hazard managers because it is often difficult to predict whether an eruption will occur, while the hazards associated with the unrest can, themselves, cause disruption and harm.

Even when there has been no recent eruption – or for years after an eruption has finished – several volcanic hazards can affect communities, such as persistent gas emissions (leading to chronic exposures), minor earthquakes that the community can feel, hot spring activity, landslides and mudflows.


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Figure 5. Hazards posed by active volcanoes



Source: U.S. Geological Survey

2.2 Life-safety hazards and impacts

Between 1500 and 2017, a total of 278,368 fatalities from volcanic eruptions were recorded[7] with multiple events happening since, often where tourists (including school groups and guides) were climbing volcanoes despite warnings of potential activity. There is no consolidated figure for how many children under the age of 18 years have been killed by volcanic hazards, as age disaggregation has not been consistently carried out across countries. Therefore, child-specific data are scarce, and the available evidence does not allow us to determine whether children are consistently more likely than adults to be injured or killed during volcanic eruptions. However, it should be borne in mind that younger children may require adult assistance to recognize danger and evacuate rapidly.

Historically, the three eruption hazards that have caused the greatest number of fatalities and injuries are pyroclastic flows, more accurately known as pyroclastic density currents (PDCs), mudflows (also known as lahars), and tsunami (often triggered by landslides), although blasts from phreatic eruptions have recently caused fatalities at several volcanoes. While volcanogenic tsunami are rare events, the 1883 Krakatau eruption in Indonesia led to the death of 36,000 people because of the wave it triggered. Additional large incidents in terms of lives lost include the 1902 Mont Pelée eruption in Martinique (28,000 deaths), caused by PDCs, and the 1985 Nevado del Ruiz eruption in Colombia (24,000 deaths), caused by a lahar.[8] However, the type of fatal incident which occurs also depends on the distance of people from the volcanic vent. Ballistic projectiles (airborne rocks) are the most common cause of fatal incidents within 5 kilometres of the vent, PDCs are most common between 5 and 15 kilometres, and lahars, tsunami, and tephra (volcanic ash and larger particles) are most common at distances over approximately 15 kilometres.[9] The only safe approach to managing the risks of these hazards is by evacuating people. Climate change may exacerbate hazards such as lahars, through more intense and frequent rainfall events.

There are studies that have documented the range and severity of injuries borne by children. Thermal burns, especially to the respiratory tract and skin, are the predominant acute injury type for those exposed to PDCs;[10, 11, 12] however, chemical burns have also been recorded where explosions disrupt acid crater lakes.[13] Causes of death among burn victims are inhalation injuries and resulting acute respiratory distress syndrome and systemic infections predominantly caused by *Aspergillus fumigatus*, a pathogenic fungus.[14, 15]

Another primary cause of injury (and death) is physical traumatic injury from crushing by rocks and debris being carried by flows, and by ballistic projectiles. These, in turn, can also cause other effects, from bacterial infections and oedema to damage to the nervous system.[16]

Tephra, lava flows and volcanic gases can also cause injuries and fatalities. The main volcanic life-safety hazards and their impacts, and risk management options, are presented in more detail in a table in **Annex A**.

2.3 Respiratory health hazards and impacts

Respiratory health hazards and impacts are caused by inhalation of volcanic gases, especially sulfur dioxide (SO_2), ash and aerosol. Such airborne volcanic emissions can travel downwind and affect air quality. In the largest eruptions, air quality can be affected hundreds, or even thousands, of kilometres from the volcano, potentially in different countries. Many urbanized areas already suffer from substantial air quality issues. Volcanic emissions will add to the existing anthropogenic burden of airborne pollutants.[17]

Volcanic gases: SO_2 is one of the most abundant and hazardous gases released by volcanoes. In the atmosphere, SO_2 can react with sunlight and water to create sulfate aerosol, also known as sulfuric acid (H_2SO_4), and sometimes known as 'vog' (particularly in Hawaii). Additionally, geothermal systems can be active when the volcano is not erupting and, even for millennia after a volcano has become dormant, and people who live near or on them may be frequently exposed to raised concentrations of hydrogen sulfide (H_2S). All sulfurous gases and aerosols can irritate the respiratory tract. There is little evidence that these sulfurous pollutants cause respiratory diseases, but they can certainly exacerbate existing diseases. Asthmatics are particularly sensitive to SO_2, resulting in wheezing and shortness of breath, and it can trigger asthma attacks.

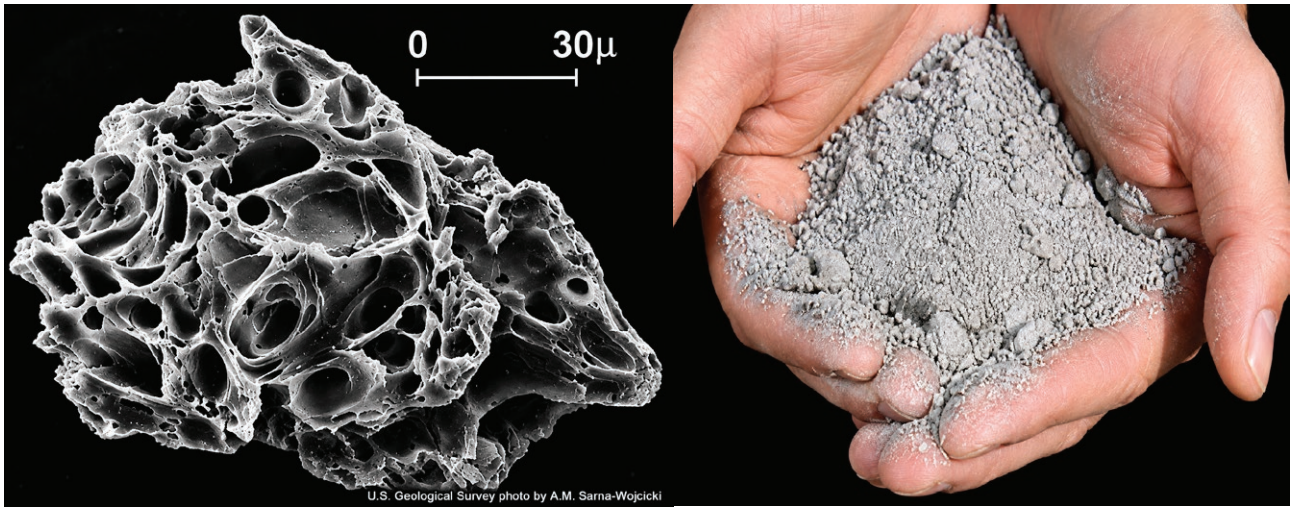
Another airborne hazard is created if lava flows into seawater. The interaction creates acidic steam plumes called 'laze' (from lava + haze) laden with hydrochloric acid (HCl) gas and volcanic glass particles,[18] both of which can be highly irritating to the respiratory system.

Carbon dioxide (CO_2) and H_2S are heavier than air and can pool in low spaces such as basements, particularly in geothermal areas, where there have been a number of fatalities.[19] Accidents in geothermal locations, and areas of passive CO_2 degassing are not uncommon.[20, 21] There are also some examples of 'limnic' eruptions where volcanic lakes suddenly overturn, releasing a suffocating, ground-hugging cloud of CO_2. The best-known example of this was in 1986 when Lake Nyos, Cameroon, suddenly overturned, emitting a cloud of CO_2 gas which suffocated approximately 1,700 people and thousands of livestock in nearby villages.[22]

Volcanic ash: Volcanic ash is produced by all explosive volcanic eruptions. It is one of the most frequent and widespread volcanic hazards, and the most likely to affect communities, farmland and infrastructure around the world. It consists of small (<2 mm) fragments of volcanic glass, crystals and material torn from volcanic vents. These grains are hard and angular (**Figure 6**) and do not dissolve in water, though they can have surface salt deposits which are released when they contact water.[23]

In **Figure 6**, below, the left-hand image shows a single particle of ash observed by microscopy. Note that this particular particle, at 0.1 mm diameter (100 µm), may enter the nose or mouth but is too large to be inhaled into the lungs. The right-hand image shows what fine-grained volcanic ash looks like. Coarser-grained ash may be darker in colour.

Figure 6. Volcanic ash particles



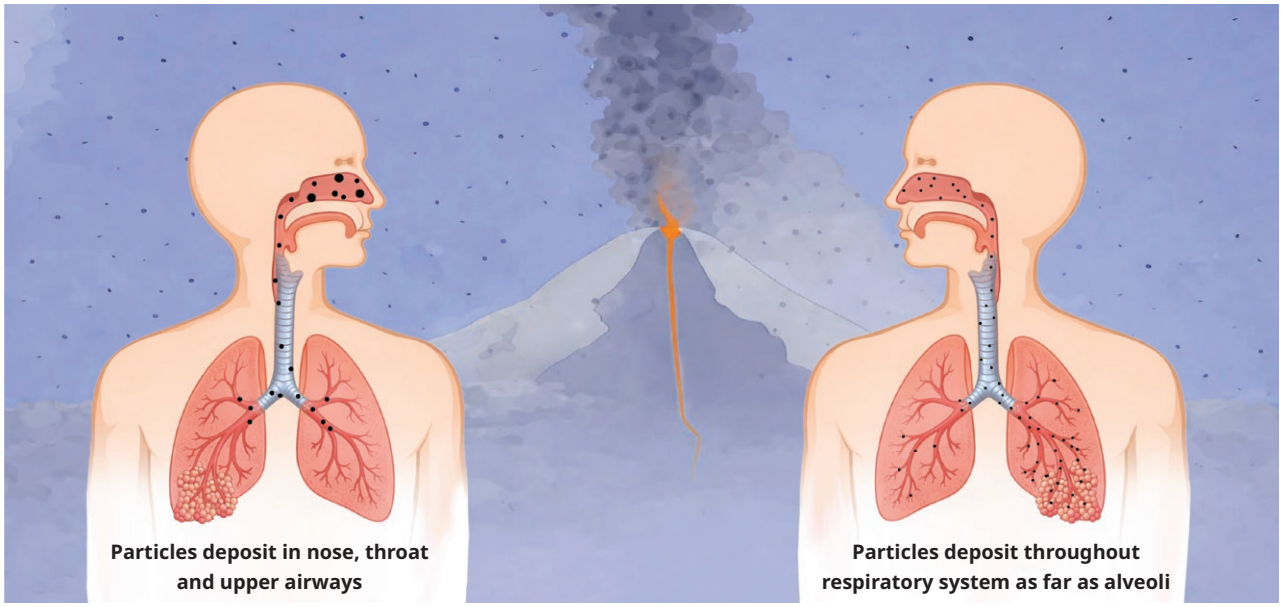
Source: U.S. Geological Survey

Inhaled volcanic ash can have similar respiratory health impacts to volcanic gases and other particles. It can contain very small particles, such as $PM_{2.5}$ and PM_{10} (particulate matter less than 2.5 and 10 µm diameter, respectively) which are known, in general terms, to cause harm to one's health, especially for young children (including neurodevelopmental impacts and impaired lung growth), and unborn babies (including low birthweight and preterm births).[24] Short-term, the particles may cause symptoms such as exacerbation of asthma, sore throats and coughs (see **Annex B**). The abrasiveness of volcanic ash can also cause damage to delicate tissue, particularly the eyes and skin (see **Section 2.4**, below). Despite being angular, and sometimes made of volcanic glass, due to their tiny size, the particles do not lacerate the lungs after inhalation.[25]

While there is little or no proven link between extended exposures to high concentrations of volcanic ash (including ash containing the mineral crystalline silica) and chronic particle-related diseases such as pneumoconiosis (including silicosis) and respiratory cancers, this may be because there has not been a sufficient number of studies. A precautionary approach should therefore be taken during risk assessments.[26]

A detailed review of studies conducted on children exposed to volcanic emissions is found in **Annex B**. A summary is given in **Figure 7**, below.

