Institution: Durham University		
Unit of Assessment: 7 - Earth Systems and Environmental Sciences		
Title of case study: Preparing for volcanic eruptions: protection of public health by governmental (GO) and non-governmental (NGO) agencies		
Period when the underpinning research was undertaken: Between 2007 and present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Claire J. Horwell	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** Between 2007 and present
Period when the claimed impact occurred: Between 2014 and 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Communities living near active volcanoes, and the agencies protecting them, require evidence-based advice on how to best reduce exposure to volcanic emissions, in order to prevent respiratory symptoms and diseases. This case study documents how research, led by Horwell, has generated critical evidence and protocols which have enabled both global and community-specific advice to be produced. The evidence has been incorporated into World Health Organization (in the Americas; Pan American Health Organization, PAHO) guidelines and has directly led to changes in policy and practice in several volcanic eruptions since 2017, with agencies providing communities with effective respiratory protection in Indonesia, Hawaii and Guatemala.

2. Underpinning research

Over the past decade a variety of research projects, led by Horwell, have been conducted at Durham University with the aim of enabling community protection from potentially harmful volcanic emissions. When volcanic ash falls on a community, the questions that are immediately asked by both the public and disaster management and health agencies are 'Is it harmful to breathe this air?' and 'How can I protect myself?'. Medical studies (e.g., epidemiology or clinical studies) may take months or even decades, to assess if the emissions are harmful so Horwell developed rapid techniques and protocols for physicochemical analysis of ash, enabling swift health hazard assessment. Laboratory experiments and social surveys have also been conducted to build the first evidence base on the effectiveness of various forms of respiratory protection for community protection.

i) Ash characterisation research

Since 2007, Horwell and her group have developed a range of physicochemical techniques for rapidly assessing the respiratory-health-pertinent characteristics of volcanic ash, to enable decision making on the need for exposure reduction during volcanic crises. Following testing and publication of the underpinning techniques [e.g. R1], a rapid analysis protocol was developed and published on the International Volcanic Health Hazard Network (IVHHN)* website. The protocol was then applied in three eruptions [e.g. R2] and tested in other non-crisis situations. The protocol has four stages: I) sample collection; II) particle size analysis (a critical step, because if ash is too coarse to enter the lung then it cannot be a respiratory hazard); III) full characterisation of health-pertinent physicochemical properties; IV) reporting. Agencies can decide on whether to enact the full or partial protocol, depending on the scale of the eruption and how fine-grained the ash is.

ii) Effectiveness of respiratory protection used for ash exposure reduction

The Health Interventions in Volcanic Eruptions (HIVE; Horwell was PI) consortium project built the first evidence base on effective respiratory protection for community use, for exposure reduction against volcanic ash. Laboratory studies were conducted, at the Institute of Occupational

Medicine, Edinburgh, on 17 different forms of respiratory protection (RP) used by communities during eruptions around the world. The RP ranged from handkerchiefs, shawls and hijab to facemasks including surgical masks and industry-certified devices (e.g. N95 masks). The RP were tested for their filtration efficiency (FE) and their 'leakage' – a combined measure of both fit and filtration, tested on human volunteers [R3]. The results showed that the best type of RP, in terms of both FE and fit, was the N95 mask. Around the world, surgical masks are commonly distributed by agencies but, whilst the results showed that these had excellent filtration, they did not fit well, unless an extra layer of cloth was added to hold the mask better to the face [R3], which the lab volunteers, and community testers in Indonesia, found uncomfortable. All of the tested cloth materials performed poorly against volcanic ash. Folding cloth into multiple layers improved its FE, but multi-layered facemasks, such as surgical masks, were more effective. Many agencies recommend wetting cloth materials or surgical masks, but the experiments did not find any additional protective benefits to wetting. An ethical framework was also developed to aid agency decision making on which types of RP to recommend [R4]. The social research showed that different cultures have different perceptions of the health risk from volcanic ash, and the need to protect themselves, so advice must be tailored to fit the needs of individual communities [e.g. R5].

iii) Community perceptions of vog exposure, protection and advice on Hawaii Island

In 2015, Horwell worked with communities (by conducting focus group discussions and questionnaire surveys) to understand how they protect themselves from the impacts of the constant gaseous emissions (known as 'vog') from Kīlauea volcano, Hawaii and how this relates to official guidance given by federal and state agencies. The research found that, whilst it was difficult for many people to reduce exposure to vog, given their outdoor lifestyles, the tropical climate and, hence, lack of robustness of housing design, the communities had developed a range of strategies for coping with the symptoms which they attribute to the vog [R6]. The work resulted in the formation of an interagency (GO) partnership to revise the existing public health advice, based on the study.

