Standardized Epidemiological Study Protocol to Assess Short-term Respiratory and Other Health Impacts in Volcanic Eruptions

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1. Introduction

This document presents a standardized protocol to facilitate epidemiological studies of populations that have been, or may be in the future, exposed to volcanic emissions, including ash and gases. This protocol will help answer the question: Is there a short-term increase, at a population level, in adverse health outcomes following a volcanic eruption?

The intent is for the protocol to be applicable in all volcanic contexts and settings, regardless of resource availability, health records systems, or timeframe. The protocol presented herein is for a basic study of respiratory and other health outcomes, to be conducted during or immediately following a volcanic eruption, ideally with timely results available shortly after an episode occurs. In a separate document, a protocol is presented 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 (though one may be completed regardless of prior results). Although such a survey can provide better quality data on individual health effects and their association with exposure to volcanic ash or gases, its results would not be available until at least several months following the eruption.

This basic study protocol can be of use to governmental and other relevant health agencies, research institutes, and hospitals that wish to assess in a timely manner the respiratory and other potential health effects in populations exposed to volcanic emissions. While undertaking this study in a disaster setting will be difficult amidst the many other emergency management responsibilities, the data collection forms included in the appendices below can be integrated into response activities for efficiency and to minimise any duplication.

Therefore, it is strongly advised that efforts to undertake a study during/following an eruption are coordinated with concurrent emergency responses or other associated activities. To expedite study implementation, it is recommended that studies be planned in advance, where possible, ***including the initiation of a dialogue with the relevant ethics board in case any such approval is required*****.**

In developing this standardized protocol, the focus is on efficiency, cost containment and an emphasis on providing information on the health risks for the public at the earliest opportunity.

2. 'Basic' Epidemiological Study

Once a volcanic eruption has occurred, local officials will want to know if there are any detectable adverse health effects (morbidity) or deaths (mortality), due to the eruption, in populations exposed. Syndromic surveillance systems, if established, may provide these data. Such surveillance systems automatically collect and summarise routine health data, including reasons for hospital visits or admissions, which may be coded according to local custom or using an international scheme such as the International Classification of Diseases (ICD). However, if no such system is in place, epidemiological studies may be set up to collect equivalent data before, during, and after an eruption occurs.

We outline steps below for a basic epidemiology study for local health officials to use. If appropriate, results can be used to justify further research with additional resources.

1. Size and location of study

The study should focus on the area(s) with visible levels of volcanic ash deposition, known as the exposed area. However, depending on the severity and duration of the eruption, the actual exposed area may be considerably larger. Whilst the study should include **all major public hospitals/health**

clinics in an exposed area (i.e., all health facilities that receive individuals affected by the eruption), this may not be practicable for eruptions where ash clouds travel long distances. Instead, in these cases, all major health facilities in specific towns/population centres in a relatively highly exposed area should be included in the study. The situation may be complicated by the existence of multiple healthcare systems, e.g., public and private, though inclusion of public hospitals would possibly ensure inclusion of the most vulnerable people. Collection of data from all relevant facilities in this area would help **reduce bias** in the subsequent analysis by tracking the majority of healthcare visits from the affected population. Further, the inclusion of more facilities would yield higher counts of visits, which would **increase the statistical power** of the study (i.e., the ability to detect health impacts specifically related to the eruption). This should be balanced against any increased cost of extending the surveillance.

While achieving a large sample could prove challenging due to limited local population sizes and/or the background rates of disease (for example, less common diseases would require larger sample sizes to detect any increases), a small sample size should not preclude a study going forward. As an example based on UK hospital admissions data, if respiratory diseases represent about 8% of all admissions[1], about 250 total admissions each from before and after the eruption would be needed to detect a doubling of respiratory risk from exposure. This example notwithstanding, a statistical power calculation using local data should be completed to help with the interpretation and confidence of results[2]. Regardless, small studies can still be helpful, as results can be pooled to help assess overall health effects.

In reality, the number of hospitals or clinics from which to collect information, and the completeness of data collection, will depend on the:

- Availability of an electronic or paper surveillance system that can readily produce health data;
- Personnel and financial resources available to carry out the study and, if needed, collate records from the healthcare facilities (local health authorities would need to be involved to extract requested data from surveillance systems); and
- Extent to which emergency clinics are established to treat individuals following the eruption.

