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Photo: Tri Wahyudi, Yogyakarta, Indonesia, February 2014.

Street children were given free masks during the 2014 Kelud eruption.

Preparing for, and protecting communities from, respiratory exposure to volcanic ash

Around 10% of the world's population lives near a historically active volcano. When a volcano erupts, there may be critical dangers for those caught in the explosive force of the eruption (for example, lateral blasts, ballistic 'bombs' and pyroclastic density currents). However, by far the most wide-spread hazard is airborne emissions, carried by winds over hundreds to thousands of kilometers from the volcano. These emissions include volcanic ash (particles of fragmented magma less than 2 mm in diameter), aerosols and gases.

Inhaling fine-grained ash can cause irritation in the respiratory tract (rhinitis, sore throat, cough) and can exacerbate existing respiratory diseases like asthma, bronchitis and COPD [1]. It is still not established whether long-term exposures can trigger respiratory diseases like lung cancer and silicosis [1]. Due to these uncertainties, a precautionary approach is usually taken, so humanitarian agencies will often distribute facemasks to protect communities.

Research led by Prof Claire J. Horwell (Durham University, UK) has, for the first time, investigated the effectiveness of different forms of respiratory protection for community use in volcanic eruptions. The project, 'Health Interventions in Volcanic Eruptions' (HIVE), involved laboratory testing of the efficacy of different facemasks and wearability trials in communities affected by volcanic ash. Social surveys and interviews, in Indonesia, Mexico and Japan, were also implemented to explore behavioral and socio-cultural dynamics that influence the use of respiratory protection, and how to tailor effective messages on protection. An evaluation of the ethics of agencies distributing low-quality respiratory interventions was also undertaken.

The research findings have already influenced agency decision making in several eruptions, including the eruptions of Agung, Indonesia (2017; see Case Study at the end of this article), Fuego, Guatemala and Kīlauea, Hawaii in 2018. A suite of PAHO-endorsed public information products, co-designed with communities, are available online.

Editorial

Major explosive eruptions are infrequent, even in countries like Indonesia that are well populated by active volcanoes, yet their ash falls can impact on many thousands of people living in their vicinity and occasionally much further afield. Mount St. Helens, in the US, spurred a revolution in risk reduction measures in volcanic crises when it erupted in 1980, leaving its ash covering central Washington State. From that iconic disaster, we learned that massive clouds of fine ash mobilized from ash deposits by wind and traffic will severely limit visibility and disrupt all forms of transport for days in the absence of rainfall, and expose whole populations to dramatically high concentrations of an inhalable mixture of very fine and coarse ash particles in the air. Invariably, such high exposures continuing over weeks or even months, 24 hours a day, after explosive eruptions, not only interfere with every aspect of indoor and outdoor living, but raise major anxieties concerning the harm to health from breathing the contaminated air over such prolonged periods.

Wholesale removal of ash deposits is essential to reduce exposure in these crises if only to allow normal life to resume, and the huge task will involve the whole community as well as municipal workers and their equipment. Exceptionally high exposures to airborne ash over weeks, and even months, are inevitable and individual wearing of respiratory protection will be needed to protect families and outdoor workers as a top priority.

Prior to the urgent investigations at the Mount St. Helens emergency, natural mineral particles like volcanic ash were thought to be inert. But the finding that 90% of the ash particles were less than 10 μm in diameter, enabling them to be inhaled into the upper and lower airways, created alarm over the potential to exacerbate pre-existing lung disorders such as asthma and bronchitis and to harm sufferers with chronic lung disease. The concerns bordered on panic when the mineral crystalline silica, the cause of the occupational disease silicosis, was found to be present with implications for the risk of exposure to children and adults in the community. In the eruption of the Soufrière Hills volcano, on the island of Montserrat, which began in 1995 and lasted over ten years with intermittent ash falls, the concentration of the mineral was high enough to be a factor in decision making on whether or not to evacuate the island community.

