Chapter 12

Volcanic ash fall impacts

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12.1 Overview

All explosive eruptions produce volcanic ash (fragments of volcanic rock < 2mm: Figure 12.1), which is then dispersed by prevailing winds and deposited as ash falls hundreds or even thousands of kilometres away. Volcanic ash suspended in the atmosphere is well known as a hazard for aviation, as was demonstrated during the 2010 eruption of Eyjafjallajökull, Iceland, which led to substantial disruption to flights in Europe and an estimated US$5 billion loss as global businesses and supply chains were affected (Ragona et al., 2011). Volcanic ash fall can also create considerable impacts on the ground. As a general rule, impacts will be more severe with increasing thickness of ash fall. Relatively thin falls (< 10 mm) may have adverse health effects for vulnerable individuals and can disrupt critical infrastructure services, aviation, agriculture and other socio-economic activities over potentially very large areas. Thick ash falls (>100 mm) may damage crops, vegetation and infrastructure, cause structural damage to buildings and create major clean-up requirements. However, they are typically confined to within tens of kilometres of the vent and, as they occur with large eruptions, are relatively rare.

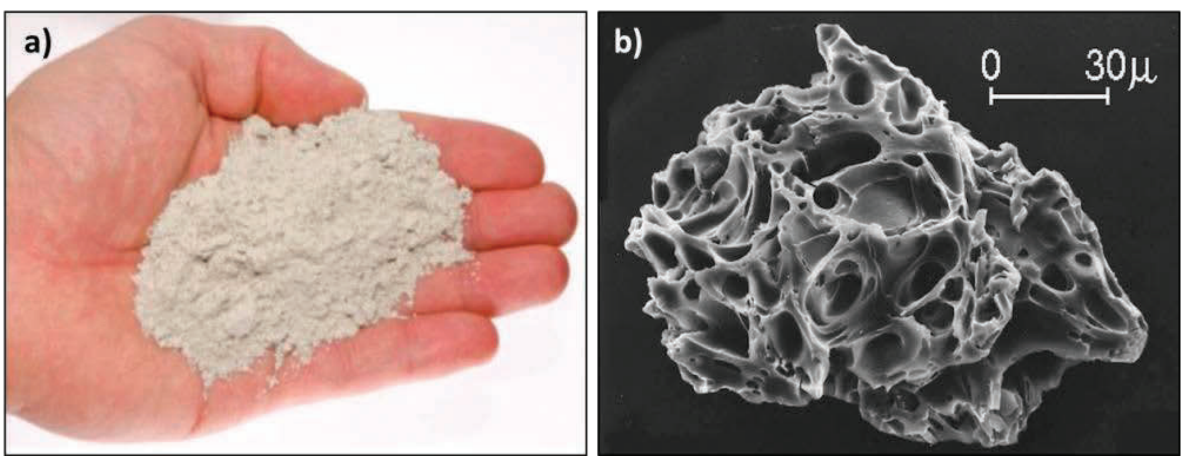

Figure 12.1 a) Rhyolitic ash produced by the eruption of Chaitén volcano, Chile, in 2008 (median grainsize: 0.02 mm). Photo: G. Wilson; b) Scanning electron microscope image of an ash particle from the eruption of Mount St Helens, USA, in 1980. Vesicles, formed as gas expanded within solidifying magma, are clearly visible. Ash is often highly abrasive because of its irregular shape and hardness. Photo: A.M. Sarna-Wojcicki, USGS.

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The quantity of ash (thickness or loading) is not the only mechanism by which ash can cause damage or disruption; the surface chemistry of ash, abrasiveness, friability, ash grain size and density can all influence, or even control, how some systems or components may respond to an ash fall. The physical and chemical properties of fallen ash are largely controlled by eruptive dynamics and magma composition, although dispersal conditions, e.g. wind and rain, also play a role. Ash properties can therefore vary among different eruptions and even during the same eruption. Environmental factors such as wind and rain may lead to ash remobilisation, which may extend and/or intensify the level of impact.