Any temporary emergency clinics are not likely to have baseline data (i.e., prior to an eruption) with which to compare visits following an eruption. Nevertheless, if clinics are set up, the number of patients attending and their reasons for doing so should be included in the basic study analysis to provide an accurate estimate of health impacts (i.e., combined with, and compared to, those collected from hospitals/permanent clinics).

2. Exposure assessment

The study should be conducted in an area where exposure to volcanic emissions has occurred. **Exposure levels** can be assessed by:

- Quantitative assessment (preferred) through measurements of:
  - (i) **ambient air quality**, e.g., concentrations ($\mu g/m^3$ or ppm) of particulate matter (PM) or SO_2, or

[1] NHS, 2017

[2] As an example, see: https://select-statistics.co.uk/calculators/sample-size-calculator-two-proportions/

(ii) **sampling ash on the ground** (g/m^2); categories might be defined as follows: none, <1 mm, ≥1 mm[3]. Guidance for collection of ash samples is available on the IVHHN website[4].

or, if neither is possible:

- Qualitative observations to indicate relative exposure, e.g., **the presence of any ash.** One option would be to designate areas as having high/medium/low ash, though this categorisation would necessarily be subjective.

Quantitative population exposure estimates could be based on concentration readings from available air quality monitoring stations. These exposure estimates could be refined if there are multiple air monitors (though unlikely) or clearly differing ash levels among locations. Estimates based on ambient concentrations of airborne PM, rather than ash on the ground, provide a quantitative description of inhalable material which allows modelling of dose-response and comparisons with other environmental exposures, e.g., urban air pollution.

Exposure duration should also be estimated in relation to: i) duration of eruptive emissions; ii) the implementation of interventions such as on-the-ground **clean-up activities** (to prevent the resuspension of ash) and protective measures; iii) timeframe of return to background ambient air quality concentrations.

3. Health outcomes

Past studies of exposure to volcanic ash and gases indicate the sensitivity of the respiratory system[5] to volcanic emissions, particularly in young and elderly populations; therefore, examining visits to hospitals and/or clinics for **respiratory diseases and symptoms** would be most suitable for the evaluation of potential health impacts. Respiratory disease is coded (J00-J99) in the ICD (version 10) classification, though it would be more effective to focus on those conditions that could be precipitated by inhalation to ash and/or SO_2, namely **acute (J20-J22) and chronic (J40-J47) lower respiratory infections or diseases**, as well as **acute (J00-J06) and chronic (J40-J47) infections or diseases of the upper respiratory tract.**

Other potential health outcomes to evaluate with exposure to volcanic emissions, and from generally being in a post-disaster setting, include:

- Cardiovascular (I20-I52) and cerebrovascular (I60-I69) endpoints;
- Disorders of the eye (H55-H59);
- Accidents (V01-X59), including exposure to smoke, fire and flames (X00-X09);
- Mental health[6], i.e., reaction to severe stress (F43); and
- If data are available, dispensing of medications e.g., inhalers.

The type of health data selected for the basic study depends on the level and detail of information available in the locality of the eruption. To address morbidity, the most likely accessible administrative health data are recorded from **visits to hospitals, emergency departments, or health clinics**. In addition to the list presented above, it would be useful to request total visits to account for any

[3] Hawaii Public Schools provided guidance with similar categories and action levels after the 2018 Kīlauea Eruption: http://www.hawaiipublicschools.org/DOE%20Forms/Safety/SchoolActionPlan-Ashfall.pdf
[4] https://www.ivhhn.org/guidelines
[5] Hansell & Oppenheimer, 2004; Horwell & Baxter, 2006
[6] Shore et al., 1986

variation or poor coding of certain health endpoints. As discussed further in the analysis section below (#7), ideally health data are needed both from before and after the eruption. One point to keep in mind is that some health systems may periodically adjust data to account for corrections. The study team should be aware of any such practices to ensure analysis is carried out on the most up to date and accurate dataset.

4. Demographic and other information

Other information included with the visit record will help detect if any adverse health outcomes are isolated to, or heightened in, specific sub-groups:

- **Age/date of birth, sex & ethnicity**: Younger or older individuals may be more susceptible to volcanic gases and ash. Therefore, allocating records to **age groups** is important to indicate young, adult, and older individuals**:** <19, 19-65, >65 years. Sex and ethnicity should also be recorded with age.
- **Date and details of visit/admission**: Specific dates can provide more information on when health effects were observed and whether there were time lags between exposure and health response. Any treatment/medication provided would also be useful.
- **Address** details confirm whether an individual lives in an area exposed to volcanic emissions (if possible, it would be useful if addresses were geocoded, potentially using mobile apps).
- **Occupation**, **smoking status**, and any **pre-existing conditions** could help determine if any particular groups are more likely to visit healthcare facilities after an eruption, e.g., smokers, individuals with asthma or other respiratory diseases, pregnant women.