Globally, childhood mortality from pneumonia is elevated in many low-income countries and grossly raised exposures to airborne ash may add to the acute risk. Inhaling mineral dusts containing crystalline silica may worsen the prognosis in pulmonary tuberculosis. Within the last few years, scientific opinion has veered towards attributing the adverse health effects of PM2.5 in traffic-related air pollution to all forms of PM2.5, regardless of its source. Epidemiological studies on ash emissions are too few to know if this applies to volcanic ash, but it will serve to add to public anxiety in a crisis.

For almost two decades the IVHHN (International Volcanic Health Hazard Network) website has been a worldwide resource keeping us updated on the latest research on volcanic ash and the health mitigation measures that are available. This Supplement is a summary of the first international study to evaluate different masks and other face coverings in filtering out fine ash particles, together with findings on their wearability and acceptability in different cultural settings. Accompanying educational materials published by IVHHN include leaflets available in several languages showing how to fit a facemask and advice on the gamut of measures to protect against exposure to volcanic ash and not to rely on mask wearing alone.

Finding the right respiratory protection has risen to public prominence in other health crises stretching from wildfires in California to forest burning in Indonesia, not to mention the COVID pandemic. This project could not be more timely.

Peter J. Baxter MD, Cambridge Institute of Public Health. University of Cambridge, UK.

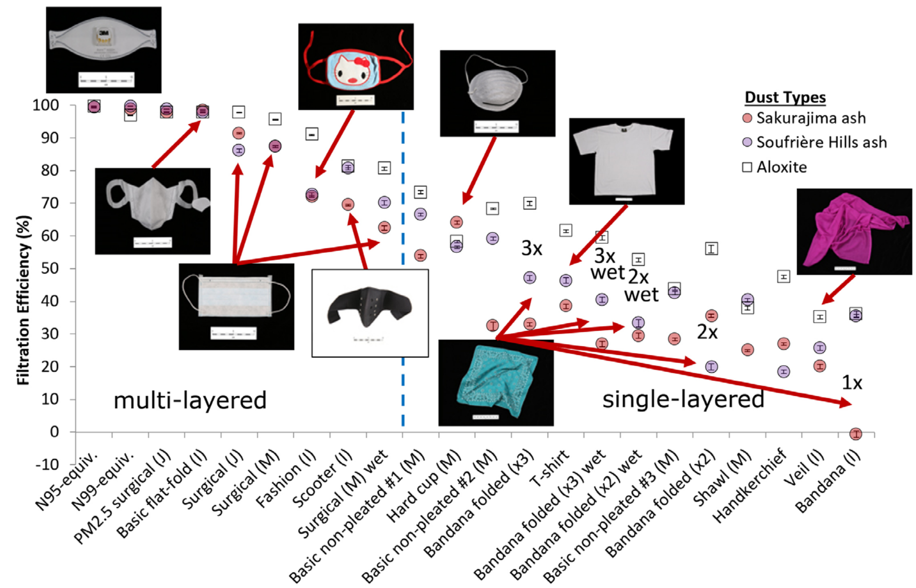
To test the effectiveness of different types of respiratory protection at filtering volcanic ash, laboratory tests of filtration efficiency (FE) and 'total inward leakage' (TIL) (a measure of mask filtration and fit, on volunteers) were conducted at the Institute of Occupational Medicine, Edinburgh, UK. Seventeen different types of protective materials were sourced from communities living near volcanoes, ranging from industry-certified (N95/N99-equivalent masks – FFP2/3) to hijabs, shawls and bandanas.

The most effective facemasks for filtering ash, and for fit, were shown to be N95/N99-style masks [2, 3] (Figures 1 & 2). Surgical masks, often provided by responders [4], had good filtration but did not seal well to the face [2, 3] although adding an extra layer of cloth (a bandage, in this study), tied around the head on top of the mask to better secure it to the face, did reduce the leakage. Many cloth materials provided little to no protection [2].

The laboratory studies also showed that folding cloth into several layers increased filtration (but not to the level of a surgical mask) but that wetting cloth/masks did not help with filtration [2] (Figure 1).

