Chapter 13

Health impacts of volcanic eruptions

C.J. Horwell, P.J. Baxter and R. Kamanyire

13.1 Overview

Volcanoes emit a variety of products which may be harmful to human and animal health. Some cause traumatic injury or death and others may trigger diseases, particularly in the respiratory and cardiovascular systems, or mental health problems. The impact on health is related to the style of eruption and type of volcano. Effusive eruptions tend to emit gases and aerosols, which may damage the respiratory system, and lava flows which rarely kill but may cause thermal injuries and mental stress due to the threat of loss of property. Explosive eruptions kill, injure and potentially trigger disease via a multitude of hazards ranging from proximal impacts related to production of fragmented rock and more distal impacts from ash, gas and secondary effects.

13.2 Injury agents

Injury and death are caused by a range of volcanic hazards (e.g. Auker et al. (2013)), which can be summarised by their impact on the body:

1) *Mechanical injury where the body is crushed.* Explosive eruptions may produce large volumes of fragmented rock, which range in size from boulders to fine ash. Mechanical injury/death occurs from a range of volcanic processes relating to the ejection of material and its transport through air or water (lahars, rock avalanches, ballistics). In 1985, the eruption of Nevado del Ruiz volcano, Colombia, led to glacial melt mixing with ash/rock deposits to form a lahar which buried 23,000 people downstream in the town of Armero. Roof collapse is also a common crushing injury, from the weight of ashfall, particularly on flat roofs [see Chapter 12]. Occasionally those proximal to the volcano may be buried by deposits or suffer asphyxiation from inhalation of particles.

2) *Thermal injury (burns) caused by hot volcanic emissions.* These take the form of pyroclastic density currents (PDCs) and surges (composed of searing gas, ash and rocks), lava flows and hydrothermal waters (which are used for recreational bathing). On Montserrat, West Indies, most of those killed during the Soufrière Hills eruption died on 25 June 1997 when PDCs and surges swept into the exclusion zone, where locals had returned to maintain their farms. Even survivors at the margins of the surge zone suffered serious burns from walking across the hot surge deposits to safety (Loughlin et al., 2002). In most PDC-related deaths, severe burns to the

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skin (cutaneous) and airways (resulting in pulmonary oedema) cause immediate mortality, or delayed mortality from respiratory complications and infection (Baxter et al., 1982).

3) *Toxicological effects where emissions react with the body.* Gases, ash and aerosols may be inhaled or ingested. A range of potentially-toxic elements may leach from particles. Cases of poisoning have been associated primarily with high levels of bioaccessible fluorine in ash, particularly for livestock which may ingest large quantities of ash during grazing (Cronin et al., 2003). The surfaces of the mineral particles themselves may be reactive in the lung, particularly if the ash is rich in crystalline silica or iron (Horwell et al., 2007, 2012). Potentially toxic elements, in particular fluorine, may present issues in some eruptions if ash contaminates water supplies. However, experience has shown that more common problems include ash blocking and restricting access to livestock drinking water, causing drinking water to become unpalatable and causing water shortages during cleanup operations (Stewart et al., 2006, Wilson et al., 2013).

4) *Electrical impact.* Lightning, generated from friction of particles in the ash plume, may strike people directly or trigger fires.

13.3 Airborne volcanic emissions

Gases. Volcanoes emit hazardous gases (e.g. CO_2, SO_2, H_2S, HF, HCl & radon). Gas exposures may occur during and following eruptions, and during periods of quiescence, and may be proximal or distal to the vent, depending on the size of eruption. Most gas-related deaths occur due to carbon dioxide or hydrogen sulfide pooling in depressions near the volcano, but large eruptions may generate mega-tonnes of SO_2 which can be transported globally and potentially trigger acute respiratory diseases, such as asthma, in exposed populations. Following the 2010 Eyjafjallajökull and 2014 Holuhraun eruptions, the potential for a large, effusive Icelandic eruption, such as the Laki eruption of 1783, is considered a major risk to Europe and is ranked as one of the highest priority risks in the UK National Risk Register with concerns that sulfur dioxide, sulfate aerosols and other gases may have substantial health and environmental impacts. Chronic dental fluorosis has been observed in rural residents of Ambrym island, Vanuatu, and linked to volcanic degassing and contamination of rain-fed drinking water supplies by the volcanic plume (Allibone et al., 2012).

Figure 13.1 Ash remobilisation in Yogyakarta following the 2104 Kelud eruption. Photo: Tri Wahyudi

Ash. Whilst ash may cause skin and eye irritation, the primary concern for humans is ash inhalation; the style of eruption and composition of the magma govern the size and composition of the particles which, in turn, control the pathogenic potential of those particles when inhaled. The most hazardous eruptions are those generating fine-grained, crystalline silica rich ash, as silica has the propensity to cause chronic lung disease.