5. Data collection

The US Centers for Disease Control[7] have made available **surveillance forms** that can be used for recording individual visits (adapted form in Appendix 1) or to tally the number of visits at each clinic per 24-hours (Appendix 2) if documentation systems are not already in place. This recording should be done both for overall visits and, if available, visits for more specific reasons, particularly respiratory and cardiovascular causes. Depending on the extent of damage from a volcanic incident, existing surveillance systems may not be able to capture information right away, so paper-based surveillance forms may be needed in the meantime.

Although information from temporary clinics would help capture any adverse health problems associated with the eruption, the inclusion of these results may inflate the number of cases, since they would represent an additional opportunity to record cases compared to any infrastructure recording information before the eruption. Regardless, these data should be incorporated in the analysis, but the interpretation of the results should reflect this potential bias.

6. Mortality

It is worth noting that there are two different underlying causes of mortality associated with volcanic eruptions. First, deaths may occur as a direct consequence of the eruption itself, e.g., from lahars or pyroclastic flows. These deaths would be classified as an external cause of mortality and should be coded by 'X35' using ICD-10 to denote a 'victim of volcanic eruption'. The investigation of any such deaths could help refine preparedness measures to avoid future casualties in an eruption; however, the direct deaths would be excluded from the basic epidemiological study to assess impact of inhalation of volcanic emissions, rather than from direct physical harm.

[7] CDC; 2018

Second, there may be some increase in respiratory or cardiovascular mortality caused by the inhalation of volcanic emissions, which could only be detected through a comparison of mortality counts in a given area prior to and after the eruption. Recommended analysis methods of the collected data are discussed below.

7. Analysis

Tracking the data during the 'eruption period' will provide an estimate of the incident cases during that period, some of which (but not all) may be due to exposure to volcanic emissions. To estimate the disease associated with **short-term eruptions**, weekly visit counts during and shortly following the event should be compared to the weekly average during the same time over the previous three years. For **longer-term eruptions** (e.g., >1 month), weekly average visits in each month during the eruption should be compared to the same month during the preceding three years; this method would take into account any changes in visits due to seasonality. However, a caveat with this approach is that there may be population shifts over time if volcanic eruptions persist. Further, the population exiting may not be representative of the overall population, so results must be interpreted accordingly.

For both the short- and longer-term scenarios, **(1) the overall average weekly visit counts[8] and (2) the proportion[9] of overall visits**, for instance the proportion of respiratory compared to overall visits, should be compared during the pre- and post-eruption time-periods. As an option to produce a more robust analysis, this same analysis could be completed in an area *unaffected* by volcanic emissions. If no difference in counts is detected in the unexposed area, but an increase in visits occurs in the exposed area, this type of 'difference-in-differences'[10] approach would more strongly suggest that any observed increase was due to the eruption. An option for longer-term eruptions is to compare visits during higher and lower exposure weeks if there is variation in the emission intensity during the overall eruption period. One caveat of the 'difference-in-differences' approach, however, is to the need to ensure that control areas have not been affected by the eruption. For example, clean-up workers may come in from surrounding areas and, if adversely affected by ash exposure, might use health services in their home areas. Therefore, it would be important to be aware of any inward migration of workers, and from where, to ensure control data are unaffected by the eruption.

Simple, and free, online software is available[11] to calculate these differences. More intricate analyses are possible; for example, time-series regression models have been used to examine fluctuations in hospital rates[12].

This same analysis can be done to examine overall (as well as respiratory or cardiovascular) mortality levels before and following the eruption.