The laboratory volunteers, and local volunteers who tested mask wearability, near Sinabung volcano, Indonesia, agreed that N95-equivalent masks were not very comfortable to wear [3, 5]. Poorly-fitting (and, hence, less effective) masks were considered more comfortable but the addition of a piece of cloth, to help with facial seal, was not comfortable. There is, therefore, a balance to be struck between the effectiveness and comfort of facemasks.

The effectiveness of respiratory protection



Mean FE (%) of each RP for all dusts for both flow rates (40 L/min and 80 L/min) and particle concentrations (1.5 and 2.5 mg/m^{-3}). J = Japan; I = Indonesia; M = Mexico. Dashed line is division between multi- and single-layered materials. 1-3x ± wet indicated layers of bandana material and whether the material was wetted or not.

Figure 1. Results from FE tests showing that industry-certified masks offer almost 100% FE whereas single-layered cloth offers much less filtration. The amount of filtration also depends on the types of particle: Sakurajima and Soufrière Hills are different samples of volcanic ash; Aloxite is a non-toxic analogue dust also used later in the TIL volunteer trials.

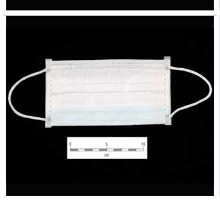
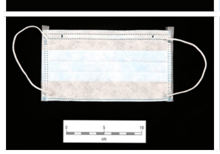
Mask Type	Mask Type	Features	Leakage	Filtration	Notes
	Industry-certified (N95/FFP2)	Nose clip, elasticated head- straps, foam/rubber edge seal	< 10 %	> 99%	Not very comfortable
	'Flat-fold' ('3D') mask (Japan)	No way of adjusting fit and not clear which orientation it should be worn	35%	> 98%	Very comfortable but 'flimsy'
	PM2.5 surgical mask (Japan)	Cheek and chin 'flaps' which fold out. Nose clip, stretchy ear loops	22%	98%	Quite comfortable
	Surgical mask	Nose clips, stretchy ear loops	35%	~ 90%	Quite comfortable
	Surgical mask + bandage	Closes gaps around the face	24%	~90% + ?	Not comfortable

Figure 2. Summary table of filtration efficiency (see figure, above) and Total Inward Leakage. The most efficient mask had the lowest leakage.

Figure 3. A woman wears a surgical mask (incorrectly) during the 2010 eruption of Merapi volcano.

The importance of cultural contexts in protection motivation

Every society and, possibly, community in the world may react differently to the hazard of volcanic ash, dependent on many cultural and demographic conditions, which will influence their perceptions of the health risk, and the need to protect themselves.

The HIVE team conducted comparative research in Indonesia, Mexico and Japan, with over 2000 questionnaire surveys and 190 interviews across the three locations.

The survey research focused on factors that influence people's motivation to protect themselves during eruptions. It found that perceptions of harm/worry were stronger predictors of mask use in Japan (around Sakurajima volcano) and Indonesia (around Merapi volcano) than they were in Mexico (around Popocatépetl volcano), where beliefs about mask efficacy were more important [6, 7]. This highlights the need for agencies to listen to community concerns, to explain volcanic health risk and to provide information on mask efficacy, if efforts are being made to promote mask use.

The anthropological research studied people's relationship with their volcano and its hazards, and how this relates to protective behaviors, including mask wearing.

In Indonesia, in the Special Region of Yogyakarta, grassroots, community-embedded volunteers, who engage in the management and communication of volcanic hazards and risk, are at the center of a support network in which people feel comfortable sharing spiritual and scientific insights. These monitoring networks have led to a high uptake of mask use during recent Javanese eruptions [4, 8].

In Mexico, communities on Popocatépetl volcano's slopes are influenced, to varying degrees, by a range of authorities in relation to protection from volcanic eruptions, from hazard management agencies to spiritual leaders. Varying advice among these authorities, and general lack of availability of masks, may influence use of respiratory protection.

In Japan, people in Kagoshima prefecture follow regular updates about Sakurajima's volcanic activity via mobile apps and other social media. However, they also encounter different opinions about the health risks of volcanic ash among public health officials. For the most part, local communities consider ash to be a nuisance, but it is also an important element of the ecology that is part of people's daily experience.