Explosive eruptions generate inhalable ash through fragmentation of magma; the fine particles travel in a plume and, depending on the size of the eruption, ash may fall over wide areas causing disruption and anxiety to populations [see Chapter

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12]. A recent World Health Organization report found that acute and chronic exposures to particles from ambient air pollution, such as $PM_{2.5}$ which can penetrate deep into the lungs, increase both mortality and morbidity (World Health Organisation, 2013). In the volcanic setting, inhalation of fine ash may trigger asthma and other acute respiratory diseases in susceptible people, but chronic effects have not been adequately studied. Active public health precautionary measures will always be needed to protect the population from heavy exposure. Some volcanoes mass-produce crystalline silica in lava domes – viscous lava piles which grow within volcanic craters - which are prone to collapse, generating clouds of fine-grained silica-rich ash. Strict controls to minimise population exposure may be needed because, in industrial settings, crystalline silica causes silicosis, an irreversible and potentially fatal lung disease, and is also classified as a lung carcinogen. This type of eruption, if long lived, may produce frequent ash falls leaving local populations periodically exposed to potentially hazardous levels of ash which, over time, may place them at higher risk of developing silicosis, although presently no cases have been recorded. At Soufrière Hills, Montserrat, West Indies the eruption, which began in 1995 and has lasted for over 15 years, generated dome-collapse ash composed of up to ~25 wt.% crystalline silica (Baxter et al., 2014, Horwell et al., 2014). Stringent and costly clean-up measures after ash falls were maintained by the UK government to protect the population. The first risk assessment of its kind, by Hincks et al., (2006), found that those potentially at greatest risk of developing silicosis, if protective measures were not undertaken, were outdoor workers e.g., gardeners, and children.

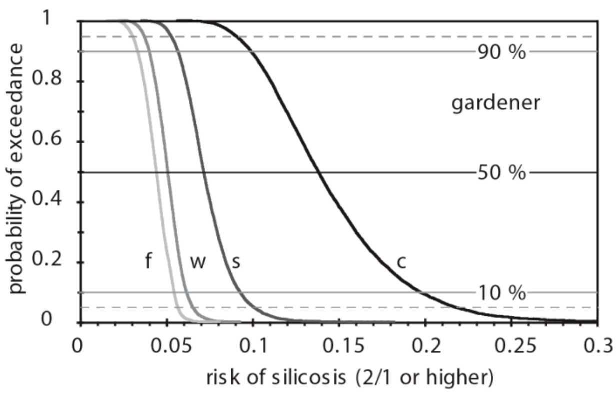

Figure 13.2 Probability of exceedance curve for risk of silicosis (classification ≥2/1) for gardeners, calculated from simulated cumulative exposures (see Hincks et al. 2006 for key to curves, which are for specific Montserrat locations).

13.4 Secondary effects

Large populations brought together in evacuation camps may contract diseases through poor sanitation. Some evacuees may suffer mental stress and other psychological disorders related to displacement and violence is also possible. Widespread ashfall or gas impact (acid rain) may lead to crop failure, loss of livestock and contamination of water supplies which, in turn, may trigger famine and related diseases. Livestock may starve due to smothering of feed and/or if feeding is impaired due to excessive tooth wear as ash is highly abrasive. Ingestion of ash by livestock can also cause fatalities due to intestinal blockages (Wilson et al., 2013). Heavy ashfall can cause roof collapse and is also slippery, making clean-up and driving hazardous. Infrastructure may be impacted, affecting primary healthcare responses [see Chapter 12].

13.5 Hazard impact and response planning

Planning for ash falls and gas release at volcanoes in states of unrest is an essential part of volcano crisis management. Concerns about the health effects of ash and gases may, in the public perception, exceed even volcanologists' warnings on the risks of death from PDCs. Public health officials must be involved in eruption planning and in the response, and work closely

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with scientists monitoring the volcanic activity. Planning should include setting up and maintaining airborne particulate (PM_{10} and $PM_{2.5}$) monitoring networks (or gaining permission to utilise existing urban networks) so that timely data can be obtained to assess population exposure to airborne respirable ash. National regulatory or WHO guideline limits for particulate pollution (24 hour) are likely to be exceeded for as long as ash is visibly present in the air or on the ground. During and post-eruption, syndromic surveillance of acute respiratory health symptoms is also helpful for informing public health advice and providing reassurance to the public.