8. Interpretation

The results of this basic study will not necessarily prove a causal link[13] between observed health effects and exposure to volcanic emissions, but they will identify health needs and provide evidence for deployment of further resources. Caution needs to be taken when interpreting the results. Where no evidence of increased healthcare visits is found, this could indicate that there were few or no health

[8] Longo et al., 2010
[9] Lombardo et al., 2013
[10] Benmarhnia et al., 2016
[11] For example, see https://www.medcalc.org/calc/comparison_of_proportions.php
[12] Gordian et al., 1996; Naumova et al., 2007; Carlsen et al.,2015
[13] Establishing a causal link typically requires a number of studies and considerations. A good discussion of this topic is presented in Bradford Hill's seminal paper: '*The environment and disease; association or causation?*'.

effects from the eruption, but could also reflect that affected persons chose not to seek medical treatment, or chose to leave the affected area, or couldn’t reach a health facility.

By contrast, an observed increase in hospital visits may not be due to the volcanic emissions, but could be due to e.g., closure of local general practice (GP) offices, thus directing additional people to hospitals and other healthcare facilities, or encouragement from local authorities for residents to attend hospital if concerned about their health. In the event of any public health emergency, separating the ’worried well’ individual from those with genuine symptoms or conditions may be challenging. Nevertheless, any excess visits can assist with deciding where to focus resources and where additional research efforts are needed to investigate potential health impacts in more detail and over longer timescales, as described in the companion IVHHN protocol for a cross-sectional study.

Study findings and interpretations should be made available to the public, for transparency and clear communication, and also to the wider research community, who may benefit from the research methods and results.

9. Protocol

The figure below presents a step-by-step protocol for the basic epidemiological study, which should be used with reference to the information in sections 1-8, above.

1. **Size and Location of Study**
   - Identify the size and location of the study area, i.e., places subject to ash deposition.

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2. **Exposure Assessment**
   - Assign area-level exposures using ambient concentrations of ash ($PM_{10 \text{ or } 2.5}$) or gases (SO_2) or, if not possible, qualitative assessment (e.g., high/medium/low or yes/no).
   - Determine areas or towns exposed and not exposed.
   - Track the duration of exposure based on volcanic emissions and clean-up activities.

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3. **Health Outcome**
   - Identify all healthcare facilities receiving patients from exposed areas.
   - For each week of the exposure period, collate number of and reasons for visits.

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4. **Demographic and other information**
   - Collect demographic information with health outcome data, e.g., age.

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5. **Data collection**
   - Combine data from facilities and calculate the counts and proportion of respiratory and cardiovascular visits in exposed areas separately for pre- and post-eruption periods. If possible, separate visits by gender and age group.

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6. **Mortality**
   - For the same period, obtain mortality counts for each of the exposed areas.

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7. **Analysis & Interpretation**
   - Compare counts and proportional visits in week(s) during/following event with pre-eruption levels. If there are multiple exposure groups, compare each to the pre-eruption reference group.
   - Determine if there has been a statistical increase in visits or deaths and interpret carefully. Use positive results to justify deployment of resources and more in-depth investigations.

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Appendix 1 CDC Natural Disaster Morbidity Surveillance Individual Form

Adapted from:
https://www.cdc.gov/disasters/surveillance/pdf/NaturalDisasterMorbiditySurveillanceIndividualForm.pdf

Part I: VISIT INFORMATION	Name of Facility	City	State / Province	Date of Visit	Time of Visit
				/ /	AM / PM

Part II: PATIENT INFORMATION	Unique Identifier/Medical Record Number	Age ☐ <1yrs	Gender	Pregnant	If yes, due date
		yrs	☐ Male ☐ Female	☐ Yes ☐ No/NA	/ /

Race/Ethnicity ☐ White ☐ Black ☐ Hispanic or Latino ☐ Asian ☐ Other

Did reason for visit occur as a result of work (paid or volunteer) involving disaster response or rebuilding efforts? ☐ Yes ☐ No/NA

If Yes, occupation/response role

Activity at time of injury/illness

Part III: REASON FOR VISIT (Please check all categories related to patient's current reason for seeking care)

ACUTE ILLNESS/SYMPTOMS

☐ Conjunctivitis/eye irritation

☐ Dehydration

☐ Dermatologic/skin, *specify:*
- ☐ Rash
- ☐ Infection
- ☐ Infestation (e.g., lice, scabies)

☐ Fever (≥100°F or 37.8°C)

☐ Gastrointestinal, *specify:*
- ☐ Diarrhea
  - ☐ Bloody
  - ☐ Watery
- ☐ Nausea or vomiting

☐ Neurological (e.g., altered mental status, confused/disoriented, syncope)