The social surveys also confirmed that, in all locations, there was little to no information or communication provided by agencies about the varying effectiveness of respiratory protection, or how to best wear it.

Challenges in assessing the health impacts of volcanic eruptions and the benefits of mask wearing

The health risks of inhaling volcanic ash are still largely unknown, as is the health benefit of reducing exposure through respiratory protection and other interventions. The lack of evidence is primarily due to the challenges of conducting clinical trials and epidemiological surveys in crisis conditions, as well as the difficulties in following cohorts over decades to determine chronic disease risk. This risk is of particular concern at volcanoes which produce crystalline silica in lava domes [9], where eruptions may continue, in phases, over years or decades.

The HIVE project was aiming to conduct a clinical trial of the benefits of mask wearing, in ashy conditions, for individuals with mild asthma. The study was to be undertaken with communities living around Sakurajima volcano, Japan, which had been erupting several times per day for the previous few years. A challenge in conducting any clinical trial in a natural setting is the variable exposure to the pollutant. In fact, the volcano stopped erupting shortly before the trial started, highlighting a major challenge of trying to conduct natural hazard-based health research.

One way to improve evidence of health impact is to have standardized measurement methodologies so that studies in different volcanic crises can be compared. The HIVE project, in association with the International Volcanic Health Hazard Network (www.ivhhn.org), produced a set of epidemiological protocols to be used in the days and months following onset of an eruption [10].

The first protocol provides a method for a basic study, tallying hospital and clinic visits of respiratory (and potentially other health) outcomes, to be conducted during or immediately following a volcanic eruption. The second protocol is for a more detailed, cross-sectional survey of individuals exposed to volcanic emissions, which may be undertaken if the basic study indicates adverse health effects.

It may also be possible to estimate the health impact of future eruptions, using scenario-based health impact assessments (HIA). The HIVE project also conducted a review of whether such HIA were possible in volcanic environments where, usually, it is hard to gather the exposure and medical data from which to calculate concentration-response functions (CRFs). The study investigated whether it was possible to use urban pollution CRFs in lieu of exposure and health data from volcanic locations, and concluded that this was the best available strategy, although there would be inherent uncertainties in the calculation [11].

Ethical and legal implications of agency provision or recommendation to use facemasks in eruptions

The HIVE project research found that agencies often distribute masks in eruption crises and that these are usually loose-fitting surgical (or similar material) masks [4]. Yet, the laboratory studies showed that such masks offer a low level of protection due to poor fit [3]. In an affiliated project, led by Dr Fiona McDonald (QUT, Australia), we developed a framework to assist agency decision making on which type of respiratory protection to recommend/distribute based on ethical principles [12].

Some agencies only recommend public health interventions based on their known efficacy (the 'principle of effectiveness') whereas others take a precautionary approach, where any intervention is considered better than no intervention, even when there is a lack of evidence of the intervention's efficacy or the health risk. Agencies distributing surgical masks take the latter approach. Since the HIVE study was completed, there has been a global shift, towards the precautionary principle, in attitudes on community use of respiratory protection, as a result of the COVID-19 crisis [13].

The project also evaluated whether agencies may have a legal duty of care, arising out of tort law, to provide warnings about the health risks associated with air pollution disasters and/or to recommend facemasks as a protective mechanism for community use to reduce exposure to particulate matter. There is also potential for liability, if a receiver of an inadequate facemask alleges that they have been harmed as a consequence and seeks compensation [14]. Further research is necessary to determine how the negligence framework may work in each jurisdiction.

Transforming evidence into public information

The aim of the HIVE project was to generate an evidence base from which to develop public information on the effectiveness of respiratory protection for volcanic ash exposures.

The social research confirmed that communities have varying motivations for uptake of protective interventions in eruptions so, in order to ensure that new public information would be useful and relevant, the HIVE team worked with communities and health/hazard management agencies in Indonesia to co-design a series of informational products, in different media chosen by those communities. The co-development of the products involved workshops where we applied learning bias theories to determine which types of role models (e.g., health professionals, parents) people would most respond to in the videos and what the products would look like. Following production, an evaluation of the products' effectiveness was also undertaken with communities.