Figure 7. The health effects of volcanic particulates

Particles from 2.5–10 µm	Particles less than 2.5 µm
	
Particles deposit in nose, throat and upper airways	Particles deposit throughout respiratory system as far as alveoli
Health effects	
Exposure can worsen pre-existing respiratory conditions like asthma.	Potential for chronic lung and cardiovascular impacts.
Irritates eyes, skin, throat and nose.	
Pregnancy and birth outcomes	
Limited research suggests that exposure to high concentrations of volcanic particulate matter during pregnancy may be associated with increased risk of preterm birth and low birthweight.	

2.4 Other physical health impacts

Populations exposed to volcanic ash, SO_2 gas and sulfate aerosol may experience numerous eye and skin issues. Commonly reported ocular symptoms included conjunctival and eyelid infection and inflammation, clear mucous discharge and damage to the cornea, each varying in prevalence based on exposure duration and intensity.[27, 28] Some people (adults) also report headaches, 'brain fog', dizziness and nausea when exposed to vog.[29] Evidence specific to children on dermatological issues is lacking but, in exposed populations generally, contact with volcanic ash and gases can cause skin irritation, redness, itching and dermatitis, and may exacerbate pre-existing skin conditions such as eczema.[30, 31]

Volcanic emissions can raise fluoride concentrations in drinking water supplies. Good oral health is critical to good general health for children, and a small, sustained intake of fluoride is necessary for the prevention of tooth decay. However, optimal intake of fluoride is narrow, and lengthy exposure to excess fluoride, while their permanent teeth are developing, could lead to children developing dental fluorosis. This can have impacts on their appearance, well-being and social inclusion.

Globally, the occurrence of dental fluorosis is strongly associated with high-fluoride groundwaters.[32] However, in a few cases, it is associated with active volcanism, notably in Vanuatu where studies have documented high incidences of dental fluorosis in paediatric populations living downwind of the active volcanoes Ambrym and Yasur.[33, 34] There may also be short-term risks from volcanic ashfall raising fluoride concentrations in rainwater-fed drinking water supplies.

Lolovotali, South Ambae, Vanuatu, received approximately 80 mm ashfall during the 2017–2018 eruptions of Manaro Voui volcano, and the loss of drinking water was an important factor behind two evacuations from the island between 2017–2018.



This roof catchment tank in Lolovotali, Vanuatu contained 8 mg/L fluoride (F), well in excess of the WHO drinking-water standard of 1.5 mg/L F, after the Manaro Voui eruption; it also had very high concentrations of dissolved aluminium, copper, manganese and zinc.
Photo credit: Carol Stewart

2.5 Mental health impacts

The psychological and psychosocial consequences for children are also important, often persisting long after an eruption finishes. Children may experience post-traumatic stress symptoms, including anxiety, depression and re-experiencing the event through intrusive thoughts or dreams. The mental well-being of a child may also be closely tied to their parents' emotional state; parental distress and multiple relocations can exacerbate anxiety in children. Recovery can be supported through social networks and cognitive-behavioural interventions, such as teaching children to replace negative self-talk with positive coping strategies.

Listening to children in Saint Vincent and the Grenadines

Children in Saint Vincent and the Grenadines were invited by their teachers to write poems about the 2021 La Soufrière eruption as a means of coming to terms with what they had been through.

The Volcano Woke Up

The volcano woke up one night,
Lava running up and down like the crazy man Mike
Mummy said, "Boy, Taijaun, wake up!"
Gather your things, walk with your dog,
And all your belongings.
They say that we must go to a shelter.

When I looked on the road,
I saw Fancy people running up and down Helter Skelter.
Fire was blazing, the ash got into my eyes,
They shouted to gather the old and young as the plumes darkened the skies.
See all of us Fancy people like some happy pickney
When we were on the bus heading to safety.

Written by: Taijaun Lewis

Soufrière, ah come! / La Soufriere is Coming

A thunderous sound, what could it be?
Like stones rolling from the mountain to the sea.
The earth was trembling, dear, oh dear.
"Soufriere, ah come!" is all I could hear.

Plumes of ash filled the air,
Dangerously, beautiful, we had to stare.
Lightning filled the sky that morn,
Even though, there was no storm.

Ash was on the ground looking like snow,
We had to watch out for pyroclastic flow.
Mountains were scorched, no longer green,
Oh, what a sight to have ever seen.

Homes were destroyed, agriculture was flat,
Our lives were stagnant, we had to build back,
But we are resilient, that's who we are
Strong and united, better by far.

Written by: Ethan Michael

While recovery timelines vary – with some symptoms taking years to improve – structured community support and clear communication are vital for helping children navigate the mental aftermath of a disaster. Children's reactions are shaped by age, gender and pre-existing health conditions and recognizing developmentally specific manifestations of distress can help caregivers, teachers and humanitarian agencies to provide age-appropriate support.

Annex B gives a detailed overview of studies of the mental health impacts in children, following eruptions.

2.6 Indirect impacts on food security

Undernutrition near Mount Sinabung

The prolonged 2010–2019 eruptions of Mount Sinabung, Indonesia, caused widespread and thick ashfalls, prolonged displacement of local populations, and severe damage to crops across neighbouring regions which, in turn, led to household food insecurity. A study of children under the age of 5 living in 444 households located in the area affected by the ashfall[1] found that the prevalence of underweight, stunting and wasting was higher than the national average. Analysis of risk factors showed that children who suffered from respiratory infections, skin irritation and diarrhoea were more prone to malnutrition, supporting previous research indicating that undernutrition is associated with other health problems. Some refugees received nutritionally supplemented foodstuffs twice per week as short-term food aid. Resettled farmers were also provided with seed, fertilizer and crop-protection products.[2]

[1] www.tandfonline.com/doi/full/10.1080/03670244.2023.2258794#d1e231
[2] www.giz.de/en/projects/sinabung-agricultural-response-project

Eruptions can have widespread and prolonged impacts on food security, which is particularly important for children because they are more vulnerable to nutritional shortages during critical stages of growth and development. This is particularly true in areas where there is subsistence farming where the primary focus is on food security for the household. In the past, major eruptions caused drought, famine and disease epidemics (e.g., Tambora (Indonesia) in 1815 which resulted in 60,000 fatalities).[35] Severe damage to crops was one of the key factors prompting a second evacuation of the entire population of Ambae Island, Vanuatu, in August 2018, following widespread and heavy ashfalls from the eruption of Manaro Voui volcano.[36]



Officials from the Philippines Department of Agriculture Regional Field Office inspect ashfall-damaged pineapple crops after the 2020 eruption of Taal volcano.
Source: Wikimedia Commons

2.7 Impacts on education and health care services

All impacts on infrastructure affect children (see **Annex C**), but the impact of a volcanic event on education and health care has a direct bearing on their well-being. Damage to school infrastructure and contaminated water supplies may make conditions unsafe for students and staff. Indoor air quality may be compromised, posing health risks. Schools may need to close temporarily, interrupting learning continuity.

Education services: Schools are frequently repurposed as temporary evacuation shelters for displaced populations, as seen during the 2018 Mount Mayon (Philippines) and the 2010 Mount Merapi (Indonesia) eruptions. Additionally, teachers may be asked to manage these shelters. While this serves an immediate humanitarian need, it indefinitely suspends regular classes and leads to the degradation of school facilities.

High concentrations of particulate matter and sulfur dioxide may create hazardous air quality, forcing school closures to protect student health, especially in warm climates where classrooms cannot be sealed. Research in Hawaii[37] has linked these volcanic emissions to a significant decline in student test scores, particularly among economically disadvantaged groups.

Additionally, due to severely disrupted transportation networks and lack of visibility due to ashfall, roads may be unsafe to use, which can further reduce access to educational services.[38]

Education disruption near Mount Mayon

The 2018 eruption of Mount Mayon in the Philippines significantly disrupted education for tens of thousands of children as schools were repurposed as emergency evacuation shelters for approximately 70,000 displaced residents. With 49 schools located within the 'permanent danger zone' and many others serving as shelters, regular classes were suspended for weeks, forcing educators to implement double-shift schedules, online lessons, and temporary learning spaces to maintain academic continuity.

Read: https://theirworld.org/news/philippines-volcano-mount-mayon-disrupts-schools-education



Heavy ash contamination inside a classroom, Ambae, Vanuatu, following the 2017–2018 Manaro Voui eruptions.
Photo credit: Carol Stewart

Health care services: Health care facilities may be directly damaged by volcanic hazards (e.g., lava, PDCs, lahars, ballistics or ash loading). There may also be indirect impacts from disruption to transport networks. For example, ashfall can impact ambulances, staff attendance and critical supply deliveries. Power outages will also affect heating, lighting and have cascading impacts. This can include reduced surgical capacity, disruption of cold chains (including storage of critical medication and vaccines), and inability to power critical equipment necessary to manage infection prevention and control measures.

The ubiquitous presence of airborne ash may present challenges for treatments that demand clean spaces, such as operating theatres. Ashfall impacts on telecommunications systems may complicate coordination with emergency response agencies.

Summaries of the impacts to infrastructure and agriculture are given in **Annexes C** and **D**.



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3. Preparing for and responding to eruptions

Responses to past eruptions offer valuable insights for humanitarian agencies working alongside local governments and communities before, during and after volcanic eruptions, to save lives and safeguard children, in particular. Preparedness before an eruption helps build trust with local communities as well as increasing awareness and resilience. Planning the response and recovery phases is also essential and, ideally, will happen prior to any eruptive activity. Prior design of public communications, which are consistent among agencies, and coordination of dissemination strategies, will enable a more efficient response. To note, national or regional volcano observatories (where they exist) are the primary technical authority for volcanic hazard information. Responding agencies should ensure that they align and complement public messaging with observatory-issued alerts. Co-developing the messaging with the local volcano observatory or equivalent technical body is helpful.

The following sections provide general recommendations to governmental ministries and humanitarian and development agencies on how to help the public, and particularly caregivers of children, prepare for and respond safely to a volcanic eruption. Where possible, these recommendations are drawn from successful preparedness and response operations around the world. These recommendations will need to be adapted for each eruption and, possibly, as an eruption evolves, depending on the hazards posed and local context and infrastructure. Links to resources that can be utilized for preparing a community, or national level preparedness plan, are integrated.

Multisectoral collaboration, and clearly assigned roles and responsibilities across agencies, have proved effective in volcano disaster preparedness and response. **Annex E** provides an example of how these responsibilities can be divided up across agencies, while ensuring that the actions are collaborative. Out of scope of this document is longer-term land-use planning such as ensuring that buildings, roads, bridges and telecommunications are not located in the valleys down which volcanic flows will travel.[39]

3.1 Before an eruption (long- and short-term preparedness)

3.1.1 Early warning systems and surveillance

- Establish, maintain or update early warning systems that provide timely, accessible and actionable alerts to communities, including families and, potentially, children;[40] this should be a collaboration between national or regional volcano observatories and local civil protection agencies.

- Ensure consistent alerts are disseminated through multiple, accessible channels (in formats and languages understood by different groups), including radio, apps, SMS, community loudspeakers and schools.