The International Volcanic Health Hazard Network (www.ivhhn.org), the umbrella organisation for volcanic health-related research and dissemination, has produced pamphlets and guidelines on volcanic health issues (such as preparing for ashfall) for the public, scientists, governmental bodies and agencies. IVHHN has also developed protocols for rapid characterisation of ash (such as particle size, crystalline silica content, leachate chemistry and basic toxicology) giving timely information to hazard managers during, or soon after, an eruption, to facilitate informed decision-making on health interventions. These analyses have been carried out following recent crises at Rabaul, Eyjafjallajökull, Grímsvötn, Chaitén and Merapi volcanoes (see e.g., Horwell et al. (2013)). IVHHN Expert Members are currently researching the effectiveness of various health interventions used during volcanic crises, such as types of respiratory protection.

It is essential to determine levels of crystalline silica as an urgent priority after a heavy ash-fall, by sending ash samples to a laboratory with experience of undertaking the analysis (e.g. through IVHHN). If raised levels are suspected, confirmation will be needed, which is best done by sending split samples for analysis in different laboratories and under strict scientific protocols. Specialist advice on risk assessment may be needed for reassuring the population and providing guidance on measures to reduce exposure to ash to safe limits, particularly for outdoor workers who may be most exposed, as well as children, who may be most susceptible to developing silicosis. Regular measurement of personal exposure to the ash will need to be undertaken for risk assessment purposes by an experienced team of occupational hygienists.

Even without significant concentrations of crystalline silica, there will be many who suffer acute respiratory symptoms on exposure tovolcanic emissions (gas, ash and aerosol) in the inhaled air. People with asthma and chronic respiratory conditions are most likely to be adversely affected. The public will need advice on limiting their exposure and officials will need to institute measures to remove ash deposits in public areas. Ash and gas may affect areas hundreds of kilometres away from the volcano, and cross national borders, raising public anxiety over air pollution. Fears may also arise over the presence of fluorine and other toxic elements in erupted ash, and the impacts on the environment and animal health, even with fine or sparse deposits from dispersing plumes. Most laboratories are not used to the analyses required to assess the toxic hazard and the main danger is from alarmist, but erroneous, results being disseminated to the public, politicians and media demanding rapid answers.

13.6 Long-lasting versus short-lived eruptions

The most disruptive types of eruption are the continuous, open vent eruptions (e.g., Eyjafjallajökull 2010 which lasted 6 weeks, or Kilauea, which has been ongoing since 1983) or the long-lasting dome growth and collapse type (e.g., Montserrat 1995 to present). On

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Montserrat, most people abandoned the island, with the health risk of the ash playing an important part in their decisions; keeping the accumulating ash deposits clear of populated areas to minimise the risks has been a huge and highly costly undertaking (see Baxter et al. 2014, where most of the evidence-base on the health risks of volcanic ash may be found). These contrast with the major one-off eruptions such as Mount St Helens, 1980, and Pinatubo 1991, where visible, re-suspendable ash deposits may persist for many months or even a few years but are not replenished by repeated episodes of emissions or continuous venting of ash and gases with plumes being persistently blown over populated areas by prevailing winds. Another scenario arises where one-off heavy ash falls occur in semi-arid areas, for example, in Patagonia after the large eruptions of Hudson in 1991 and Puyehue Cordón-Caulle in 2011 (Wilson et al., 2013). Abandonment of farm areas and continuing problems with poor air quality in settlements on the steppe occurred due to huge ash deposits downwind of the Andean volcanoes. These deposits continue to be re-suspended by very strong winds, causing economic losses compounded by anxieties over the human health effects of such high, repeated exposures.

An important recent example of the effects of continuous, small scale eruptions in densely populated areas was at the port of Rabaul, Papua New Guinea which, for 2 years (2007- 2008), was subjected to exposure to gases (mainly SO_2), and freshly erupted fine ash from the Tavurvur cone every day for 6 months until the seasonal prevailing winds moved away from the populated area of 70,000 people. In the second year, a drought lasted for 3 months in the middle of the 6 month eruption period; the disruption nearly closed the main hospital, closed schools and many adults and children experienced asthma symptoms, causing the authorities to consider evacuating Rabaul Town. Fortunately, the eruption subsequently stopped and ordinary life resumed. IVHHN analyses, using the rapid analysis protocol, found the ash to be relatively coarse grained and low in crystalline silica (Le Blond et al., 2010). Rabaul is an active caldera and other populated calderas could experience similar small-scale but high impact eruptions due to their persistence, including disrupting infrastructure and transport, especially in modern cities (a potential example is Naples and the currently quiescent Campi Flegrei; see Chapter 6).

Further reading

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