A video and pamphlet explain, in detail, how people can protect themselves from inhaling ash, including the effectiveness of different kinds of respiratory protection (Figure 4). The information is also summarized as a poster, designed for bulletin boards within communities, schools and health clinics.

A leaflet and accompanying video explain how to fit a facemask (Figure 5). This small leaflet is intended to be handed out by humanitarian agencies during ashfall events, along with facemasks.

The HIVE team also produced a video documenting people's experiences in protecting themselves during the 2010 eruption of Merapi volcano, Indonesia, to help people prepare for future eruptions.

All of the informational products are published on the IVHHN website (www.ivhhn.org), in multiple languages, and the printable products are endorsed by PAHO/WHO.

Additionally, the International Society for Respiratory Protection (ISRP), with the HIVE team, conducted a train-the-trainer initiative in Yogyakarta, Indonesia, on how to fit a facemask (Figure 6). Seventy-three agency representatives were trained who, in turn, have trained at least 800 people, including teachers, police, healthcare professionals, NGO and humanitarian agency staff.

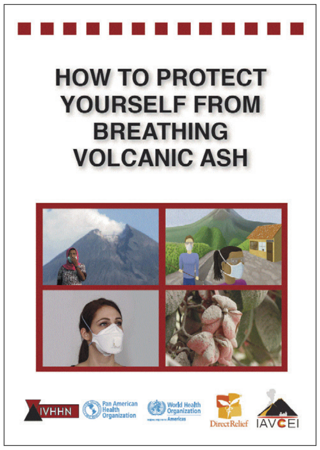


Figure 4. Front cover of the IVHHN/PAHO leaflet on protecting yourself from ash

Figure 5. IVHHN/PAHO leaflet (inside panel) on how to fit a facemask, available at www.ivhhn.org

Figure 6. Keith Roddan (ISRP/3M) trains stakeholder reps in how to fit a facemask. The reps then trained each other so that they, in turn, were then ready to train others. Event organized by HIVE/ISRP/Red Cross (PMI Yogyakarta).

Case study

A new age of effective community respiratory protection?

The Mt. Agung volcano crisis appeal

Introduction

In September 2017, Mount Agung, Bali, Indonesia, started to show signs of unrest, with swarms of deep earthquakes recorded on seismographs, and felt by communities, indicating movement of magma beneath the volcano. A large eruption looked imminent and, by early October, up to 146,000 people were evacuated, spread across 427 shelters [15].

Explosive volcanic eruptions generate ash which can cover many tens to thousands of square kilometers around a volcano. In Bali, the local Volcanology and Geological Hazard Mitigation Office (PVMBG) estimated that if Agung erupted there could be a layer of ash 40 cm (16 in) deep over a 30 km (18 miles) radius.

Beyond the immediate threat of lethal, proximal hazards such as pyroclastic flows and lahars within ~20 km (12 miles) of the vent, potentially hundreds of thousands of people living further afield would have concerns about inhaling ash. This is because ash particles can be small enough to enter the lung, causing irritation in healthy people and exacerbation of symptoms in people with existing respiratory diseases [1]. Ash can also contain potentially-toxic minerals such as crystalline silica, although it is not proven that volcanic silica can cause diseases such as silicosis or lung cancer [1]. In addition, uncertainties about the harm caused by breathing ash can lead to anxiety and psychological distress [16], as well as it being uncomfortable to have in the mouth and nose.