- Create risk communication messaging to accompany alerts that is consistent among agencies and available in multiple media channels.
  - Adapt messages for children, including those with disabilities and those in remote areas. This could include messaging specifically for caregivers on how to provide support for children ahead of, during and after an eruption, such as ensuring that they have contact information for the family if separated, messaging on preparing child-friendly emergency kits, and messaging directly aimed at children on safe evacuation practices.

- Activate syndromic surveillance[41] through the government health department, with support from humanitarian agencies, to monitor spread of infectious disease or water/food-related illnesses, and symptoms related to exposure to volcanic emissions.

- If syndromic surveillance is not possible, an emergency surveillance system such as the WHO Early Warning, Alert and Response System (EWARS)[42] can be used to rapidly track disease outbreaks. IVHHN has also developed rapid epidemiology protocols designed for volcanic eruptions.[43]

- Consider deploying an air quality monitoring network through governmental environmental or health departments to monitor baseline concentrations and help assess respiratory health risks post-eruption, particularly for vulnerable groups such as children.[44] See the Air Quality Monitoring and Management section, below, for further information.

3.1.2 Hazard and exposure mapping

Exposure mapping is particularly important to protect the most vulnerable populations. Exposure to specific populations like children can be quantified using resources like UNICEF's Global Child Hazards Database.[45]

Maps should be developed to provide information on which populations are most at risk and to what volcanic hazards. Geologists are responsible for determining zones for potential volcanic hazards like lava flows, pyroclastic density currents (PDC) , and ashfall, and creating associated hazard maps. Local agencies may then contribute additional data (e.g., from geographic information systems (GIS) databases) to identify:[46]

- population centres, schools and hospitals
- the number of children and other vulnerable groups in hazard-prone areas
- critical infrastructure (bridges, power grids and water sources)
- safe evacuation routes and assembly areas that are located on high ground and shielded by natural topography
- evacuation shelters

It is important to note that different kinds of hazard maps can serve different audiences. Geology-based maps are useful for understanding hazard footprints. Maps can also be plotted to show the likelihood (statistical probability) of a hazard occurring in specific locations. More qualitative maps can delineate hazard zones to support decision-making which, in turn, can be used to create administrative maps showing exclusion and controlled-access zones.[47]

3.1.3 Public emergency preparedness and response planning

Governmental disaster management/civil protection departments should develop and regularly update school and community-level disaster preparedness plans, in collaboration with the education department and local governments, respectively, that clearly describe roles, evacuation routes, safe shelters and procedures for protecting children during volcanic events. Plans should be inclusive of children's needs and developed with the participation of children and other key stakeholders. The plans should address and support the following child-specific recommendations:

Disaster risk management for volcanic eruptions in Vanuatu

Vanuatu's National Health Disaster Risk Management and Climate Change Adaptation Plan is a robust, multi-hazard health-centric strategy for volcanic eruptions and other disasters. Its focus is a decentralized response that coordinates at the lowest effective level first.

Preparedness efforts include:

- continuous risk assessments
- national and provincial disaster committees
- dedicated disaster funds
- operational plans for all health facilities
- public awareness activities and simulation drills
- National Disaster Management Office emergency procedures
- Ministry of Health coordination with partners to deploy emergency medical teams, conduct patient referrals and medical evacuations, scale up disease surveillance, and test water quality
- long-term focus on relocating health facilities away from high-risk zones and a 'build back better' approach during recovery

Evacuation planning

- Evacuation plans should include safe routes for evacuation and locations where families can remain together, in safe and welcoming spaces, with adequate nutritional food, clean water, hygiene and sanitation facilities, and access to medical care. Shelters should be located away from hazard zones.

- Evacuation centres should plan to include safe places for young children to play, provision for safe sleep for infants and private spaces for mothers to breastfeed (as well as infant formula for those who need it).

- Post-evacuation planning should include provision of sufficient supplies for returning families (including food and drinking water) to cover the resettlement period, until normal services are resumed.

Household planning

- Families should be advised to develop household plans to establish how to respond in a volcanic emergency, in alignment with advice from schools. For example, if schools have responsibility for evacuating children during the school day, parents should evacuate independently rather than first collecting their children.

- Families should be advised to develop 'reunification' plans that equip children with key information about their families: emergency contact cards in school backpacks for younger children, and helping older children memorize family member names and phone numbers.

Emergency drills

- Drills should be planned with volcano observatories and civil protection agencies, simulating realistic volcanic scenarios, including ashfall and hazardous flows (depending on the location), and be inclusive of all children, including those with disabilities. Drills should include both shelter-in-place and evacuation, depending on the hazard scenario.

- Post-drill debriefings should be used to identify gaps and improve preparedness.

Risk communication messaging

- Encourage the use of reliable information sources (governmental and non-governmental agencies) on social and other media.
- Develop a set of risk communication messages targeted at different stakeholder groups, and communicate regularly ahead of, during and after eruptions on safe practices, evacuation, resources and other relevant information, especially for families with children.
- Use clear, '[if possible] do this' instructions rather than complex scientific jargon. For children, frame protective actions as 'safety rules', and encourage them to listen to trusted adults.
- Ensure that messaging is provided in a range of media, to support populations without digital access or literacy. This may include radio and television broadcasts, infographic posters for bulletin boards and public meetings.
- Teach children the importance of respiratory protection by demonstrating the use of child-sized respirators (or well-fitting surgical or other facemasks if suitable disposable respirators are unavailable) to protect themselves, using age-appropriate demonstrations (see box for guidance).

Messaging and educational resources

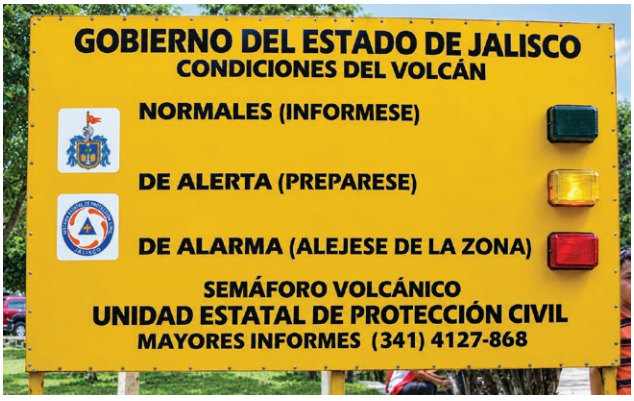
The International Volcanic Health Hazard Network has a range of public information products on preparing for, and protection from, volcanic ashfall and gases: www.ivhhn.org/information

Save the Children developed Feel Safe, an online educational tool for children, to help them build their resilience before and during disasters: https://feelsafe.savethechildren.it/en

To learn about using child-sized respirators or masks properly, visit: https://ceh.unicef.org/events-and-resources/knowledge-library/protecting-children-air-pollution

Alerts and warnings

- Establish emergency communication channels that are accessible to residents, and ensure that the populations at risk are aware of the alert system. For instance, governments may be able to leverage SMS or instant messaging apps to connect directly with the individual to issue alerts.
- Supplement sirens or text alerts with colour-coded flags or lights at schools and community centres (see picture of an alert system in Mexico).



Example of an alert system for Volcán de Colima in Jalisco Province, Mexico.
Photo credit: Claire Horwell

Preparing resources and emergency kits

- Disaster planning should include advising families to set up stores or sources of non-perishable items such as canned goods, dry foods and powdered milk with essentials such as can openers, bottled water and basic utensils.

- If ashfall is likely, advise households and other building owners to cover open-air storage tanks, disconnect downpipes and remove guttering to prevent contamination and damage from ash and acid rain. Where practical, cover equipment and ponds. Covers can be improvised from tarpaulins or materials such as plywood.

- Promote the preparation of family and school emergency kits that include child-specific items such as age-appropriate food, water, hygiene supplies, essential medicines and assistive devices, child and adult-sized respiratory protection, flashlights and comfort items such as toys or books.

- Provide guidance for accessing and setting up a high-velocity fan with a high-efficiency particulate air (HEPA) filter attached (see box for detail); these are useful for deployment in institutional facilities, such as schools, where air purifiers are unaffordable.

- For buildings which are highly susceptible to collapse under even small depths of ashfall, advice should be given that risks may be reduced by propping up roof beams and/or draping tarpaulins across thatched roofs, in advance of an eruption, to help shed ash.

Protecting indoor air quality

A self-assembled fan and HEPA filter unit (i.e., fan filter unit) can be effective at reducing indoor particulate matter. The approach can be cost-prohibitive for individual households in low- and middle-income countries. However, it may be feasible for institutional use, such as in schools and health facilities, but only where rooms can be sealed (to prevent further ash ingress and where there is air conditioning for cooling the space). Several units may be required, depending on the size of the rooms.

To learn more, visit: https://kopernik.info/en/insights-reports/kinsights/a-simple-alternative-to-homemade-hazehacks-can-reduce-nearly-threetimes-the-pollution

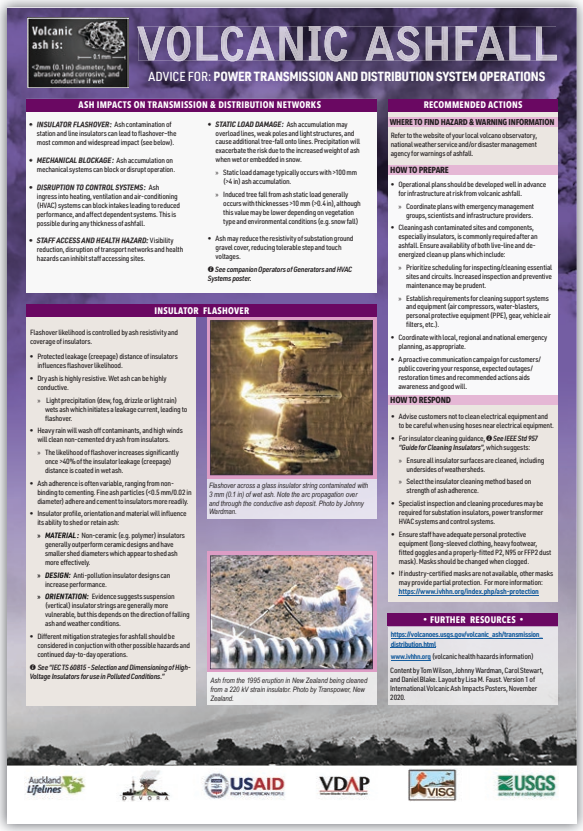

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3.1.4 Preparedness by utility, health and education sectors

Protection of power supply systems and communications networks

- Facilities that are critically dependent on continuous power should acquire, maintain and regularly test a dedicated backup generator with a secure fuel supply.
- Install ash-resistant covers on satellite dishes, antennae and other exposed equipment, where possible. Establish and test alternative communication channels and backup systems, such as:
  - satellite phones
  - two-way radios
  - mesh networks (e.g., meshtastic long range sensors)[48]



Ash impact advice

A series of posters with detailed information on ashfall impacts and mitigation advice for critical infrastructure and city managers is available here: https://volcanoes.usgs.gov/volcanic_ash/resources.html

Preparing health care services

- Health care facilities must be assessed for structural and operational resilience against ashfall.
- Health care facilities, governmental and humanitarian agencies should coordinate to maintain an emergency stock of necessary medical supplies, focusing on respiratory and eye care equipment, including certified respirators (including those designed for children's faces), nebulizers, oxygen tanks and asthma medication. Consider how to establish a fair allocation of resources.
- Health care facilities should take measures to exclude ash as it can contaminate operating theatres and exacerbate respiratory illnesses.
- Health care facilities should prepare a triage plan to manage the expected surge in patients presenting with respiratory issues, eye irritation, psychosocial issues and injuries such as burns. This includes identifying and preparing off-site or temporary care areas if necessary.
  - Evidence from the Whakaari/White Island 2019 eruption indicates that volcanic burn injuries may necessitate increased surgical intervention time, prolonged hospitalization and higher health care utilization compared to predictive models, reflecting their severity and complexity.[49]

Mexico health sector's eruption preparedness plan

'Health Plan Popocatépetl' is the blueprint drafted by the State of Puebla, Mexico, for response to a future eruption of Popocatépetl volcano. Its multi-faceted approach involves several Government sectors across health, education, essential services and community government.