12.2 Impacts

Impacts depend upon the amount of volcanic ash deposited and its characteristics (hazard), as well as the numbers and distribution of people and assets (exposure), and the ability of people and assets to cope with ash fall impacts (vulnerability). Three main zones of ash fall impact may be broadly expected, each requiring a different approach to impact management and planning: 1) Destructive and immediately life-threatening (Zone I); 2) Damaging and/or disruptive (Zone II); and 3) Disruptive and/or a nuisance (Zone III). These zones are summarised in the schematic Figure 12.2 where physical ash impacts to selected societal assets are depicted against ash deposit thickness – which generally decreases with distance from the volcano source. The more severe impacts depicted in Zones I and II may not occur in smaller magnitude eruptions because there is insufficient ash fall. A further impact zone (Zone IV) could be applied to areas that extend beyond those receiving ash fall, as aviation disruption from airborne ash can occur in areas where no ash falls on the ground. Below, we elaborate on the impacts shown in Figure 12.2. See Chapter 3 and references therein for more detailed information on each point:

Impacts to people: Exposure to volcanic ash fall rarely endangers human life directly, except where very thick falls cause structural damage (e.g. roof collapse) or indirect casualties such as those sustained during ash clean-up operations or in traffic accidents. Short-term effects commonly include irritation of the eyes and upper airways and exacerbation of pre-existing asthma; serious health problems are rare (Horwell and Baxter (2006); see Chapter 13 and www.ivhhn.org). Affected communities can also experience considerable direct and indirect social impacts, for example, impaired psychological functioning due to factors such as disruption of livelihoods and consequent anxiety.

Impacts to critical infrastructure: Damage and disruption of critical infrastructure services from ash fall impacts can substantially affect socio-economic activities. Electricity networks are vulnerable, mainly due to ash contamination causing flashover and failure of insulators (Wilson et al., 2012). Ash can also disrupt transportation networks through reduced visibility and traction; and be washed into drainage systems. Wastewater treatment systems that have an initial mechanical pre-screening step are particularly vulnerable to damage if ash-laden sewage arrives at the plant. Suspended ash may also cause damage to water treatment plants if it enters through intakes or by direct fallout (e.g. onto open sand filter beds). In addition to direct impacts, system interdependence is a problem. For example, air- or water-handling systems may become blocked by ash leading to overheating or failure of dependent systems. Specific impacts depend strongly on network or system design, typology, ash fall volume and characteristics, and the effectiveness of any applied mitigation strategies (Wilson et al., 2012).

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Impacts to agriculture: Fertile volcanic soils commonly host farming operations; ash falls can be beneficial or detrimental to soil depending on the characteristics of the ash (particularly with respect to its surface composition and the soil (Cronin et al., 1998). The time of year in the agricultural production cycle strongly determines the level of impact (Cook et al., 1981). For example, ripe crops close to harvest are particularly vulnerable to contamination, pollination disruption and damage. Under very thin ash falls (< 1 mm) crops and pastures can suffer from acid damage or reduced UV light and, with increasing thicknesses, plants may be broken or buried and soil potentially smothered. Thick ash falls (>100 mm) typically require soil rehabilitation, e.g. thorough mixing or removal, to restore agricultural production (Wilson et al., 2011). For livestock, ash falls may cause starvation (damaged or smothered feed), dehydration (water sources clogged with ash), tooth wear, deaths from ingesting ash along with feed and (more rarely) acute or chronic fluorosis if ash contains moderate to high levels of bioaccessible fluoride.

Impacts to buildings: The load associated with an ash fall can cause the collapse of roofing material (e.g. sheet roofs), the supporting structure (e.g. rafters or walls) or both and, under sufficiently great loads (>> 100 mm), the entire building may collapse (Blong, 1984, Spence et al., 2005). Non-engineered, long-span and low-pitched roofs are particularly vulnerable to collapse, potentially under thicknesses of around 100 mm. Under thinner ash falls (< 100 mm), structural damage is unlikely although non-structural elements such as gutters and overhangs may suffer damage. Ash falls with increased moisture content, as a result of rain for example, will impart a greater load so that resulting damage is more likely. Building components and contents may also be damaged from ash falls due to ash infiltration into interiors, with associated abrasion and corrosion.