Due to these risks, agencies (governmental and non-governmental organizations with public health, civil protection, disaster management and humanitarian remits) will usually advise that those proximate to ash, especially those with respiratory problems, should stay indoors. Many agencies also distribute facemasks. A summary of advice offered around the world can be found at: https://www.ivhhn.org/information/global-ash-advice

Surgical masks are commonly stockpiled for public health emergencies (e.g., for influenza pandemics) and are inexpensive and easy to procure and store in bulk. In Indonesia, PMI Yogyakarta (Red Cross), regional health (Dinas Kesehatan) and local disaster management (BPBD) governmental agencies distributed over a million surgical and 'flat-fold/3D' masks during the eruptions of Merapi (2010) and Kelud (2014), in Java [4]. These masks are not industry-certified, but are marketed as being effective at capturing particles sub-2.5 µm diameter – $PM_{2.5}$ – and a recently-tested mask in the HIVE project confirmed this high standard of efficiency [2]. Surgical masks, although not designed for such purposes, also have a high capacity for filtration [2, 17]. Like surgical masks, 'flat-fold/3D' masks often have poor design which compromises facial fit [3]. Until the HIVE study, there was little-to-no evidence of the effectiveness of these masks for community use against volcanic ash; the new evidence shows that effectiveness of these masks is compromised by poor fit [3; and Figures 1 and 2].

More rarely, agencies have distributed masks to communities during volcanic eruptions which are designed for occupational use in dusty workplaces (e.g., industry-certified N95-type particulate respirators). N95 and other, similar industry-certified respirators (e.g., FFP2 in Europe) have been demonstrated, in laboratory studies, to provide better levels of protection than surgical and other masks [2, 3, 17, 18]. Occasionally, high-income countries have distributed such masks during eruptions, which were already stockpiled for healthcare workers in pandemics (e.g., Eyjafjallajökull in Iceland in 2010).

The advent of the Agung eruptions in 2017-2018 saw a shift in the approach to community protection in a low-to-middle income country (LMIC). Unlike many eruptions, the prolonged period of unrest (which culminated in the start of a magmatic eruption on 25 November 2017, with eruptions continuing intermittently throughout 2018) allowed organizational-level preparedness of public health interventions on a scale and a type not previously observed in Indonesia, or other LMICs. This resulted in a combination of changes in humanitarian practice: greater coordination of grassroots response, the use of crowdfunding platforms and a change in ethical decision-making practices around preparedness, as discussed below.

These changes led to the donation, stockpiling and distribution of more than 75,000 N95 respirators, in 2017, across 52 evacuation camps, by the Mount Agung Relief (MAR) group.

The MAR group is a consortium of several local NGOs, including Kopernik (who strive to find effective, affordable solutions to poverty reduction), and concerned community members whose goal was to deliver critical supplies to the thousands of evacuated people. To our knowledge, the distribution of these types of masks had not previously occurred in a volcanic crisis setting in Indonesia or any other LMIC [4].

Coordinated agency action and responses

While coordination is not novel, it was particularly effective during the Mount Agung crisis. This was potentially because of the prolonged period of volcanic unrest, giving time for efforts at the grassroots level to be aligned. In Bali, this resulted in the founding of the MAR group. Their coordinated response allowed pooling of donations (US$ 133,000 by the end of November 2017; https://kopernik.info/news-events/news/mount-agung-emergency-response-update) to deliver targeted interventions to evacuees (N95 respirators, water filters, toilet and handwashing stations and communications/education kits on disaster preparedness). The initiative was also promoted through a Facebook page (https://www.facebook.com/MtAgungRelief/) allowing simultaneous information dissemination and donations and to leverage support from a broad range of donors for delivery of N95 respirators which, previously, would have been inaccessible due to cost.

Crowdfunding

This specifically relates to internet-mediated fundraising of large amounts of money through many small public donations. Through web-based platforms, donations to fund specific interventions can be requested. Small NGOs, like Kopernik, harnessed this for the Agung eruption by advertising that they were seeking funding to supply facemasks to protect their socio-economically deprived communities from volcanic ash inhalation. They further stated that, based on emerging evidence [2, 3], they would only supply N95 masks (https://kopernik.info/insights-reports/project-reports/mount-agung-emergency-response-phase-four) because these provide the greatest protection. Previously, due to high cost, these masks were not considered a relevant intervention in Indonesia, but crowdfunding is a way to partially remedy the imbalance in protection offered between high and middle-to-low income countries and between rich and poor in the country concerned. The MAR group received 912 separate donations. Due to the visibility of their crowdfunding platform, Kopernik also received multiple donations of N95 masks from interested individuals and businesses.