- The initial phase identifies 10 evacuation routes that connect high and moderate-risk areas with 191 temporary shelters capable of housing more than 70,000 people. During an eruption response, established primary and secondary control points provide initial medical assessment, triage, care, referral, epidemiological reporting and health promotion.
- Health departments then actively manage shelters and a State Committee for Health Security (CESS) meets quarterly to coordinate health, defence, education, and any other necessary agencies. Health districts are individually analysed to categorize their risk.
- Post-eruption mental health support is a specific provision and the recovery phase is based on the situation analysis, continuity of essential services, resource reallocation, facilitating the return of evacuees and establishing reconstruction plans.

Preparing educational facilities

- If possible, designate and equip specific, well-sealed rooms in schools as 'safe rooms' or clean air zones for students with pre-existing conditions like asthma or severe allergies. These rooms should ideally have dedicated air purifiers to maintain superior indoor air quality, and air conditioners to maintain safe temperatures, during and following ashfall events. See the 'Protecting indoor air quality' box, in the previous section, for alternative lower-cost fan-filter options.
- Maintain an up-to-date register of students with pre-existing respiratory and cardiovascular conditions.
- Ensure schools are equipped with emergency cleaning supplies, including mops, cloths and, ideally, HEPA-filter vacuum cleaners (preferable to dry sweeping, which causes ash resuspension) to safely remove volcanic ash.
- School preparedness plans must be child-centred and inclusive, clearly describing shelters, evacuation procedures and staff roles for protecting children, particularly those with disabilities or special needs, during both shelter-in-place and evacuation scenarios. To note, teachers may also become first responders and their well-being should be considered.
- Schools should maintain kits with first aid supplies, and child- and adult-sized respiratory protection for reducing exposure to volcanic ash.
- If possible, identify and test remote learning options and alternative learning spaces, in advance, to ensure classes can resume quickly and that education continuity is maintained during prolonged school closures.

- Empowering children as messengers within their families and communities also strengthens overall resilience and promotes a culture of safety. Integrate age-appropriate education on volcanic hazards and impacts into school curricula and community programmes to build children's knowledge, confidence and preparedness. Interactive methods – such as games, storytelling and role-playing[50] – can help children retain key messages. Lessons should cover basic volcano science, local risks, early warning signs and protective actions.

- Schools should communicate, in advance, to caregivers who has responsibility for children in an evacuation (or shelter-in-place order) during school hours.

- Schools may find it useful to teach children about mental health resilience in advance of an eruption.



3.2 Eruption response

First response: Saint Vincent and the Grenadines

After the La Soufrière eruption in Saint Vincent and the Grenadines in 2021, UNICEF advised that children should be the last group to return to affected areas, once schools and outdoor play spaces had been thoroughly cleaned, to minimize any risk to their health from volcanic ash. Ideally, decisions would also be based on air quality monitoring data.

The multi-agency response effort focused on immediate relief, child protection and building long-term resilience. More than 20,000 people, about a quarter of them children, had to be evacuated from the area around the volcano. UNICEF support for the Government response focused on WASH services, dispatching pre-positioned supplies such as water purification tablets and hygiene kits within 24 hours, and child protection services such as family reunification and creation of safe child-friendly spaces. A critical lesson learned was that institutional readiness, like that of Saint Vincent and the Grenadines National Emergency Management Organization, is essential for effective coordination and command.

3.2.1 Evacuation/shelter-in-place decisions and management

If children must be evacuated from their homes due to either life-safety risks or deteriorating environmental health conditions, many indirect impacts can be expected, particularly if children need to be housed in evacuation shelters. These can include anxiety and other psychosocial impacts, particularly if their caregivers' livelihoods or homes are at risk; and the spread of communicable or foodborne diseases if children are living in cramped and unsanitary conditions.

The decision whether to evacuate or shelter in place (usually within the home) will be taken by local authorities and leaders, informed by monitoring of the volcano, and based on the expected hazards and their associated risks. This process should include an assessment of both social and economic costs and benefits and be reviewed regularly.

Hazard management zones (which will be based on prior hazard assessments by volcanologists) can vary based on distance from the volcano and topography. Exclusion zones will signal the need for evacuation from areas at greatest risk of flows (lava, pyroclastic, lahars), ballistics, blasts and heavy ashfall. Introduction of other zones, further from the volcano, may establish shelter-in-place orders or trigger advice to help communities reduce exposure to volcanic emissions such as advice that children should not play outside.

Effective evacuation shelter services are crucial for mitigating the trauma and health risks associated with volcanic displacement. To protect children's health, safety and psychosocial well-being, shelters must be well-managed from the start to meet essential humanitarian standards that take into account the unique vulnerabilities of children in crowded, stressful environments.

Evacuation shelters should provide:[51]

- 'reunite' contact points to gather and coordinate information about displaced children and the families looking for them
- staff and volunteers trained in child safeguarding and referral procedures to:
  - ensure rapid response to protection concerns
  - consistently monitor health-related issues and needs

- **Water, sanitation and hygiene (WASH) – ensuring, immediately post-eruption:**
  - at least 15 litres of safe water per person per day
  - adequate, accessible and gender-segregated toilets
  - handwashing stations nearby
- **Health and nutrition:**
  - screening as families enter shelters, identifying and isolating those who need treatment to protect the healthy
  - prioritizing the needs of infants and children, creating separate areas for them and their caregivers
  - prioritizing safe storage, and prompt dispensing, of medication, particularly for children with chronic respiratory illnesses such as asthma
  - ensuring that the provision of food takes into account the special nutritional needs of infants, children and pregnant women
- **Psychosocial and safe spaces:**
  - establishing 'child-friendly spaces' to be safe, supervised areas for structured play and recreation to promote normalcy and reduce mental stress
  - protection from violence, exploitation and abuse
- **Education:**
  - providing temporary learning opportunities and materials using local resources and teachers, minimizing educational disruption
- **Special needs:**
  - facilities and services should be accessible to children and other groups with special needs
  - registration processes should identify their needs as early as possible
- **Support for breastfeeding women**:
  - they should not be offered infant formula, but it should be available to those who need it, with the means to prepare it safely
  - interventions on sexual and reproductive health needs are provided by the United Nations Population Fund (Minimum Initial Service Package)[52]
- **Post-evacuation:** Returning families should be given sufficient supplies to cover the resettlement period, until normal services are resumed.

Leveraging existing humanitarian guidance

Developed by the Interagency Working Group on Infant and Young Child Feeding in Emergencies, the guidance includes recommendations for minimizing infant and young child morbidity and/or mortality risks associated with feeding practices during emergencies: www.ennonline.net/sites/default/files/2024-11/ops-guidance-on-ife_v3_english.pdf

The Minimum Standards for Child Protection in Humanitarian Action would support developing child-friendly spaces and avoiding exposing children to further harm: https://image.savethechildren.org/cp-min-standards-12.pdf-ch11044404.pdf/ju5bb5487y454h18d646jj5qys6ywd83.pdf

The Guidelines on Mental Health and Psychosocial Support in Emergency Settings can help enable necessary social supports that protect children's mental health and psychosocial well-being during emergencies: https://interagencystandingcommittee.org/iasc-task-force-mental-health-and-psychosocial-support-emergency-settings/iasc-guidelines-mental-health-and-psychosocial-support-emergency-settings-2007

3.2.2 Managing food safety and security concerns

Volcanic eruptions may threaten food security and safety. Following an eruption, agricultural and food safety agencies should provide the following advice:

- Ash deposits on the skin or peel of food crops will not necessarily make the food unsafe to eat. In general, food that can be washed or peeled (such as pineapples or bananas) should be safe, unless advised otherwise by food safety agencies.
- Animals or fish that are found dead should not be eaten.
- Food distribution programmes may be necessary as damage to crops may cause shortages.
- Ensure that safe food handling practices are followed in evacuation shelters.

3.2.3 Air quality monitoring and management

During and following an eruption, air quality can be severely affected by volcanic emissions. Ideally, regular bulletins on this should help agencies and communities assess likely health risks for more vulnerable groups, including children. As well as referring to air quality indices, agencies may also compare measured concentrations to either national air quality standards or international guidelines (for example, the World Health Organization's Air Quality Guidelines).[53]

However, setting up accurate monitoring of airborne particulates and gases can be a challenge in some settings. The most accurate instruments (regulatory-grade) are costly and, if volcanic activity is infrequent, cost benefit may be hard to justify for lower-income countries. A range of lower-cost sensors are available for airborne particulate monitoring and are useful to fill in monitoring gaps, but they are not as accurate as regulatory-grade instruments as they cannot be calibrated after purchase, and their data may drift with time. Therefore, unless calibrated against reference-grade instruments, they can be used to give an indication of air quality but should not be used to determine if concentrations are above or below air quality standards.[54]



Figure 8. Hawaii State Department of Health guidance on short-term sulfur dioxide (SO_2) advisory levels

SO_2 Conc. (ppm)[1]	Color Code & Air Quality Condition	Air Quality Description	Recommended Action/Activity[2]		
			Sensitive Groups[3]	People Experiencing Health Effects[3]	Everyone Else
0 – 0.10	Green (Good)	Considered satisfactory & poses little or no risk	Highly sensitive individuals may be affected at these levels		Potential health effects not expected
0.11–0.20	Yellow (Moderate)	Acceptable, however, may be moderate health concern for small number of people	Be aware that levels are slightly elevated	If you experience breathing difficulties, such as chest tightness or wheezing, stop activities, use a rescue inhaler and find a place to sit down and rest.	Potential health effects not expected, however actions to reduce exposure to vog may be useful
0.21–1.00	Orange (Unhealthy for Sensitive Groups)	Members in sensitive groups, including healthy individuals with mild asthma, may experience health effects. They may be affected at lower levels than general public. Toward the upper end of this range, most asthmatics who are active outdoors are likely to experience some breathing difficulties. General public not expected to be affected in this range.	Avoid outdoor activities that cause heavy breathing or breathing through the mouth[4]	If you experience breathing difficulties, such as chest tightness or wheezing, stop activities, use a rescue inhaler and find a place to sit down and rest.	Potential health effects not expected, however actions to reduce exposure to vog may be useful
1.01–3.00	Red (Unhealthy)	Everyone may begin to experience health effects. Members of sensitive groups may experience more serious health effects.	Avoid outdoor activities & remain indoors	Consider leaving the area	Avoid outdoor activities that cause heavy breathing or breathing through the mouth[4]
3.01–5.00	Purple (Very Unhealthy)	Triggers health alert, meaning everyone may experience more serious health effects.	Avoid outdoor activities & remain indoors	Leave the area & seek medical help	Avoid outdoor activities & remain indoors
> 5.01	Maroon (Hazardous)	Triggers health warnings of emergency conditions. Entire population is more likely to be affected.	Avoid outdoor activities & remain indoors. Leave the area if directed by Civil Defense	Leave the area & seek medical help	Avoid outdoor activities & remain indoors. Leave the area if directed by Civil Defense

Source: Hawaii Department of Health, Air Quality Data Portal, www.hiso2index.info/SO2_Exposure_Levels.pdf

Figure 8, above, is an example of air quality guidance developed by the Hawaii State Department of Health (DOH) specifically for the volcanic context, focused on short-term (15-minute average) SO_2 gas concentrations. Note that other countries may use different units for airborne pollutant concentrations (e.g., $\mu g/m^3$) or an air quality index. 'Sensitive groups' refers to children and individuals with pre-existing respiratory conditions such as asthma, bronchitis, emphysema, lung or heart disease (Hawaii State Department of Health, 2011).[55]

Airborne ash poses a particular hazard for children during and after an eruption but, unless families are able to leave the affected area, they must find other ways to reduce exposure.