Impacts to the economy (including clean-up): Economic losses may arise from damage to physical assets, e.g. buildings, or reductions in production, e.g. agricultural or industrial output (Munich-Re, 2007). Most economic activities will be impacted, even indirectly, under relatively thin (< 10 mm) ash falls, for example through disruptions to critical infrastructure. Losses may even result from precautionary risk management activities, e.g. covering water supplies, business closure or evacuations. During or after an ash fall, clean-up from roads, properties, and airports is often necessary to restore functionality, but the large volumes make it time-consuming, costly and resource-intensive

12.3 Hazard and risk ranking

The wide geographic reach of volcanic ash falls, and their relatively high frequency, makes them the volcanic hazard most likely to affect the greatest number of people. However, forecasting <u>how much</u> volcanic ash will fall, <u>where</u> it will fall, <u>when</u> it will fall, and <u>with what characteristics</u> is a major challenge. Probabilistic volcanic ash hazard maps [see Chapter 6], developed using ash dispersal models and statistical analyses of likely eruption styles, frequencies, magnitudes and wind conditions, take a step towards robustly quantifying ash fall hazard. Most importantly, the probabilistic nature of such hazard maps means that some of the epistemic uncertainties associated with forecasting how much ash will be erupted, to what height and into what wind conditions are accounted for by simulating many thousands of possible ash fall footprints. By aggregating these difference scenarios, areas of relatively high and low hazard can be identified. A probabilistic ash hazard model was developed for 190 active volcanoes in the Asia-Pacific

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region, home to 25% of the world's volcanoes and over two billion inhabitants, and the average frequency of ash falls that exceed critical impact thicknesses estimated on a location-by-location, rather than volcano-by-volcano basis (see Jenkins et al. (2012)). By multiplying these hazard estimates with freely available exposure data (in this case LandScan population density) and a proxy for human vulnerability (the UN Human Development Index), a crude 'risk' score could then be established (Figure 12.3). This offers an insight into the relative risk across the region, building on the probabilistic ash hazard maps. By disaggregating the score, the key risk driver can be identified, which may suggest how risk can best be reduced. For example, Tokyo's risk is dominated by the high cumulative hazard (54 active volcanoes lie within 1000 km), Jakarta's risk is dominated by population exposure and Port Moresby's risk by the vulnerability. While this approach is useful at large regional to global scales, it should never replace a local risk assessment, which should use more detailed knowledge of the volcano and local analyses of societal assets and vulnerability to produce a robust assessment.