3. References to the research (indicative maximum of six references)

Number after each URL is journal 5-yr impact factor

R1. Horwell C.J., Fenoglio. I., Fubini. B. 2007. Iron-induced hydroxyl radical generation from basaltic volcanic ash. Earth and Planetary Science Letters. 261, 662-669. https://www.sciencedirect.com/science/article/pii/S0012821X07004888?via%3Dihub. 5.273

R2. Horwell, C.J., Baxter, P.J., Hillman, S.E., et al. 2013. Physicochemical and toxicological profiling of ash from the 2010 and 2011 eruptions of Eyjafjallajökull and Grímsvötn volcanoes, Iceland using a rapid respiratory hazard assessment protocol. Environmental Research, 127, 63-73. https://www.sciencedirect.com/science/article/pii/S0013935113001539. 5.715

R3. Steinle, S., Sleeuwenhoek, A., Mueller, W., Horwell, C.J., et al. 2018. The effectiveness of respiratory protection worn by communities to protect from volcanic ash inhalation; Part II: Total inward leakage. International Journal of Hygiene and Environmental Health 221(6): 977-984. https://www.sciencedirect.com/science/article/pii/S1438463917308027 5.081

R4. McDonald, F., Horwell, C.J., Wecker, R., et al. 2020. Facemask use for community protection from air pollution disasters: An ethical overview and framework to guide agency decision making. International Journal of Disaster Risk Reduction 43: 101376. https://www.sciencedirect.com/science/article/pii/S2212420919308295 3.275

R5. Covey, J.A., Horwell, C.J., Rachmawati, L., Ogawa, R., Martin del Pozzo, A.-L., Armienta, M.A., Nugroho, F. and Dominelli, L., 2019. Factors motivating the use of respiratory protection against volcanic ashfall: A comparative analysis of communities in Japan, Indonesia and Mexico. International Journal of Disaster Risk Reduction, 35: 101066. https://www.sciencedirect.com/science/article/pii/S2212420918313670 3.275

R6. Horwell, C.J. Community perceptions of volcanic gas exposure, protection and advice on Hawai'i island: a first assessment. Executive Summary and Report submitted to Hawaii Agencies (Department of Health, Civil Defence, National Park Service, US Geological Survey). December 2015.

Horwell is regarded as a leading publisher of research on volcanoes and health. She was awarded the European Geosciences Union's 2020 Plinius medal for interdisciplinary research on natural hazards and is currently the President and founding leader of the American Geophysical Union's GeoHealth Section. She has 59 papers published in high impact factor international journals across the environmental, health, volcanology, toxicology, social and humanitarian research disciplines. *Horwell is also Director of the International Volcanic Health Hazard Network (www.ivhhn.org) which is the international umbrella organisation for research and public dissemination of information about health issues related to eruptions.

Underpinning grants:

1. Wellcome Trust & DfID Consortium Grant. 'A new evidence base for respiratory Health Interventions in Volcanic Eruption crises' (HIVE). Horwell, C.J. (P.I.) Awarded through Elrha's Research for Health in Humanitarian Crises Programme. GBP611,710. 11/15-03/19. http://community.dur.ac.uk/hive.consortium/
2. British Council Researcher Links grant: 'Health interventions and messaging downwind of Kilauea volcano, Hawaii'. Horwell, C.J. (P.I.) GBP9,604. 03/14-03/15.
3. NERC Urgency Grant. 'Rapid assessment of the potential health hazard of ash from Eyjafjallajökull volcano, Iceland' Horwell, C.J. (P.I.) GBP37,689. 07/10-03/11.

4. Details of the impact

Changes to volcanic health response policy

Horwell's research, to build an evidence base on the respiratory health hazards of volcanic emissions and effective methods of community protection, has resulted in incorporation of methodological protocols into country-level emergency management plans, co-development of informational products with communities and agencies, and their uptake and use during volcanic crises. This has resulted in raised awareness of effective actions in communities and changes in policy and practice related to mask distribution by agencies.