When there is ash in the air, or deposited on the ground, the following advice can be given to help improve indoor air quality:

- Take steps to keep ash out of buildings by tightly closing all doors, windows, and openings (including air vents), where possible. Cover ventilation gaps with thick fabric or plastic sheeting. Raised internal building temperatures can present an additional hazard, particularly to very young children; opening windows in between ashfall events (once the air has cleared) can help reduce temperatures and disperse other types of indoor pollution.

- For buildings with double doors, setting up 'ash locks' where ashy clothing and footwear can be removed before going indoors may help reduce ash exposure indoors. Otherwise, leave ashy footwear and outerwear outdoors.
- Ensure that HVAC systems are switched to recirculate mode so they do not draw outdoor ashy air indoors or into vehicles. Increased maintenance of HVAC systems will be required in ashy conditions. Air purifiers should be used, if available.
- Remove ash from around properties. Lightly dampen the ash to stop particles becoming airborne during clean-up (unless advice is given to preserve water supplies) and follow instructions on ash disposal.

When outdoors, respiratory protection can be worn. Well-fitting facemasks designed to capture fine particulates are the only effective respiratory protection – cloth is a poor filter. Respirators, such as KN95 or N95 certified products, are designed to capture at least 95 per cent of fine particles, but a good fit is essential.[56] Small sizes are increasingly available for children, but they should not wear such devices while sleeping. Surgical masks may filter particles but are not designed to fit well to the face. Using an ear-loop clip may help to improve fit. Decisions on whether a child is old enough to wear respiratory protection should be based on their ability to tell someone if they feel uncomfortable, and to remove the device.

It is much harder to reduce exposure to volcanic gases. Disposable facemasks only filter particles, and gas masks are not recommended for the public, and especially not for children. If homes or other buildings cannot be effectively or safely sealed from high concentrations of volcanic gases, children should be removed from the area.

Protecting children from air pollution

The Factors Affecting Childhood Exposures to Urban Particulates (FACE-UP) project developed a booklet for caregivers and educators, to answer questions on how to best protect children from (general) air pollution. This includes how children can fit respirators/masks correctly. Accompanying the booklet is an animated video for children and an associated comic-strip infographic. https://ceh.unicef.org/events-and-resources/knowledge-library/protecting-children-air-pollution

The International Volcanic Health Hazard Network also has extensive resources (booklets, posters, leaflets and videos) on protecting communities from volcanic emissions, including advice on preparing for ashfall. www.ivhhn.org/information

3.2.4 Water quality monitoring and management

Following an eruption, health and emergency management agencies should do the following to protect household water supplies:

- If not already done before the eruption, advise households to cover open-air storage tanks, disconnect downpipes to tanks and pre-emptively remove guttering to prevent damage.
- Reinforce advice to disinfect water supplies, advise on appropriate methods such as filtering, boiling or chemical disinfection and, if necessary, provide equipment and/or consumables for disinfection.
- Distribute alternative water supplies to households in need, for example using water tankers.
- Initiate rapid analyses of drinking water and communicate results to the public in a timely and informative manner. Advice on water sampling and analysis following a volcanic eruption is available here: www.ivhhn.org/uploads/IVHHN_briefing_note_water_quality.pdf

Considerations for making up infant formula:[57]

- Water used to prepare infant formula should meet normal drinking-water standards. These specify safe levels of chemical contaminants such as lead and fluoride for infants. If safe, treated water supplies are not available, commercial bottled drinking water may be used. If neither are available, other water supplies such as roof-collected rainwater may be used but must be boiled prior to use.

- Because powdered infant formula is not sterile, it should be prepared using water heated to at least 70°C as this greatly reduces the risk of harmful bacteria surviving.

Implications for medical services:

- Some medical procedures depend on a continuous supply of highly purified water that is much cleaner than normal drinking water. Damage to water treatment systems can compromise this supply. Management may involve transfer of patients to other facilities or restoration of water treatment as an urgent health care priority.

3.2.5 Protecting stormwater and wastewater systems and managing health risks

- As far as possible, prevent ash from entering underground pipe networks as it can cause blockages which can be extremely difficult to remove. All efforts should be made to clean ash from roads before rainfall, and sandbags should be placed around drains to keep ash out.

- If ash-laden wastewater does reach a wastewater treatment plant, the best option may be to temporarily bypass the plant and discharge raw or partially treated wastewater to the environment. Risks to public health must be managed by measures such as installing warning signage at access points, closing beaches and fisheries, stepping up monitoring and communicating results to the public, and establishing surveillance for gastrointestinal diseases in the exposed population.

- In the event of localized flooding caused by ash blockages of stormwater systems, children must be kept out of floodwaters as they are typically contaminated and may contain hidden hazards. Clear messaging should advise caregivers to prevent children from playing or wading in floodwaters.



Water storage tank well covered with metal roofing materials, tarpaulin and concrete blocks to protect the stored water from ashfall contamination. South Ambae, Vanuatu, August 2018.
Photo credit: Carol Stewart

3.3 After an eruption

3.3.1 Post-eruption clean-up and rehabilitation

It is important to clean up volcanic ash promptly from homes and neighbourhoods as it is a health hazard, can cause damage and disruption to critical infrastructure such as power and water supplies, disrupt transport networks, block storm drains and cause corrosion damage to building materials. Psychologically, it is also important to remove ash so that communities can return to normality and children can resume regular routines.

Key considerations during clean-up operations:

- Keep children indoors, particularly vulnerable children, and discourage them from playing in the ash.
- Do not allow children to help with outdoor clean-up; ash lifted into the air is a breathing hazard and ash clean-up is also physically demanding as ash is much heavier than people expect.
- When removing ash that has settled indoors, use wet cloths and (if possible) vacuum cleaners with HEPA filters to avoid remobilizing ash. Consider moving children to cleaner spaces, or giving them well-fitting respiratory protection, while cleaning is taking place indoors.
- City managers may wish to adopt measures such as restricting vehicle speeds and dampening the ash with water to prevent it from lifting into the air.

Ash clean-up resources

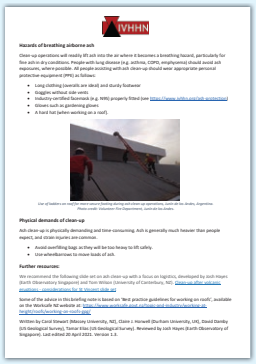
The following resources on ash clean-up may be useful:

- For detailed advice on ash cleanup, refer to the USGS website: https://volcanoes.usgs.gov/volcanic_ash/cleanup_disposal.html

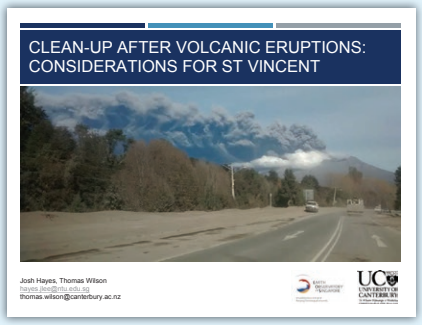


- For health and safety considerations during clean-up, including recommended personal protective equipment, refer to the IVHHN briefing note: www.ivhhn.org/uploads/IVHHN_briefing_note_clean-up_health_safety.pdf





- Slide set on ash clean-up with a focus on logistics: www.ivhhn.org/uploads/Hayes_Wilson_Clean-up%20after%20volcanic%20eruptions.pdf





During prolonged exposure to thick ashfall from the 2011 Cordón Caulle eruption, Chile, residents from Jacobacci, Argentina were advised to drive slowly to reduce ash remobilization.
Photo credit: Municipality of Ingeniero Jacobacci, Argentina

3.3.2 Coordinating broader recovery and health system support

In addition to ash clean-up, a range of other recovery services are essential to help communities and health systems recover in the weeks and months following an eruption. Coordinated action across government departments, alongside international and humanitarian partners, where relevant, helps ensure that families can access the support they need to rebuild, and that health facilities can continue delivering both emergency and routine care throughout the recovery period.

Broader recovery services

- overall coordination of recovery timing and resource scaling across sectors, which should also include coordinating a multisectoral debrief to understand what went well and what could be improved before the next eruption
- damage and needs assessments of housing, schools, health facilities and critical infrastructure to capture loss and damage data
- insurance and disaster relief access, including simplified claims processes and cash or in-kind assistance for affected households
- livelihoods and economic recovery support for households that have lost crops, livestock or other productive assets
- monitoring of secondary hazards (e.g., lahars during the rainy season) to inform safe return of displaced families
- restoration and continuity of education by reopening schools once they have been structurally assessed and cleaned, and supporting continuity of learning in the interim

Health system recovery

- Surge health workforce and supplies, including stockpiling essential medicines (e.g., respiratory, wound care, and other medications anticipated to be in high demand), to manage acute injuries, respiratory illness and other eruption-related morbidities that manifest during and after the eruption.
- Mortality management, including mortuary services and support for bereaved families.
- Structural assessment and repair of health facilities before resuming full operations.

Lessons: Recovering from Guatemala's 2018 eruption of Volcán de Fuego

Lessons learned from the response to the 2018 Volcán de Fuego eruption in Guatemala centred on three key areas: public health, education and disaster risk financing.

Health: While the Ministry of Public Health and Social Assistance had coordinated medical care and hygiene for displaced families, a later review discovered an urgent need to strengthen inter-institutional coordination among health officials, the national disaster coordination secretariat and municipal government.

Education: Schools in Escuintla and Sacatepéquez were destroyed, and a social recovery plan coordinated by the Office of the First Lady emphasized the need for psychosocial support for children who were living with their families in shelters and whose education had been interrupted.

Finance: Post-eruption, the Ministry of Finance led the design of new transparent post-disaster expenditure systems that made it possible for the country to access instruments such as the Caribbean Catastrophe Risk Insurance Facility – a multi-country risk pool – and the Catastrophe Deferred Drawdown Option. This meant rapid finance was secured for health and education recovery. Guatemala's national disaster risk financing framework now ensures accountability and the swift mobilization of funds for disaster recovery.

Linking cash transfers to post-eruption recovery programming

After the La Soufrière eruption in Saint Vincent and the Grenadines in 2021, the World Bank introduced temporary cash grants for displaced households in collaboration with UNICEF, which provided the financial and technical assistance to temporarily expand the national social protection system to reach more affected families.

This successful 'cash-plus' model linked monthly grants to a 12-week Family Life Education programme which included modules on mental health, financial literacy, essential household budgeting and hygiene promotion, addressing eruption and disease-related hazards. A further component provided short-term income through ash clean-up and debris removal and promoted the involvement of women.

The overarching recovery strategy stipulated that the replacement of damaged critical infrastructure such as schools, roads and water systems must adhere to 'build back better' principles, bedding in resilience against future volcanic and climate-related hazards.

