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# The International Volcanic Health Hazard Network (IVHHN): reflections on 20 years of progress

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## Introduction

The International Volcanic Health Hazard Network (IVHHN; www.ivhhn.org) is an interdisciplinary organization which coordinates research and provides advice on volcanic health hazards and impacts.

The field of research on the human health hazards and impacts of volcanic eruptions dates to 1980 with the eruption of Mount St. Helens (Baxter et al., 1981; Buist and Bernstein, 1986; Horwell and Baxter, 2006). The principal concerns revolved around the respirable crystalline silica (RCS) content of volcanic ash, which blanketed a vast swath of the north-western United States, and its potential to cause the fibrotic lung disease silicosis in exposed communities. A well-known occupational hazard for mine and quarry workers exposed to natural mineral dusts, the consequences of 24-h exposure to the airborne ash, for children and the public, in general, required urgent appraisal to allay panic amongst the million people living and working in the affected areas.

State and federal agencies were immediately mobilised to respond to the emergency and the later recovery phases of the disaster, in collaboration with academic and other research groups. The public health component of this vast undertaking involved many disciplines and was summarised in a volume edited by Buist and Bernstein (1986). The research at Mount St. Helens was reassuring in resolving the health concerns at the time, but also highlighted the future need to systematically identify and quantify the hazards and provide informed advice on mitigation measures because the mineralogy of volcanic ash, along with its respiratory hazard, varies with every eruption.

The Mount St. Helens response was, without doubt, enabled by the financial resources and expertise in the United States. Indeed, the next eruptions to receive a concerted (or any) health response were related to other high-income countries: Sakurajima volcano, Japan, starting in the 1980s (reviewed by Hillman et al., 2012), and Soufrière Hills volcano, Montserrat, a British Overseas Territory, in the late 1990s (reviewed by Baxter et al., 2014), where RCS concentrations were substantially higher than at Mount St. Helens, presenting a significant silicosis risk for the islanders that required special mitigation measures (Hincks et al., 2006). The UK government had the legal responsibility for the health and safety of the Montserrat population and funded the health research as well as supporting the island's disaster management. Apart from these events, individual research studies have been