☐ Respiratory, *specify:*
- ☐ Congestion, runny nose, sinusitis
- ☐ Cough, *specify:*
  - ☐ Dry
  - ☐ Productive
  - ☐ With blood
- ☐ Pneumonia, suspected
- ☐ Shortness of breath/difficulty breathing
- ☐ Wheezing in chest

☐ Sore throat

EXACERBATION OF CHRONIC DISEASE

☐ Cardiovascular, *specify*:
- ☐ Hypertension
- ☐ Congestive heart failure

☐ Respiratory, *specify:*
- ☐ Asthma
- ☐ Chronic Obstructive Pulmonary Disease

MENTAL HEALTH

☐ Agitated behavior (i.e. violent behavior/threatening violence)

☐ Anxiety or stress

☐ Depressed mood

OTHER NOTES

Part IV: DISPOSITION

☐ Discharge to self-care

☐ Refer to other care (e.g., clinic or physician)

☐ Admit/refer to hospital

☐ Left before being seen

☐ Deceased

Appendix 2. CDC Natural Disaster Aggregate Morbidity Report Form

Available from:
https://www.cdc.gov/disasters/surveillance/doc/NaturalDisasterMorbiditySurveillanceTallySheet.doc

Part I. General Information

1. Disaster Name: ______________________________
2. Reporting Start Date: ___/___/___ Time: _____
3. Reporting End Date: ___/___/___ Time: _____
4. City: _____________________________ State _____
5. Shelter Name: ______________________________

Part II. Number of Client-Related Interactions

Tally (卌 卌 卌)	Total (#)
7. **Total Client-related Contacts (includes CMIST):**	
7b. **Total of Health-related Client Visits:** **(fill part III)**	

Part III. Demographics (for Health-related Visits Only)

		Tally (卌 卌 卌)	Total (#)
Gender	Male		
	Female		
Age	≤ 2		
	3 to 18		
	19 to 64		
	≥ 65		

Functional/Access Needs: mark each individual need based on C-MIST model per 24 hours

	Tally (卌 卌 卌)	Total (#)
Communication		
Maintenance of Health		
Independence		
Safety and Security		
Transportation		

Part IV. Reason for Visit: for each client visit, tick ALL reason(s) for visits.

	Tally (卌 卌 卌)	Total (#)
Injury		
Bite (includes *ALL* bites)		
Burn (thermal or chemical)		
Cut/laceration/puncture		
Foreign body (e.g., splinter)		
Fall/slip/trip		
Hit by or against object		
Use of machinery/tools/equip.		
Assault		
Carbon Monoxide (CO) exposure		
Poisoning, non-CO		
Other injury		
Illness/Symptoms		
Fever (>100.4°F or 38°C)		
Conjunctivitis/eye irritation		
Dehydration		
Heat stress/heat exhaustion		
Hypothermia/cold-environment		
Oral health		
Pain: chest, angina, cardiac arrest		
Pain: muscle or joint pain		
Pain: head, ears, eyes, nose, throat		
Pain: other, not specified above		
Gastrointestinal (GI): diarrhea		
GI: nausea/vomiting		
GI: other (constipation, GERD)		
Genitourinary (GU)		
Skin (includes *ALL* skin conditions)		
Allergic reaction		
Respiratory (include *ALL* resp.)		
Influenza-like-illness (ILI)		
Neurological, new onset		
Other illness/symptoms		

	Tally (卌 卌 卌)	Total (#)
Behavioral/Mental Health		
Agitated/disruptive/psychotic		
Anxiety/stress/depressed mood		
Suicidal/homicidal thoughts		
Substance addiction/withdrawal		
Other mental health		
Exacerbation of Chronic Illness		
Asthma		
Obstructive pulmonary disease		
Cardiovascular (HTN, CHF, CHD)		
Chronic muscle or joint pain		
Diabetes		
Neurological (seizure, stroke, dementia)		
Previous mental health diagnosis		
Other chronic illness		
Health Care Maintenance		
Blood pressure check		
Blood sugar check		
Pregnancy/post-partum care		
Dressing change/wound care		
Immunization/vaccination		
Medical refill (please mark one tick for *each* med refill)		
Other health maintenance		

Part V. Disposition	Tally (卌 卌 卌)	Total (#)
Provided Red Cross care		
Referred to...		
Hospital		
Physician/dentist/clinic		
Pharmacist		
Other (e.g., DMH)		
Refused Red Cross care		

***Complete one form per service location per 24 hours. Submit by 4pm local time.**

Print name: _________________________ Contact information: ____________________________