3.3.3 Accessing mental health support

Mental health support after the 2022 Tonga eruption

The 2022 volcanic eruption and tsunami in Tonga affected 36,000 children and their families. Alongside assistance with technical and financial assessments for the Ministry of Health and training for health workers on managing malnutrition in crises, UNICEF created a psychological first aid programme for children and adolescents. A hundred recreational kits were also distributed to support psychosocial services in child-friendly spaces.

Tevalyn, who was 17 years old when the eruption struck, became a peer supporter through the *Support My Friends* training programme introduced in Tongan schools by UNICEF. "When I help my friends, it teaches me to handle my own problems," he says. What he has learned about psychological first aid has not only helped him deal with his own anxieties, but also to identify and help friends in distress. The programme aims to teach children aged 9 to 17 the mental health first aid principles of 'LOOK, LISTEN, and LINK' and emphasizes the empowerment of young people so that they can help each other under adult supervision. Tevalyn hopes one day to become a surgeon, and he believes the programme has also helped him develop important skills that will advance his career ambitions.

In the immediate aftermath of an emergency, layered support structures such as those outlined in the IASC guidelines[58] are crucial. At the foundational level, restoring basic services and security, including ensuring access to food, shelter, health care, education and family reunification, is critical to preserving mental health, dignity, safety and predictability in children's lives.

Psychological first aid (PFA) may be provided by trained responders to promote a sense of safety, calm, connectedness and hope. Early identification and triage are essential to detect children and caregivers who are at heightened risk of distress or trauma. Psychoeducation delivered in developmentally and culturally appropriate ways can help normalize emotional responses and dispel misconceptions about the eruption.

Keeping families together and supporting caregiver mental health and parenting capacity can be protective anchors, as a child's recovery is often inseparable from that of their parents or broader caregiving system. As the situation stabilizes, mental health and psychosocial support should shift towards long-term community-based, non-specialized support that improves children's well-being and social connectedness. Communities should be supported to organize social support networks, cultural and spiritual healing activities, and youth-led initiatives which embody local coping traditions and collective efficacy as core determinants of sustainable recovery.

Providing post-eruption psychosocial support in Vanuatu

After the Government of Vanuatu ordered the total evacuation of the island in September 2017 in response to the eruption of the Manaro Voui volcano, international partners supported Government efforts to address the complex needs of the evacuated communities.

UNICEF and its partners gave crucial psychosocial support to children and families through Government-led efforts focused on culturally and age-appropriate, safe activities. Sports and games were organized, designed to help young people develop life skills and coping mechanisms and strengthen community resilience. These activities were anchored to the existing traditional support systems and networks of Vanuatu's unique culture, and helped the displaced communities process the traumatic experience of mandatory evacuation and uncertainty.

The Gender and Protection Cluster (GPC), led by Vanuatu's Department of Women's Affairs, worked to ensure humanitarian responses were inclusive, equitable and sensitive to vulnerabilities, creating clear referral pathways for vital services like gender-based violence (GBV) and child protection.

4. Conclusion

Globally, more than 166 million children live within 100 km of a recently active volcano, approximately 60 per cent of them in low- and middle-income countries where resources for preparedness, response and recovery may be constrained. Children are particularly vulnerable to the impacts of volcanic eruptions because of physiological, behavioural and developmental factors, and their dependence on adults and essential services. These vulnerabilities extend beyond direct exposure to volcanic hazards, such as ashfall, volcanic gases and other potentially life-threatening phenomena, to the wider consequences of displacement and disruption to health care, education and other services.

Although the timing and impacts of volcanic eruptions cannot always be anticipated, experience from past eruptions provides a basis for reducing the risks to children. Government agencies, humanitarian organizations and local communities all have a role to play, from incorporating children's specific needs into early warning and evacuation planning, and ensuring access to appropriate protective equipment and supplies, to providing child protection and psychosocial support during and after volcanic crises. Volcanic risk cannot be eliminated entirely, but systematic implementation of the recommendations in this report can substantially improve preparedness and response, reduce the disproportionate impacts on children, and strengthen the resilience of communities living near active volcanoes.



Annex A: Life-safety hazards and risk management

Table A1. The main volcanic life-safety hazards and risk management options

Hazard	Definition	How they injure or kill people	Maximum travel distances (for life-safety)	Risk management options
Ballistic projectiles	Fragments of hot rock or lava thrown from a volcanic vent during an eruption.	The blocks can cause blunt force trauma, fractures and lacerations.	Typically land within 5 km of the vent but can roll further.	Impose an exclusion zone around explosive volcanoes up to ~5 km distance from the vent.
Jökulhlaup	A sudden and massive flood caused by lava under a glacier or ice cap causing rapid melting.	Like other glacial floods, jökulhlaup can injure or kill through extreme physical trauma and drowning, but also through thermal burns if the lava has heated the water.	Typically between 10 and 100 km.	Developing clear and well-rehearsed evacuation plans for communities at risk is crucial. Flood warning systems are very effective at reducing risk. Pre-event development of hazard maps can identify high-risk areas and help local communities understand the risk.
Lahars (mudflows)	Slurries of rock, mud and water that flow rapidly (up to 50 km/hr) down valleys.	Eruptions can trigger lahars by releasing water from crater lakes or by hot volcanic ash landing on and melting snow. They can also be triggered after eruptions have finished (and in non-eruptive periods) by heavy rainfall mobilizing volcanic ash deposits. Death most commonly results from drowning, and traumatic injuries.	Typically tens of km, but can travel >100 km.	Developing clear and well-rehearsed evacuation plans for communities at risk is crucial. Lahar warning systems are very effective at reducing risk. Pre-event development of hazard maps can identify high-risk areas and help local communities understand the risk.
Landslides (debris avalanches)	Collapse of sectors of the volcano, common on stratovolcanoes (steep-sided, conical volcanoes). Triggered by intrusion of magma into the volcano, explosive eruptions, earthquakes and/or heavy rainfall.	Landslides are highly destructive and can endanger nearby communities, causing burial and traumatic (crush) injuries.	Large sector collapses can travel tens of km.	Developing clear and well-rehearsed evacuation plans for communities at risk is crucial. Public education campaigns, tsunami drills and early warning systems all help reduce risk. Pre-event development of hazard maps can help local communities understand the risk.

Hazard	Definition	How they injure or kill people	Maximum travel distances (for life-safety)	Risk management options
Lava flows	Fast or slow moving flows of molten rock.	The flow front often advances quite slowly so people can easily move out of the way. However, fatalities have occurred when escape routes have been cut off. Lava can set fire to buildings, vehicles, fuel tanks and cause explosions. Explosions can also occur if lava flows enter water bodies or ice.	Tens of km.	Land-use planning and zoning can help avoid siting vulnerable infrastructure such as fuel tanks and water pipes in lava flow paths. Public education campaigns to warn people to stay well back from lava flows can help reduce risk.
Pyroclastic density currents (PDC)/ flows	Intensely hot (up to several hundred degrees Celsius), fast-moving (50–350 km/hr), ground-hugging flow of ash, gas and rock fragments that travels down the slopes of a volcano.	PDCs are highly destructive and lethal and move too quickly for people to escape. Very few people survive being caught in a PDC. Deaths result from burns to the skin and lungs, asphyxiation and traumatic injuries.	Tens of km.	Developing clear and well-rehearsed evacuation plans for communities at risk is crucial. Pre-event development of hazard maps can identify high-risk areas and help local communities understand the risk.
Tephra	Material erupted from a volcano that becomes airborne and travels downwind. Fine tephra less than 2 mm in diameter is referred to as volcanic ash.	Close to volcanoes, thick tephra falls can cause fatalities through roof collapse. Extremely high airborne concentrations could potentially cause asphyxiation and, after deposition, burial.	Usually limited to within a few km of vent.	Clearing tephra from roofs using safe working methods can limit its accumulation. Developing clear and well-rehearsed evacuation plans for communities at risk is crucial.
Tsunami	A series of large waves caused by the sudden displacement of water from volcanic activity.	Underwater or above water eruptive activity can cause tsunami that can devastate distant shorelines and travel far inland. Deaths most commonly result from drowning and/or traumatic shock or injury.	Thousands of km.	Developing clear and well-rehearsed evacuation plans for communities at risk is crucial. Public education campaigns, tsunami drills and early warning systems all help reduce risk. In some locations, vertical evacuation structures may offer refuge from tsunami waves.
Volcanic gases	Carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2) are the primary volcanic gases of concern.	CO_2 and H_2S are asphyxiant gases which are heavier than air and can pool in depressions. Rarely, lakes with CO_2 accumulated at the bottom can overturn, releasing a cloud of gas in a 'limnic' eruption. H_2S is common in geothermal locations. SO_2 is an irritant gas which can reach life-threatening concentrations close to eruption sites and can convert to sulfate aerosol (H_2SO_4) downwind. HCl exposures occur where lava reacts with seawater to form 'laze'.	Usually limited to within a few km of vent or where lava flows enter the sea, but can reach hundreds of km.	Public education, informative signage and monitoring of gas concentrations all help reduce risk.

Annex B: Literature review of respiratory and mental health impacts of volcanic hazards to children

Respiratory impacts from inhaling volcanic emissions

Acute impacts from ash

Relatively few studies have been conducted on the impacts of volcanic emissions on children, compared with other air pollution crises such as wildfires. Hlodversdottir et al. (2018)[59] investigated the physical (and mental, see below) health impacts to children (aged under 18 years) of the 2010 eruption of Eyjafjallajökull, Iceland, by interviewing their caregivers, 6 to 9 months after the eruption. They found that children exposed to volcanic ash were more likely to have experienced (non-specific) respiratory symptoms than non-exposed children. No significant improvement was detected three years later.

Forbes et al. (2003)[60] studied the respiratory impacts of volcanic ash exposures from Soufrière Hills volcano (active from 1995–2011) on children living on the Caribbean island of Montserrat (a British Overseas Territory), again through a survey of caregivers, and through exercise-induced lung-function testing. In the first study, in 1998, the prevalence of wheeze and exercise-induced bronchoconstriction was greater for children aged under 12 years who had been heavily or moderately exposed to ash compared to the group who had been exposed to low levels. Few children with asthma were receiving appropriate treatment. A similar study was conducted in 2007 but, in the new cohort, around half of the children were born overseas. In this study, there was no evidence that children living in areas of moderate to high exposures to ash had worse lung function, more allergies or asthma symptoms than those who had never lived in such areas.[61]

Sakurajima volcano (Japan) is another volcano which has displayed prolonged activity over the past couple of decades, sometimes erupting several times per day, thereby exposing local communities to frequent ashfall. Uda et al. (1999)[62] gave a self-administered questionnaire to local school children (aged approximately 6–12 years) and a control group. They did not find any difference in the prevalence of asthma between the two groups.

Regarding acute respiratory impacts in the days to weeks after an eruption, Naumova et al. (2007)[63] used Emergency Room records to study rates of visits for respiratory conditions (acute upper and lower respiratory infections[64] and asthma-related conditions) in children under 15 years old exposed to ash from the eruption of Guagua Pichincha, Ecuador, in 2000. The rate of visits for respiratory infections substantially increased in the three weeks after the eruption. Respiratory distress was especially prevalent in children under 5 years old. The rate of asthma-related conditions doubled compared to baseline data.