Shifts in ethical decision making

In previous eruptions, agencies have often needed to act rapidly, in the absence of information on effective interventions for volcanic ash exposure reduction, or even knowledge of whether the ash may be harmful to inhale. Most agencies have (knowingly or unknowingly) applied the precautionary principle, that if something, such as the ash from a volcanic eruption, raises a possible threat to human health, precautionary measures should be undertaken, even in the face of limited scientific evidence that those precautionary measures will be effective [19]. This is especially so when there is an expectation that agencies will do something visible to help [12].

This approach resulted in the mass distribution of surgical and other masks during earlier eruptions in Java, Indonesia [4]. The decision by the MAR group to supply only N95 masks marks a shift towards awareness of, and use of, scientific evidence to inform their response. The decision to supply N95 masks was, at least in part, based on the HIVE project findings, which showed that N95-style respirators perform best against volcanic ash, and fit well on volunteers, even when no training on fit is provided [2, 3]. Preliminary results of the HIVE study were posted on the IVHHN website in September 2017. These results were widely used by the public during the crisis, according to postings on community Facebook groups, and the MAR group [20]. These responses demonstrated a shift from the precautionary principle towards to the principle of effectiveness [12].

Facemasks are usually designed to only fit adults, because they are meant for use in industrial and healthcare settings. However, during the Agung eruption, the MAR group supplied masks to children. This action was based on a donation of 15,000 masks designed specifically to fit children's faces, the safety of which has been tested by clinical trial [21]. In most other volcanic crises, such masks would not be available, and adult sized masks would not fit most children's faces. Agencies have a responsibility to advise on alternative, more-suitable interventions for children, such as keeping them indoors or moving them to a non-ashy area, rather than supplying masks which would not be protective and could even be harmful.

Ethical distribution

The decision to only supply N95 masks does raise questions about who masks should be distributed to. The MAR group did not receive sufficient funding or donations to supply masks to all those affected by ash, resulting in a need to make decisions about who should receive priority allocation. There are various ways in which people distribute scarce resources and, often, in a public health context, those judged most vulnerable and/or most exposed (e.g., emergency workers) are prioritized to access these [22], as has been seen during the COVID-19 crisis. The MAR group prioritized people over 65 years old, those with existing respiratory illnesses, pregnant and breastfeeding women, and children, when children's masks were available.

A further allocative challenge at Agung was that at least fifteen different types of N95 masks were received from donors (Figure 7). While N95 refers to the certified standard of the filtration capacity of the material, some of the masks received are likely to have better fit and greater comfort than others, e.g., those with a valve on the front for humidity reduction in a hot climate. If some masks are more likely to be worn due to comfort factors or are likely to be more effective due to superior fit, then this too raises ethical questions about fair allocation. In future crises, requests for donations of particular mask types (brands and models) would overcome this issue.

The group also received some donations of non-disposable (i.e. reusable) masks made by a company which specializes in comfortable, N95-certified masks, of all sizes (including for children), specifically for community rather than occupational use. Deciding who will receive a reusable mask, and who will not, is also a challenge that can pose difficult ethical dilemmas. Therefore, issues of social justice associated with agencies providing the most effective form of protection against inhalation of volcanic particulates may not be completely overcome if allocative decisions are still being made.

The COVID-19 crisis has resulted in a global shortage of personal protective equipment (PPE) meaning that humanitarian provision of effective community respiratory protection in current or near-future air pollution crises (wild fires, eruptions) will be challenging and the affected communities may need to continue to use the cloth face coverings being employed as infection source control, which the HIVE research showed to be ineffective at filtering ash.

Even if effective protection is available, while NGOs are able to attract financial and other donations, governmental agencies may have to rely on tight budgets and in-kind donations from other humanitarian organizations, making provision of

Figure 7. Fifteen types of industry-certified N95 masks donated to, or purchased by, Kopernik for the Agung crisis.

more expensive masks on a large scale less realistic. During the Agung eruption, governmental agencies continued to distribute surgical masks. Justice in the allocation of resources to ensure best protection, for as many people as possible in LMICs, therefore remains an issue.