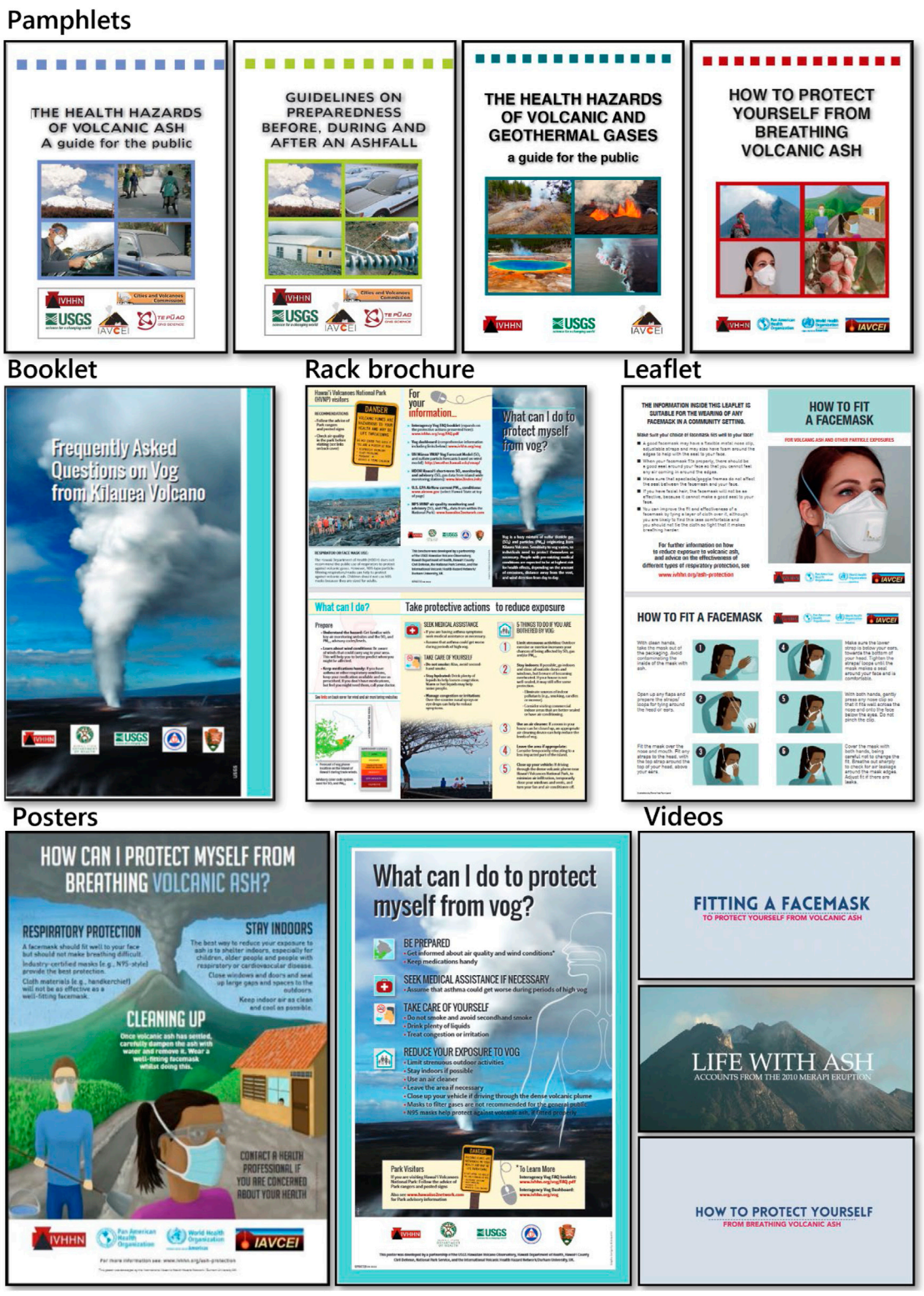


FIGURE 1
Collage of IVHHN informational products downloadable at https://www.ivhhn.org/information.

conducted at various volcanoes (reviewed in Horwell and Baxter, 2006; Mueller et al., 2020b; Stewart et al., 2022), but coordinated, interdisciplinary health responses have been rare, leaving communities both proximal and distal to volcanically active areas uninformed about exposure to airborne gas and ash emissions - and other volcanic hazards - and at risk.

Interdisciplinary responses that inform hazard assessments are essential because critical public health decisions need to be made

early in the exposure timeframe. Rapid geochemical and toxicological assessments can identify hazardous characteristics of volcanic ash (Horwell et al., 2013) that could otherwise take years or decades to manifest as respiratory or other chronic diseases. Immediate exposure assessment through ambient air quality monitoring of particles and gases can provide essential data for epidemiological and clinical studies, linking acute symptoms and future diseases to the correct exposure source (Mueller et al., 2020b; Whitty et al., 2020). Personal monitoring of high-risk individuals, such as outdoor workers, can justify implementation of mitigating measures to reduce exposures. Yet, often, experts in these different areas of environmental health sciences are not working together routinely prior to an eruption. Additionally, these experts may be inexperienced in the collection and analysis of volcanic materials.

## The birth of a network

IVHHN was launched 20 years ago, in February 2003, via a Leverhulme Trust grant (led by authors Sparks & Horwell), to bring together scientists and practitioners who were working globally to protect the health of communities during volcanic eruptions (Pickrell, 2003). Offering a forum for discussion and collaboration, IVHHN included volcanologists, clinicians, public and environmental health specialists, epidemiologists, toxicologists, and exposure scientists. A launch workshop at the third Cities on Volcanoes Conference in Hawaii (July 2003) brought together the members for the first time.