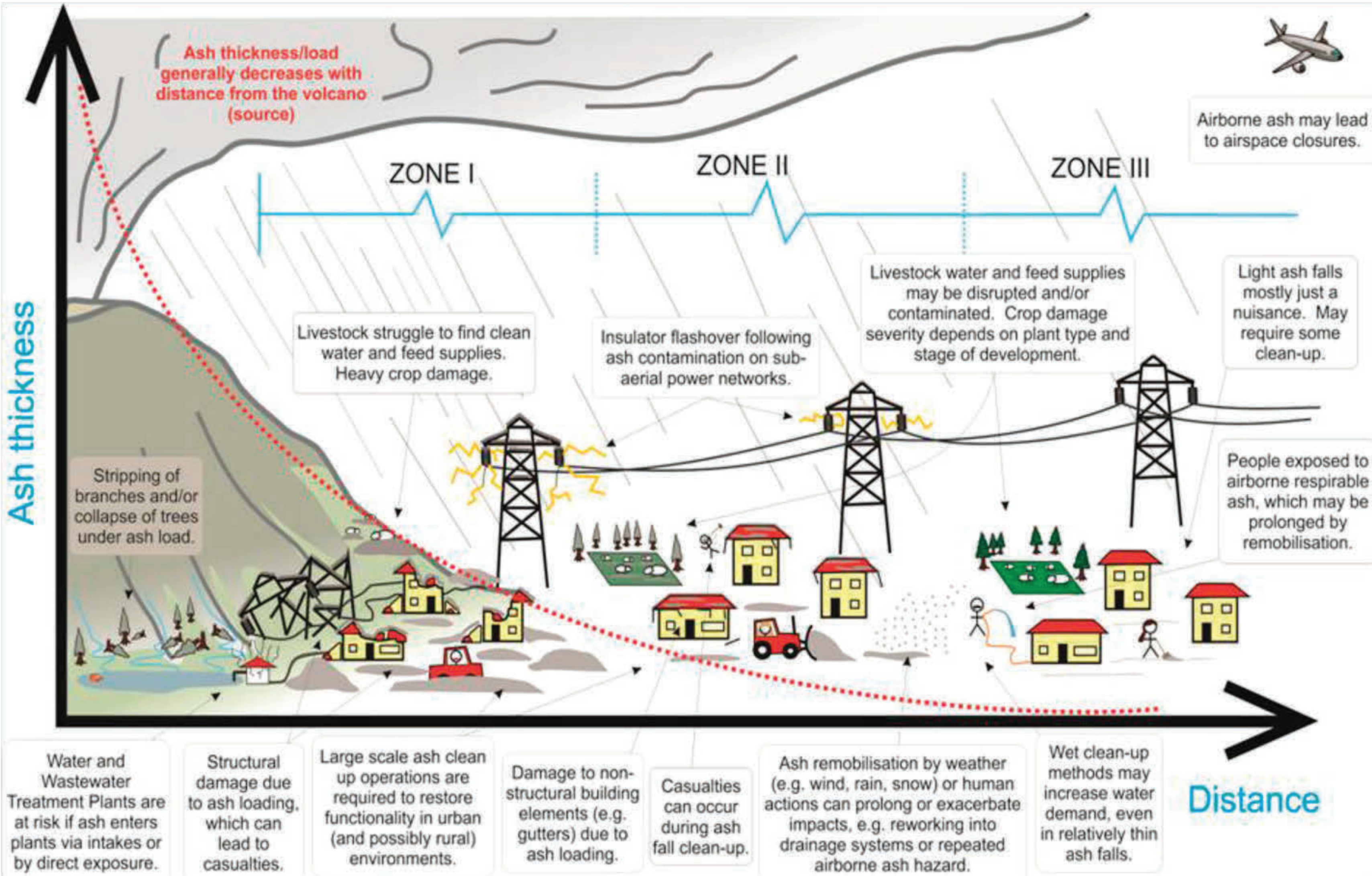

Figure 12.2 Schematic of some ash fall impacts with distance from a volcano. This assumes a large explosive eruption with significant ash fall thicknesses in the proximal zone and is intended to be illustrative rather than prescriptive. Three main zones of ash fall impact are defined: 1) Destructive and immediately life-threatening (Zone I); 2) Damaging and/or disruptive (Zone II); 3) Disruptive and/or a nuisance (Zone III).