Improved community protection

When a volcano erupts, agencies (usually GOs and NGOs with public health, civil protection, disaster management and humanitarian remits) will often distribute facemasks to reduce individual exposures to volcanic emissions, hence reducing the risk of harm from ash inhalation. Until recently, distributed facemasks have usually been those that have already been stockpiled for public health emergencies (e.g., surgical masks stored for influenza pandemics). Until the HIVE project, there was little-to-no evidence of the effectiveness of these masks in community settings for volcanic crises.

The Pan American Health Organization (PAHO) which is the World Health Organization's (WHO) Regional Office for the Americas, has rewritten its guidelines on the health impacts of volcanic eruptions. Within those guidelines, information related to respiratory protection is based on the evidence provided by the HIVE research [E1]. These guidelines replace the current information available across the WHO, globally. The HIVE findings and impact were also summarised in a special supplement of PAHO's Disasters Newsletter (October 2020), which reaches approximately 27,000 experts worldwide [E1], enabling awareness raising at a local level and, hence, faster implementation of the guidance during volcanic emergencies. A new IVHHN/HIVE standardised epidemiological protocol, for use in eruption crises, was also incorporated as part of PAHO's Regional Response Team assessment tools. Dr Ciro Ugarte, Director of Health Emergencies at PAHO, has said: "The contribution of the HIVE project has been instrumental in building and sharing scientific evidence on respiratory protection from volcanic ash within the Americas. I would like to specially recognise Durham University for this essential collaboration towards a more resilient health sector in the Americas." [E1]

In late 2017, the Mt Agung, Bali volcanic crisis triggered a critical shift in the approach to community protection in volcanic emergencies in low-to-middle income countries (LMICs). The fundamental difference between the preparedness for the Agung eruption, and that of previous volcanic crises in LMICs, came from a combination of changes in humanitarian practice, such as

the advent of crowdfunding platforms, greater coordination of grassroots response, and a sudden move away from the precautionary principle (any intervention is better than no intervention) towards the principles of effectiveness (only providing proven interventions) and social justice (equality in public health provision). This ethical decision-making was based on the results of the HIVE project [R3-5], which showed that industry-certified (N95) masks were the most effective at protecting against ash inhalation [E2]. This resulted in the donation, stockpiling and distribution of 75,000 N95 masks in Bali by a consortium of NGOs known as Mt Agung Relief (led by Kopernik), a situation which has not previously been observed in a volcanic crisis in a LMIC (see [E1] for case study). Mt Agung Relief also produced a series of public informational products on ash protection based on the findings of the HIVE project [E2-3]. Horwell also shared the findings of the HIVE project through social media and engaged in discussions with communities in Bali through local Facebook groups such as Community Ubud, resulting in evidence-based community-level decision making [E3].

The results of the HIVE research [R3-5] have subsequently been incorporated into new public information products (printable and audio-visual), downloadable from the IVHHN website. They were co-developed with Indonesian NGOs, GOs and community representatives and are now available in English, Spanish, Indonesian, Filipino, Japanese and Turkish. The English and Spanish printable products (booklet, poster and leaflet) are endorsed by PAHO/WHO and carry their logos [E1]. These products provide information on how to protect from inhaling ash (2,443 video views 09/20) and how to fit a facemask (9,946 video views 09/20). Another video documents people's experiences of protection during the 2010 Merapi (Indonesia eruption), to help people prepare for future eruption crises (9,618 video views 09/20). During the 2018 ash eruptions of Kīlauea volcano, Hawaii, a major PPE manufacturer donated over 100,000 N95 particulate respirators, in collaboration with local NGOs and GOs, a decision informed by the HIVE evidence [E4]. Local guidance was also developed by the Hawaii Department of Health (HDOH), based on the IVHHN products [E4]. Additionally, several NGOs in Indonesia have used the information to make their own products, for example, the Yakkum Emergency Unit has produced a series of posters [E5]. The Indonesian Red Cross (PMI) and Direct Relief (a US based humanitarian relief organization) have said that they will be printing and distributing the products in future eruption crises [E6; E7].