By late 2003, IVHHN expanded its remit to provide public information and scientific protocols for use during eruption crises, with a focus on the health impact of volcanic airborne emissions. In the context of the UK government, requiring evidence-based information and standardized methods for ash analysis during the Soufrière Hills eruption, a workshop was held in November 2003, led by Horwell, Baxter, and Sparks and attended by UK experts in ash and RCS analysis and exposure assessment. The workshop instigated production of two pamphlets on preparedness for ashfall and the health impacts of volcanic ash (https://www.ivhhn.org/ash-pamphlets) (Figure 1), which were translated into several languages. Protocols were also produced on how to collect ash for analyses and methods for particle size analysis (https://www.ivhhn.org/guidelines#ash-collection). The IVHHN website was developed to inform researchers, agencies, and the public about the availability of these products and encourage global use.

## Beyond networking

Since 2003, IVHHN has evolved into an international organization that provides public information and advises governments on preparing for, and responding to, the many health-related consequences of eruptions (see review in Baxter and Horwell, 2015). As a Commission of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), IVHHN took on a management structure, with Co-Directors (Elias, Stewart, and Damby from 2017 and, in 2021, Ilyinskaya) and an early career representative (Tomašek from 2021) with Horwell as Director of IVHHN since its inception. Regular meetings and workshops identify knowledge gaps, discuss real-world experiences, and set goals and targets for progress, notably protocols and analytical methods and educational materials that enable local agencies and the public to prepare to mitigate health risks.

## Protocols and analytical methods for scientists

A continued aim for IVHHN has been the development and publication/dissemination of standardized geochemical methods and protocols for volcanic ash hazard assessment (Horwell, 2007; Horwell et al., 2007; Le Blond et al., 2009; Stewart et al., 2020; Tomašek et al., 2021b). These efforts ensure reliable, time-sensitive data collection and enable comparison of data among eruptions. For example, a workshop in 2011 established best-practice methods for assessing readily leachable elements from ash (Stewart et al., 2013, revised in 2020), followed by an international intercomparison exercise to test repeatability/reproducibility to confirm the usability of the protocol in different laboratories (Stewart et al., 2020). A further study confirmed that a water leach is reliable for rapid respiratory hazard assessment (Tomašek et al., 2021b). Similarly, conflicting results for RCS analyses of Mount St. Helens ash (Analytical Chemistry, 1980) and the need to accurately quantify high concentrations of RCS in Soufrière Hills ash (Baxter et al., 1999) led to revision of a method to rapidly quantify volcanic crystalline silica (Le Blond et al., 2009).

IVHHN enacts these methods and protocols during eruption responses, either within member laboratories or with local partners. Such analyses have been conducted for eruptions of Chaitén, Chile 2008 (Horwell et al., 2010a), Kīlauea, United States (2008, 2018; Horwell et al., 2008); Merapi, Indonesia (2010; Damby et al., 2013), Eyjafjallajökull and Grimsvötn, Iceland (2010 and 2011; Horwell et al., 2013), Tongariro, New Zealand (2012; Cronin et al., 2014), La Soufrière, St. Vincent (2020-21; Horwell et al., 2023a), Hunga Tonga–Hunga Ha'apai (2021), and Tajogaite, La Palma (2021), among others. These methods have also been used on historical ash samples to estimate future hazards (e.g., at Etna, Vesuvius, Rabaul, Sakurajima and Icelandic volcanoes; Horwell et al., 2010b; Le Blond et al., 2010; Hillman et al., 2012; Damby et al., 2017; Horwell et al., 2017). Results are shared immediately with local authorities so they can make informed public-health decisions. For example, identification of abundant respirable particles in La Soufrière ash prompted the Pan American Health Organization (PAHO) to establish an air quality monitoring network on St. Vincent (Horwell et al., 2023a).