Effective resource conservation and management

If expensive masks are donated and stockpiled, it is important that they are suitably conserved. The Yogyakarta provincial disaster management agency (BPBD) in Java, Indonesia was given 13,500 N95 masks by an international humanitarian NGO. The masks were stored in an open warehouse with no temperature or humidity controls and, during a visit, the authors witnessed that the entire stock had perished as the head straps had disintegrated, rendering them unfit for use (Figure 8).

While in Europe mask manufacturers are legally required to print a use by date (usually 5 years) on their certified masks, this is not the case in Australia (where the BPBD masks originated from) making management more complex, even if stored so as to prevent degradation. There is a risk, therefore, that money will be expended on a more expensive protective intervention that will ultimately prove unusable due to degradation or unclear expiry dates.

Figure 8. Perished N95-certified masks, previously donated to BPBD, Indonesia by an international NGO. The green 'line' towards the lower front of the mask was one of the head straps, but the elasticated material has disintegrated. Every mask had broken head straps.

A new age of effective protection?

Will this effort for the Agung evacuees herald a new age of provision of effective community protection during volcanic crises? In 2018, in Hawaii, a major PPE manufacturer donated over 100,000 N95 particulate respirators during the 2018 Kīlauea crisis (personal communication with manufacturer). As with the MAR group, the donation resulted from the Hawaii Department of Health deciding to recommend particulate respirator use based, in part, on the new HIVE project evidence on effectiveness of these masks for volcanic ash [2, 3]. While such donations are available to all countries (e.g., Guatemala received around 20,000 particulate respirators during the June 2018 Fuego volcanic crisis, through the same scheme), donations are upon request from non-profit organizations, which need to be aware of the potential for support, as well as the benefits of these respirators over the more easily-available surgical masks. This suggests the need for an educational endeavor to make such information known to the relevant bodies.

Even though it seems there is a wish to move towards provision of the most effective protection, economic and logistical factors are likely to continue to sway decision making for some time to come, during most crises and for most organizations, and it is unclear how the COVID-19 crisis will have changed agency and community perceptions of facemask use.

We are, however, also observing changes in respect to other types of air pollution events involving particulate matter. For example, UNICEF Indonesia and Kopernik are working on a household haze emergency kit which will include N95 masks. We hope that greater visibility of such masks within communities, the high profile of the Agung relief effort, and the influence of social media in publicizing such activities may lead to other organizations preparing for eruptions, or other forms of air pollution crises (such as wildfires), by considering, in advance, the ethical issues surrounding recommendation and distribution of facemasks and how they will raise funds or seek donations to procure the intervention of their choice. Better communication and coordination amongst relief organizations (ideally across governmental and non-governmental organizations) will also hopefully lead to pooling of resources and, therefore, decisions on equal provision of interventions across whole populations impacted by volcanic ash and other particulates.

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The International Volcanic Health Hazard Network and the HIVE Project

The International Volcanic Health Hazard Network (IVHHN) is an umbrella organization for all research and dissemination of information on volcanic health hazards and impacts. The website (www.ivhhn.org) provides public information on the health hazards and impacts of volcanic eruptions, including a series of pamphlets on volcanic ash, gases and public protection. The website also contains epidemiological protocols and protocols for the collection and laboratory analysis of volcanic ash for rapid health hazard assessment, and a library of all research published in this field.

The Health Interventions in Volcanic Eruptions (HIVE) research was funded by Elrha's Research for Health in Humanitarian Crises (R2HC) Programme, which aims to improve health outcomes by strengthening the evidence base for public health interventions in humanitarian crises. R2HC is funded by the UK Foreign, Commonwealth and Development Office (FCDO), Wellcome, and the UK National Institute for Health Research (NIHR). Further support was also given by Durham University's Research Impact Fund.

For further information on the research described in this article, please see:

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The HIVE study papers and train-the-trainer resources are downloadable from: http://community.dur.ac.uk/hive.consortium/outputs.

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