In January 2019, the HIVE project team returned to Indonesia to conduct four train-the-trainer workshops, on how to fit a facemask, for more than 70 representatives of local agencies and health centres, with the International Society for Respiratory Protection and the Indonesian Red Cross. Those representatives are now engaged in further training and, so far, at least 800 people have received this training [E6].

In Hawaii, the research finding [R6] that communities were coping with vog (gas) exposure in different ways from the official advice, and that the advice was viewed by some as inappropriate given their lifestyles, triggered a complete rewrite of that advice by the HDOH, US Geological Survey (USGS) and IVHHN (Horwell) [E4]. The research also showed how existing advice offered by different agencies varied on different websites. Through workshops held as part of the research, a new Interagency (GO) Partnership was formed (HDOH, Civil Defense, USGS, US National Park Service, County of Hawaii etc.) and an agreement was made that all future advice on vog protection would be consistent across the different agencies. The new guidelines have been published as a booklet, rack brochure and poster, and are available online on a new, comprehensive 'web dashboard' which Horwell co-designed with the interagency partnership. The Vog Dashboard (https://vog.ivhhn.org/), is hosted by IVHHN so that no particular Hawaii/ US agency appears to lead the Partnership and all vog information and data can be accessed from one portal. The guidelines were written to be more reflective of Hawaiian lifestyles and to incorporate the communities' strategies for coping, where these were evidence based. The agencies then removed their old advice from their own websites so that there was a single point of information [E8]. In May 2018, an unprecedented volcanic crisis emerged as the Kīlauea eruption changed location and style, resulting in multiple volcanic hazards and impacts within the community. The Vog Dashboard became a key source of official information, receiving approximately 50,000 visits per week during this crisis and was also highly

recommended by various international media outlets [E9]. Fenix Grange, HDOH, said: "We are indebted to Dr. Horwell and IVHHN for the extraordinary, accessible technical resources and the expertise provided. Their contributions to the massive, multi-disciplinary response to the volcanic eruption crisis of 2018 (and prior events) were very important to the mission of HDOH to protect the people of Hawaii" [E4].

Rapid health hazard assessment

The ash analysis protocols, adopted by IVHHN, have been incorporated into New Zealand governmental policy to be enacted in any future eruptions [E10]. This coordinated framework for public health response to eruptions involves governmental ministries, the national geological survey (GNS Science), Regional Councils, the Met Service and universities. When an eruption occurs, the framework of responses will be enacted and ash collection and characterisation, in accordance with the IVHHN protocols, is part of that crisis management plan. Therefore, official guidelines and practice have been established which purposefully incorporate Horwell's protocols. Horwell was invited to New Zealand, in Nov. 2013, to present her research to the governmental ministries and at a forum of regional public health representatives, which kicked off the process of writing and establishing the framework.

In 2017, key organisers of the framework (at GNS Science and Massey University) advised on crisis response for an eruption in Vanuatu. They enacted the IVHHN protocol, as part of that response [E10]. Parts of the IVHHN protocol have also been applied in other volcanic crises by local agencies around the world. "Claire's work has led to improved capacity for rapid eruption response in both NZ and Vanuatu, including the activities of Civil Defence and Emergency Management Groups throughout the North Island." Graham Leonard, GNS [E10].

To conclude, Horwell's research on how to protect communities from exposure to volcanic emissions has influenced policy and practice in numerous health-facing organisations, around the globe, resulting in better preparedness, improved public health advice and protection, and enhanced understanding of the hazards of volcanic ash.

5. Sources to corroborate the impact

[E1] PAHO-WHO evidence compilation: testimonial letter, Disasters Supplement (https://www.paho.org/disasters/newsletter/index.php?lang=en), webpage
[E2] Kopernik testimonial letter
[E3] Agung eruption evidence compilation
[E4] Hawaii Department of Health and United States Geology Survey testimonial letters 2016-2019
[E5] Yakkum Emergency Unit poster
[E6] Indonesian Red Cross (PMI) testimonial letter
[E7] Direct Relief testimonial letter
[E8] Hawaii agencies advice change, evidence compilation (screen grabs)
[E9] International media links mentioning the Vog dashboard/IVHHN during the Kilauea crisis
[E10] New Zealand GNS Science testimonial letter