The paucity of clinical and epidemiological research has meant that we have been unable to provide sufficient evidence on the risks to respiratory health of long-term exposures to ash and gas (Stewart et al., 2022). This is partly due to the lack of resources to be able to mobilise timely and expert epidemiological studies and because a plethora of study designs has made it challenging to compare study findings. Consequently, we developed standardized epidemiological protocols (Mueller et al., 2020a) that are intended to be incorporated into, and adapted for, national crisis response plans. PAHO has been facilitating this process throughout Latin America and the Caribbean, and the Hawai'i State Department of Health adapted

the protocols for syndromic surveillance during the 2022 Mauna Loa eruption.

## Supporting agency planning and response

IVHHN members have contributed to meetings of national health agencies to prepare for and coordinate health responses in eruption crises. For example, following workshops with agency representatives, IVHHN ash analysis protocols are now embedded in eruption response plans in New Zealand. An IVHHN workshop in 2019 brought together U.S. agencies, including health professionals who responded to the 1980 Mount St. Helens eruption, to reflect, and discuss plans for the next major mainland eruption. IVHHN has also instigated train-the-trainer workshops in Indonesia for 70 agency representatives who then trained thousands more on how to fit N95-style facemasks for ash exposure reduction.

During eruptions, globally, local authorities may ask IVHHN for comprehensive yet concise advice. During the 2021 La Soufrière eruption (St. Vincent), IVHHN produced a suite of crisis management briefing notes (https://www.ivhhn.org/crisis-management) to support agencies during eruption responses. These briefing notes provide guidelines for water and air quality management, and health and safety during ash clean-up. The webpage also hosts eruption-specific guidance and reports from previous IVHHN rapid ash-hazard assessments.

### Public health and risk communication

Since the initial production of the two pamphlets on ashfall, IVHHN has developed innovative and culturally adapted public communication products for use during eruptions. Building on a study of community perceptions to agency advice, related to gas and aerosol emissions (known as 'vog') at Kīlauea volcano (Horwell et al., 2023b), IVHHN and local agencies co-developed a suite of printable information products with advice tailored to the communities' lifestyles and practices (Figure 1). In 2016, the guidance was adopted by relevant agencies on the Island of Hawai'i, thereby standardizing advice across agencies for the first time. This partnership resulted in the Hawaii Interagency Vog Information Dashboard (https://vog.ivhhn.org) (Horwell et al., 2023b), developed to centralize resources related to volcanic emissions in Hawaii, including the information products and air quality data and forecasts. During the 2018 Kīlauea lower East Rift Zone eruption (Neal et al., 2019), the Dashboard was accessed more than 50,000 times per week and was listed by Forbes as a top resource (Siegel, 2018). It was also adapted for, and heavily used, during the 2022 Mauna Loa eruption. A new, globally relevant pamphlet on the health impacts of volcanic gas emissions was published by IVHHN in 2019, based on the Hawaii guidelines.

The lack of robust evidence on the effectiveness of different types of respiratory protection worn by communities exposed to volcanic ash led to a project evaluating Health Interventions in Volcanic Eruptions (HIVE; PI Horwell). The findings resulted in a suite of new IVHHN audio-visual and printable informational products (Figure 1), the latter endorsed by the World Health Organization, which give evidence-based information on exposure-reduction interventions (Mueller et al., 2018; Steinle et al., 2018) and support agency decision-making when procuring, distributing, and recommending respiratory protection (Mcdonald et al. 2020).

The project used innovative application of social learning biases (Kendal et al., 2018) to co-develop public information products for underrepresented and underserved communities, and supporting agencies, near Merapi volcano, Indonesia. The first video, on reducing ash exposures (https://youtu.be/U9BU_xSQsm4), used a workshop format to discover the types of people and characters that local communities would best respond to (e.g., authority figures but, also, cartoons, real people, animal characters, etc.) and to storyboard the video. Women and men were seated separately to ensure that women had a voice. The second video provided an experiential account of how people in the local communities protected themselves from ash during the 2010 eruption (https://youtu.be/lQQR4_QwaxU). This lived-experience style of video supports preparedness by helping people remember what happened in previous eruptions and informing individuals elsewhere about what it might be like to experience an eruption. The third video accompanies a leaflet on how to fit a facemask (https://www.ivhhn.org/information/public-information-material/fitting-a-facemask-leaflet), designed for distribution alongside masks during eruption crises. The mask demonstrators were chosen to be widely representative (two Indonesian women, with and without a hijab, and a white man) to support information uptake (https://youtu.be/7WYN99KRHYE). These videos, as well as a video on the health impacts of eruptions, are part of the VolFilm series (https://www.youtube.com/@volfilm5670), which includes other experiential videos, for example, on volcanic gas exposures at Masaya volcano, by IVHHN Co-Director Ilyinskaya (https://youtu.be/l465HHlXPcg).