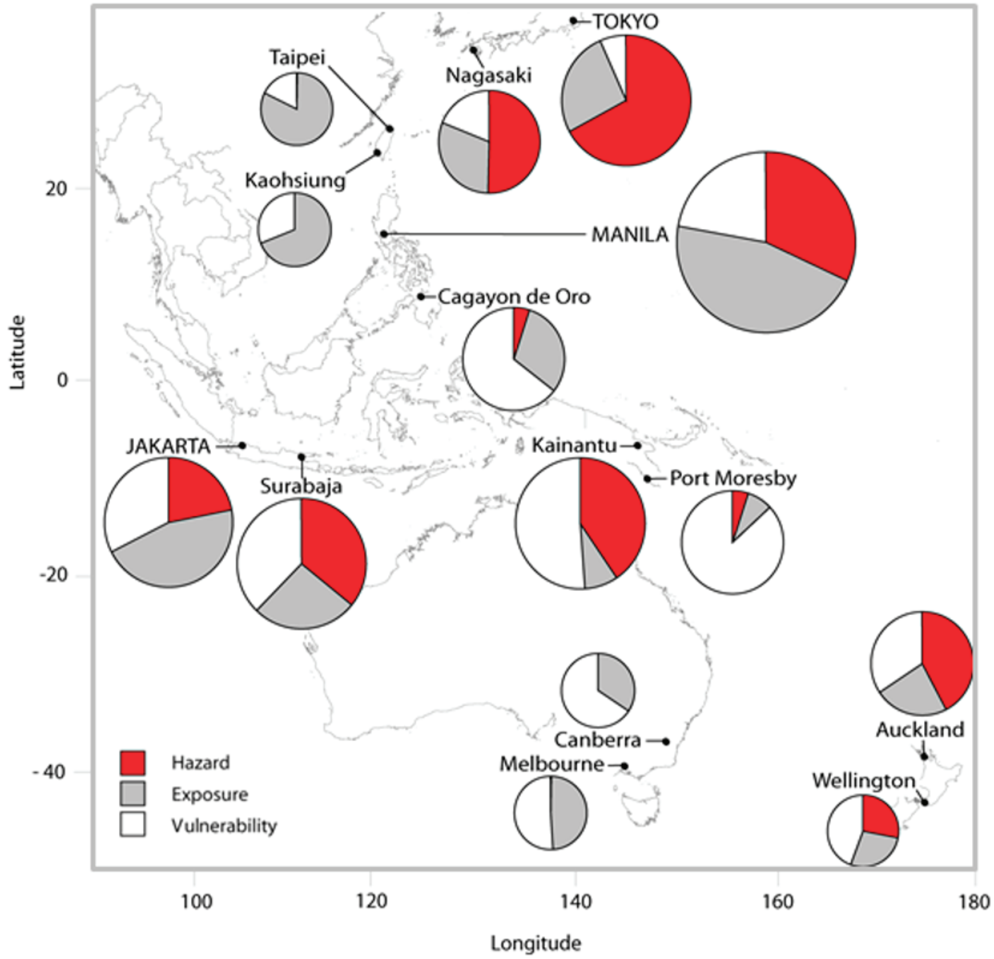

Figure 12.3 Relative risk scores (shown by circle size) and the contributions of the three factors towards the overall risk (a product of hazard, exposure and vulnerability) for cities in the Asia-Pacific region. Hazard is taken as the estimated frequency of thin (≥ 1mm) ash falls; Exposure: the population density; and Vulnerability: a composite of education, life expectancy and standard of living (the UN Human Development Index).

12.4 Mitigation strategies

Greater knowledge of the hazard and associated impact can support mitigation actions, such as crisis planning and emergency management activities. Poor preparedness for ash fall impacts can be costly, delaying an effective response.

A major concern to both the affected populace and authorities before, during and after ash falls are the potential health impacts. Key elements of an effective public health response to volcanic ash fall include: surveillance of health outcomes to inform public health advice and/or provide reassurance to the public; obtaining timely data on air quality from existing monitoring networks to assess population exposure to airborne respirable ash; and characterising ash samples with respect to their mineralogical and toxicological properties, including soluble element content [see Chapter 13]. As a relatively rare public and agricultural health hazard, it can be difficult for agencies to effectively communicate the extent of the risk and to know which ash collection and analysis methods are appropriate. The International Volcanic Health Hazard

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Network (IVHHN) is invaluable in this role (www.ivhhn.org). Other preparedness activities should include:

- providing stakeholders with access to specific and relevant preparedness and post-event response/recovery information. Communication regarding the hazard and recommended mitigation steps should be transparent, repeated and from multiple trusted and authoritative sources. (e.g. www.gns.cri.nz/Home/Learning/Science-Topics/Volcanoes/Eruption-What-to-do/Ash-Impact-Posters);
- effective and timely warnings. Ashfall warnings are now standard procedures in many countries, such as in the United States, Japan and New Zealand;
- facilitating appropriate protective actions, e.g. sealing buildings, shutting down vulnerable systems, etc;
- development of clean-up plans that prioritise critical areas or lines of communication and identification of volcanic ash disposal sites and procedures;
- mutual support or continuity agreements between municipal authorities, critical infrastructure organisations and businesses, which can facilitate greater access to resources to deal with ash fall events.

While volcanic eruptions cannot be prevented, the exposure and vulnerability of the population to their impacts may, in theory, be reduced, through the considerable tasks of hazard and risk assessment, improved land use planning, risk education and communication and increasing economic development.

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