Similarly, Kraemer and McCarthy (1985)[65] found a nearly twofold increase in paediatric asthma admissions to hospitals in Spokane County, Washington state in the month following the eruption of Mount Saint Helens, on 18 May 1980. In contrast, Buist et al. (1983)[66] found no strong evidence of effects on lung function in children (with diabetes mellitus, including some with lung diseases) attending a summer camp who were exposed to emissions from the Mount Saint Helens eruption. Similarly, Johnson et al. (1982)[67] saw no significant change in lung function in children aged ~9–11 years, participating in an air pollution study in Montana. The children's pulmonary function was tested on 23 May and compared to six previous measurements over the previous year. The authors considered that the lack of effect may have been due to advice that people should remain indoors while ash was in the air, and businesses and schools were closed for the first four days after the eruption.

Chronic impacts from ash

Regarding potential impacts from chronic exposure to volcanic ash, a comprehensive risk assessment (modelling exercise) was conducted during the eruption of the Soufrière Hills volcano, Montserrat, which included children. The risk assessment was triggered by concerns about prolonged and high exposures to the crystalline silica mineral cristobalite in the ash, and the potential for silicosis (a fibrotic and fatal lung disease caused by exposure to some types of crystalline silica). Baxter et al. (2014)[68] describe the full risk assessment in detail, and the probabilistic modelling is published by Hincks et al. (2006).[69] The estimate of children developing early radiological evidence of silicosis was less than 5 per 1,000 after 5 years of volcanic activity, 2 per 100 after 10 years and up to 4 per 100 after 20 years, which was considered a significant risk. With exposure-control measures implemented (play areas being kept clear of ash, children avoiding areas being cleared of ash, and schools and houses being made more 'ash proof'), the UK and Montserrat governments concluded that the health risk could be controlled at tolerable, or minimal levels. The predicted risks also lessened because of less-frequent ashfalls (post 2002, when the initial risk assessment was conducted) compared to the early years of the eruption (1996–2002). There have also been several studies which have indicated that the cristobalite in the Soufrière Hills ash may not be particularly toxic,[70, 71] perhaps at a similar level to mixed coal mine dusts.[72]

Nevertheless, due to the increased risk to children, following the 2007 study (the follow-on study from Forbes et al. (2003) described above)[73] 37 children from that study who had received the highest ash exposures were given chest X-rays. No evidence of silicosis was seen.

Acute impacts from gases

While the above studies focused on volcanic ash, it can be hard to separate the respiratory effects of sulfur dioxide gas, which can coexist with the ash, and also the effects of other airborne contaminants such as urban pollution. Much of the knowledge on the health impacts of sulfur dioxide gas and the resulting sulfate aerosol particles comes from epidemiological and public health investigations of the ash-poor lava eruptions at Holuhraun in Iceland and Kīlauea in Hawaii. Both islands have low to moderate levels of background anthropogenic pollution.

Sulfur dioxide (SO_2) from the Holuhraun eruption (2014–2015) was associated with increased child (under 18 years) health care utilization for respiratory conditions with respect to asthma medication dispensation, and visits to primary care and emergency departments for respiratory conditions (Carlsen et al. 2021a).[74] During the eruption, on some occasions, wind patterns enabled the volcanic plume to be directed back to Iceland after a few days, as a 'mature' cloud composed mostly of sulfate aerosol, which communities were exposed to, sometimes in combination with the 'fresh' SO_2-rich plume. In these periods (and the following day), Carlsen et al. (2021b)[75] found that – after adjustment for SO_2 – there was an association between the days when people were exposed to the mature plume and child hospital emergency department visits for respiratory conditions (but no significant association with primary care visits or medication dispensation, once concurrent SO_2 exposure was adjusted for). An association with increased child visits to primary care medical doctors was also found for circulatory system disease.

In Hawaii, gas-rich eruptions occur, mainly from Kīlauea volcano, and several studies have investigated the impact of the gases, and resulting sulfate aerosol, 'vog', on children's health. The longevity of the Kīlauea eruption presents a challenge for health studies as the same population cannot be compared before and after vog exposure. Comparison is generally made between high- and low-vog exposure zones, but the relatively small study populations and demographic differences between the zones limit the robustness of the conclusions. Longo and Yang (2008)[76] used records from clinics and emergency rooms on Hawaii and found that the greatest risk of acute bronchitis was in children aged 0–14 years in the exposed communities. Tam et al. (2016)[77] found that exposure to the 'vog' was associated with increased cough and decreased lung function but not with diagnosed asthma, bronchitis, persistent cough or wheeze in children aged approximately 9–11 years.

Mount Oyama on the island of Miyakejima, Japan also experienced a gas-rich eruption, in 2000. All citizens were evacuated from the island, due to the concentrations of SO_2. Iwasawa et al. (2015)[78] investigated the health effects of the gases on children aged 6–18 years returning to the island in 2006, when SO_2 concentrations were reduced but still present. Health check-ups, including spirometry (lung function) were conducted from 2006–2011 and effects evaluated through a self-administered questionnaire. They found exposure-dependent increases in irritative symptoms such as throat and eye soreness. Lung function was not affected. Using the same cohort, Iwasawa et al. (2010)[79] had previously found that children with a history of lung disease or respiratory symptoms had reduced lung function six months after the start of the study. An increase in phlegm and nose irritation was also observed.

Taking all of the above studies into account, it is clear that exposure to volcanic airborne emissions may result in both immediate and longer-term decreased lung function, bronchitis, wheeze and exercise-induced bronchoconstriction in children, as well as coughs and other respiratory irritation. However, results are inconsistent, with some studies showing no effects. There are several potential reasons for these discrepancies:

1) Varying precautions may have been taken to reduce children's exposure in different eruptions.

2) The composition of the emissions may have been more or less irritative in different eruptions and exposures will have been variable.

3) The study designs were variable and some designs may have been more robust than others at detecting an effect.

4) The ages of children studied were variable and it is not clear if some ages are more or less susceptible to impacts of volcanic emissions exposures.

Mental health and psychosocial well-being

Only a few studies have investigated the mental health impacts experienced by children during and after volcanic eruption crises. However, it has been documented, in adults, that the impacts of volcanic eruptions (for example, bereavement and displacement/evacuation/property loss/change in environment) can increase stress (including post-traumatic stress in the years after the event)[80, 81] and emotional distress levels,[82, 83] and impact mental health,[84, 85] including depression[86] and generalized anxiety. However, there is also evidence that social support mechanisms buffer the effects of stress on depression.[87] These symptoms can be exacerbated where adults live alone, have lost their income, feel they have not been helped, are dissatisfied with living arrangements (including temporary shelter) or have other health problems.[88]

While not all of these apply to children, distress and mental health issues in caregivers can negatively impact children's well-being. Post-traumatic stress symptoms have also been reported to be worse where people have had to relocate multiple times.[89] Psychological impacts have also been noted to be correlated with physiological health responses[90] (e.g., respiratory symptoms and headache)[91] and the level of exposure to the emissions or direct experience of the eruption.[92]

Follow-up studies in adults have shown that, while symptoms do decrease with time, it may take years for the victims to return to pre-disaster mental states.[93, 94] Ohta et al. (2003)[95] found that symptoms of psychological distress (e.g., anxiety, tension and insomnia), following the fatal eruption of Mount Unzen, Japan in June 1991, showed progressive improvement over 44 months whereas depression began to improve only after 44 months. Younger evacuees had a faster recovery than older ones. However, Hlodversdottir et al. (2016)[96] found that, three years after the Eyjafjallajökull eruption in Iceland, post-traumatic stress symptoms had diminished while distress symptoms remained similar. Support, in the form of psychological counselling, for the whole family, other forms of social support (e.g., traditional community networks)[97] and prescription medication for adults, can help recovery.[98, 99] However, Nzayisenga et al. (2022)[100] make the point that, unless traditional supporters such as religious leaders have received training, their support can lead to worse outcomes. They found that people who consulted church leaders for psychosocial support reported higher distress. Although the study could not establish whether the support directly increased distress, they speculated that people who are already distressed could feel worse if their mental health is interpreted as a moral failure, weakness of faith or evidence of supernatural forces. They suggested that training and better referral links may help church leaders provide informed support, thereby reducing stigma and increasing understanding.

Regarding studies conducted with children, Ronan (1997)[101] examined self-reported symptoms of post-traumatic stress in 118 children aged 7–15 years, following the eruption of Ruapehu volcano, New Zealand in 1995–1996. 65 per cent of children reported re-experiencing the event (in thoughts and dreams), with hyperarousal (anxiety and heightened awareness; 24 per cent) and avoidance/psychological numbing (14 per cent) also being reported. Younger and asthmatic children had a greater frequency of hyperarousal. In an associated study, Ronan[102] found that the asthmatic children had greater levels of general distress and perceived their parents to be more upset than the parents, themselves, reported. Huzziff and Ronan (1999)[103] suggested that this may relate to unclear or negative parental communication. Caregivers may need support in how to promote coping and communicate their feelings in a way that offers the child social support rather than contributing to their distress. Ronan and Johnston (1999)[104] assessed interventions to support these children with post-traumatic stress symptoms and found that exposure to information on eruptions (videos and discussions) and cognitive-behavioural modelling (e.g., children being shown how to modify negative self-talk into positive self-talk) led to significant improvements in post-traumatic stress and coping ability. The increasing lapse of time since the eruption also helped reduce the post-traumatic stress symptoms.

Hlodversdottir et al. (2018a, b)[105, 106] interviewed children's caregivers 6–9 months after the 2010 eruption of Eyjafjallajökull, Iceland. They found that exposed children were more likely to have experienced anxiety/worry and low mood than non-exposed children. This was particularly prevalent in children whose homes were damaged by the eruption, and in boys.

Effects of eruptions and evacuation on pregnancy

There has been little work on the impacts of exposure to volcanic emissions, or the stress of an eruption on pregnancy outcomes. Kushnik et al. (2021)[107] compared 97 women who were pregnant and forced to evacuate their villages during the eruption of Sinabung, Indonesia (from 2010), with 97 women who were not exposed. They found that the evacuated women experienced a fivefold increase in early or preterm births and that their babies had a shorter birth length than the non-exposed group. They also found a correlation between reduced birth length and stress in the evacuees. One study in Uruguay found that pregnant women who were exposed to PM_{10} in the aftermath of the Puyehue volcano eruption were more likely to have a preterm birth if they had been exposed during the third trimester.[108]

Child development may also be affected by broader impacts of an eruption, such as maternal malnutrition from crop failure.



Annex C: Impacts of volcanic emissions on critical infrastructure

Volcanic hazards can lead to a wide range of impacts to infrastructure and services critical for children's health and development. While destructive hazards such as tsunami, PDCs, lava flows and lahars can devastate physical infrastructure entirely, the most widespread and frequent hazards, ashfall and gases, are generally disruptive rather than destructive.

Power: Widespread ashfalls can cause power outages, either by depositing on substation or line insulators leading to 'flashover' which can overload circuits, or by causing treefall onto above-ground lines. Ash contamination of power systems can cause continuing impacts if not rapidly cleaned up. Lava flows can also engulf power pylons, if not protected or removed.

Drinking water: Volcanic ashfall can contaminate open-air water supplies both by increasing the turbidity (cloudiness) of the water and by particles releasing their surface salt deposits. Heavy ashfall contamination of rainwater harvesting systems can make water supplies undrinkable and, where rainwater is the only source of drinking water, can force community evacuation. In general, however, risks posed by waterborne pathogens (not related to eruptions) are more immediate and serious than risks from chemical contaminants added by ashfall. Ashfalls of just 20 mm thickness can also cause physical damage, breaking off gutters and disabling rainwater collection systems.[109]

Ashfall can also affect the operation of water treatment plants. Systems with intakes on streams and rivers are particularly vulnerable. In some cases, treatment plants may have to slow down or stop water production to remove ash from the treatment train. Water restrictions may need to be imposed on customers to avoid exhausting treated water supplies, and alternative supplies may need to be provided.