The IVHHN website and products are used globally by the public and by hazard/health management agencies who print and distribute the products to local communities. Recently (December 2022), the Office of Disaster Management (ODM) in Dominica printed 300 copies (initially, with more to be printed during an eruption) of each of three IVHHN pamphlets to raise awareness of volcanic hazards on the island. The pamphlets included ODM's logo to create a sense of trust that the guidance was official. IVHHN also has an agreement with the U.S. humanitarian organization Direct Relief to distribute IVHHN information on fitting facemasks (also with their logo) when they send medical supplies (including facemasks) to eruption crises. The pamphlets were also distributed in the 2018 Fuego eruption, Guatemala, by PAHO, and IVHHN advice was incorporated into many local and regional agencies' infographics and public information during the 2021 St. Vincent and Hunga Tonga–Hunga Ha'apai eruptions.

With the emergence of social media as a primary tool for public communication, IVHHN promotes awareness and advice on various platforms. This includes administering and moderating a dedicated social media group on Hawaiian volcano emissions, which is a forum for discussion and queries especially during eruption crises (Horwell et al., 2023b), and providing advice (when asked) to responding agencies' social media managers.

## Promoting scientific research

The field of research on the health hazards and impacts of eruptions is growing. IVHHN supports research by hosting an online library of all research articles published in relation to volcanoes and health. In 2023, a new, fully searchable bibliographic database will be available on the website at https://www.ivhhn.org/ivhhn-library. IVHHN also promotes research through convening workshops and sessions on health and eruptions at international conferences. Research progress was recently reviewed by Stewart et al. (2022), and the fundamental questions related to volcanic exposures and health have been a career focus for several of us, such as whether volcanic RCS is pathogenic, whether exposures are sufficiently long to cause silicosis (e.g., Baxter et al., 1999; Horwell et al., 2012; Baxter et al., 2014; Damby et al., 2016; Nattrass et al., 2017; Damby et al., 2018), and how volcanic ash interacts with the anthropogenic atmospheric environment (Tomašek et al., 2016; Tomašek et al., 2018; Tomašek et al., 2021a).

# Discussion

Reflecting on 20 years of progress, much has been done to grow IVHHN as an internationally respected organization. IVHHN now has five primary focus areas: 1) develop and implement standardized physicochemical and epidemiological protocols for use during eruptions; 2) prepare for and help coordinate health responses in advance of, and during, eruption crises; 3) compile and distil existing knowledge on volcanic crisis health management; 4) foster health hazard and risk communication, including production of public-facing audio-visual and printable informational products; 5) support the exchange of information on the health impacts of volcanic emissions including convening conference sessions and workshops. Critically, all products and advice are evidence-based, with information derived from scientific research and past eruption-response experiences.

IVHHN's existence has helped to identify critical gaps in knowledge and highlight the rarity of volcanic emissions health impact assessments (Mueller et al., 2020b). As such, IVHHN has followed a precautionary approach, emphasizing preparedness and communication, while providing tools to build a robust evidence base of hazards and impacts from eruptions globally. Despite the constraints of being a largely unfunded endeavour (since 2006), we remain committed to addressing these challenges through worldwide, interdisciplinary, operational, and research collaborations.

# Author contributions

All authors are key personnel of the International Volcanic Health Hazard Network. CH devised the manuscript and wrote the first draft. All authors contributed to the article and approved the submitted version.

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# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

# Publisher's note



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