Wastewater and stormwater: Ash will readily enter stormwater drains, which drain paved areas and roofs. It can cause blockages which can be very difficult to remove and which may lead to localized flooding.

Ash should not be able to enter sewers (wastewater pipes), which drain kitchens, laundries, toilets and showers, but it sometimes can infiltrate them through illegal connections from roofs, around poorly fitting manhole covers or through cracks in pipework. Ash-laden raw sewage arriving at a treatment plant can cause major and expensive damage. Sewage overflows can occur if there are power outages to pumping stations. Any discharges of sewage to the environment are a public health hazard which must be managed.

Transportation: Ashfall can seriously disrupt both ground and air transport. Ashfall can make driving conditions difficult or impossible with ash on the ground reducing traction and obscuring road markings, and ash lifted into the air reducing visibility. Ash is also a serious hazard to aviation. The presence of ash in airspace near airports may disrupt flights even without ashfall on the ground. Any ash deposits at airports can affect airport operations, and ash causes a range of impacts on aircraft in flight. Cascading impacts from transport disruptions can include staff not being able to travel to workplaces and disruptions to deliveries of essential supplies such as food and medication, especially critical for pregnant women and children.

Communications equipment and networks: In general, telecommunications systems have functioned well during eruptions, although networks such as cell networks can quickly become overloaded from overuse. Lightning strikes commonly associated with ashfalls can damage towers and masts and cause static interference to some signal frequencies. Cell towers may be vulnerable to power outages, and access for repair crews may be hindered by thick ashfalls. Ash plumes may interfere with satellite signal transmission, including for GPS.

Buildings: Heavy ash accumulation may lead to roof collapses, particularly in buildings of weaker construction (see picture below).[110] However, modern buildings with engineered roofs are unlikely to collapse under ash thicknesses of less than 20 cm, or 10 cm if the ash is saturated by rainfall. Roofs with a low pitch and in poor condition may be more vulnerable. Even light ashfall can damage gutters and solar panels, affect HVAC systems, and repeatedly contaminate building interiors, reducing habitability and usability. Acid rain (from volcanic emissions mixing with rainfall), though not as common as ashfall, can accelerate corrosion to building materials, machinery and other infrastructure components.



Severe damage to a traditional building under ashfall on Ambae, Vanuatu, following the 2017–2018 Manaro Voui eruptions.
Photo credit: Carol Stewart

Annex D: Ashfall impacts on agriculture

Volcanic ash and gas can have both harmful and beneficial effects on agriculture.

Crops: Ashfall can damage crops in many ways, primarily determined by the thickness of the deposit.[111] Thick layers can break stems and branches or bury crops completely, while thinner deposits can still affect photosynthesis and transpiration, cause abrasion and hinder growth. Leaves can also be burned by acid rain, or direct contact with gas or ash. The type of crop is important, with root crops such as taro and manioc being less severely impacted by ashfall than leafy crops such as island cabbage. The growth stage of the crop is also important,[112] for example, crops in the flowering stage are more vulnerable to damage from ash.



Damage to coconut, banana and taro crops on Tongatapu due to ashfall from the 15 January 2022 eruption of Hunga volcano, Tonga.
Photo credit: Soane Patolo, MORDI Tonga Trust, Tonga

Livestock: Ashfall can pose significant risks to livestock. Ash deposits can blanket and destroy pastures, depriving animals of their primary forage. Ingestion of ash-contaminated feed can cause serious health issues in livestock, including gut blockages and accelerated tooth wear due to the abrasive nature of the ash. Ash may also carry soluble elements such as fluorine which, in some cases, has caused fluorosis in livestock and wild animals.[113] Dehydration may also be a problem if water sources become heavily contaminated with ash.

Soils: The immediate impact of an ashfall on soils can be substantial. Fine ash may form a crust on the soil surface, reducing water infiltration and gas exchange which, in turn, can suppress soil biological activity. Physical smothering of the soil surface by thicker deposits may have similar effects. For thinner deposits (up to 100 mm) it may be possible to cultivate the ash into the soil, but thicker deposits may have to be removed using heavy machinery or remain uncultivated until the deposit has weathered enough to form new soil.

Despite these disruptions, ash can also bring short- and long-term agricultural benefits. In the short-term, ash may act as a natural mulch, reducing soil moisture loss. A dusting of ash onto existing soils can provide an immediate input of nutrients such as sulfur, which can reduce reliance on external fertilizers.[114] In the longer term, the soils derived from volcanic ash are renowned for their high fertility. The weathering of ash enhances soil structure, improves water retention and stabilizes organic matter. It is highly dependent on the environment where it is deposited. In more humid environments, soil recovery is much faster than for similar ash thicknesses in more arid environments.

Agricultural livelihoods: Volcanic eruptions can severely disrupt agricultural livelihoods. The impacts on crops, livestock and fisheries can lead to loss of income for households, with disruption to transport, water and electricity networks further compounding impacts. This can threaten food security and force farmers to adopt coping strategies such as temporary migration or livelihood diversification. Prolonged eruptions are particularly challenging, and authorities may set up exclusion zones to limit people's exposure to life-safety hazards such as PDCs. However, economic necessity, attachment to land and livestock, and lack of viable alternatives can drive farmers to re-enter exclusion zones, sometimes with tragic consequences.

Food safety: there is very little evidence about whether contaminants from volcanic ashfall can be taken up into food production systems. One of the few published studies to address this found that, although there was evidence of uptake of volcanic contaminants in export banana crops affected by emissions from the 2021 Tajogaite volcano eruption on La Palma, Canary Islands (Spain), levels remained well below food safety thresholds.[115] The United Nations Food and Agriculture Organization recommends that visible ash be removed from food crops before consumption; that food harvested after an eruption that cannot be cleaned and peeled should not be consumed; and that any animals or fish that are found dead should not be consumed.[116]



Annex E: Illustrative example of multi-sectoral preparedness and response to volcanic eruptions

The below example illustrates how various roles and responsibilities for instituting an effective response to volcanic eruptions can be delineated.

The existence of these departments and their specific roles varies largely by country context. The departments should strive to work closely with the national or regional geological survey or volcano observatory to ensure that government officials are preparing for and responding to eruptions with the most accurate information. This table can be reviewed and adapted for local contexts by the relevant national authorities. It is not exhaustive.

Table E1. Roles and responsibilities of departments and agencies

Department or agency	Typical roles
Meteorological	Tracks wind patterns and atmospheric conditions to forecast ash and gas cloud trajectories and potential acid rain using early warning systems, in collaboration with volcano observatories; monitors and disseminates air quality alerts and advisories. Could also include a geological survey team that monitors seismic activity and emissions, and can support issuing hazard alerts and forecasts.
Geological survey / volcano observatory	Monitors seismic activity, gas emissions, ground deformation and other precursory activity; advises on volcanic alert levels, eruption forecasts and hazard maps; advises government on the onset, escalation and cessation of volcanic unrest. Could support the meteorological department with modelling and the disaster management department on evacuation timing and zone identification. It may also support with health and education department briefings.
Disaster management/ civil protection	Activates emergency operations protocols that could include establishing an incidence command system for all agencies to use; coordinates resource allocation between agencies; declares formal states of emergency. Could support the volcano observatories and local governments in developing hazard maps and protocols for emergency services.
Health	Establishes protocols for management of surges of cases at facilities and in the community, and issues advisories based on air quality alerts. Activates syndromic surveillance to monitor possible spread of diseases. Manages respiratory health clinics; distributes respiratory protection; monitors mental health and long-term ash exposure effects. Could support other departments responsible for water, sanitation and chemical safety on preventing leaching or contamination, and can also support local governments in managing surges, protective equipment distribution and health services in evacuation shelters.

Department or agency	Typical roles
Child protection / Social welfare	Establishes family tracing and reunification systems for children separated from caregivers during evacuation; identifies and supports unaccompanied and separated children; coordinates psychosocial support and referral pathways for children showing signs of distress; sets and monitors safeguarding standards in evacuation centres and shelters. Could support local governments and education departments in establishing child-friendly spaces in shelters, and the health department in providing mental health referral pathways.
Water and sanitation	Provides advice to public on protecting roof catchment water supplies. Takes steps to protect water treatment plants. Initiates water quality monitoring post-eruption. Could support local governments in providing water and sanitation services in emergency shelters.
Education	Develops school safety protocols to activate when there are eruption alerts, including the practice of 'volcano readiness'; create safe zones for sheltering in place if advised; plan for providing continuity of learning programmes for displaced populations. Could support local governments in providing continuity of learning through distance learning or programmes in emergency shelters, and may work with the health department to distribute safety information to families with children.
Local government	Manages physical evacuations; sets up emergency shelters; enforces exclusion zones and manages public sirens/alerts. Issues guidance to households ahead of and during eruptions on how to protect children and other vulnerable populations. Responsible for infrastructural issues (e.g., energy outages) and ash clean up. Could support technical departments in coordinating the distribution of information, materials and supplies.
Transportation	Closes high-risk roads; manages traffic during mass evacuations; organizes ash removal from critical transport routes. Could support the water and sanitation department in transporting water for ash management, and local governments in providing and maintaining clear routes for evacuation and safe return to home.
Agriculture	Issues guidance for protecting crops and livestock from ashfall; manages emergency fodder and animal shelters. Could support the health department to monitor food supply contamination and distribution of nutritional supplements.

Annex F: Methodology: Calculating numbers of children at risk from volcanic activity

This calculation was based on the most up-to-date published population exposure metrics[117] alongside the Smithsonian Institution Global Volcanism Program (GVP)[118] catalogue of Holocene volcanoes screened to include only those 456 volcanoes which have erupted since 1800 and have populations living within 100 km. Although volcanic emission impacts can extend beyond this distance, the 100 km threshold provides a globally consistent way to estimate maximum volcanic exposure and reflects evidence that most life-threatening hazards from large explosive eruptions occur well within this range. Applying this threshold excluded volcanoes on remote uninhabited islands.

Two methodological options were considered for estimating the number of children exposed to volcanoes:

1. Develop a population exposure index (PEI) using established methods to measure population exposure at different distances from each volcano.

2. Estimate the number of children living within 100 km of each volcano, aggregated at the subnational administrative area level to avoid double counting exposed children.

The second option was refined using a quintile classification to ensure consistency with UNICEF work on other hazards within the Global Child Hazards Database (GCHD).[119] The 2025 global 1 km gridded data set of children under 18 years, published by Worldpop,[120] was used to estimate the global population of children currently at risk of volcanic exposure.

Initial mapping compared two measures at subnational and national levels: the number of children under 18 living within 100 km of an active volcano and the proportion of the child population exposed. Each measure produced limitations. Absolute numbers understated exposure in countries with smaller populations, such as Iceland, while percentage-based results understated exposure in countries with larger populations, such as China.

To reduce these distortions, the two measures were normalized and combined using the geometric mean. This moderated extreme values and aligned the approach with methods employed in the INFORM risk and CCRI-DRM (Children's Climate Risk Index-Disaster Risk Model) calculations.[121, 122] The resulting volcano exposure index for children is included in the GCHD.

It is estimated that 166,915,913 children under the age of 18 live within 100 km of an active volcano and are therefore considered exposed to volcanic eruption risk.

The maps presented in this technical note show the spatial distribution of children exposed within 100 km of active volcanoes, supporting interpretation of both the scale and geographic concentration of volcanic exposure.

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