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## Use of respiratory protection in Yogyakarta during the 2014 eruption of Kelud, Indonesia: Community and agency perspectives

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## ABSTRACT

The 2014 explosive eruption of Kelud volcano, Indonesia ejected fine-grained volcanic ash in a plume which travelled westwards across the island of Java. In Yogyakarta, without warning, up to 5 cm of ash was deposited within a few hours. This paper investigates the community and organizational response to the respiratory hazard of the ashfall, in the city of Yogyakarta.

In any location where ashfall is a rare event, people located away from the primary volcanic hazards will be concerned about whether volcanic ash in their environment is dangerous to inhale, and how they should protect themselves. The World Health Organization primarily recommends that people stay indoors, or use light-weight face masks if outdoors. In the first study of its kind, we undertook a rapid questionnaire survey (with 125 respondents) on the use of community respiratory protection when ash is in the air. We documented the types of masks people wore, where they had got the mask from, why people wore masks, who advised them to wear a mask, and whether people thought their respiratory protection was effective.

We also conducted informal interviews with a range of emergency management and health agencies, NGOs and a children's charity, to understand how those involved in mask procurement and distribution responded to the crisis, and to determine their understanding of the effectiveness of the masks that they provide.

The study showed that a wide range of respiratory protection is used by those who choose to protect themselves, from cloth through to highly-efficient face masks, but with most people wearing surgical masks. Masks are widely available, from street stalls and shops, but are also distributed by government agencies, NGOs and employers. The organizations interviewed mainly distribute surgical masks to the public. Most people wore masks through their own initiative because they understood that there could be a health hazard, although some people wear them anyway when riding scooters (to protect from inhaling vehicle exhaust and street dust). Around 40% of the respondents thought that their existing protection was not sufficiently effective and around 30% of the respondents took measures to try to improve the effectiveness of their chosen protection method (e.g., wearing two types concurrently).

This pilot paves the way for the Health Interventions in Volcanic Eruptions (HIVE) project which aims to provide an evidence base on effective respiratory protection for community use when ash is airborne, so that health agencies and other suppliers can provide reliable protection for the general population. The HIVE project will experimentally test the effectiveness of the range of types of respiratory protection identified in this study, as well as understanding the behaviours and environmental and cultural issues which affect whether people will wear masks when ash is in the air.

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## 1. Introduction

Kelud volcano, Java, Indonesia erupted on 13 February 2014, at 22:50 local time, sending fine-grained volcanic ash westwards, across the island of Java (Fig. 1). In the major metropolitan area of Yogyakarta,

which is around 260 km from Kelud volcano, the deposited ash was up to 5 cm deep and came without warning, overnight, whilst many of the ~4 million inhabitants were asleep. The ash stayed in the environment for several days before being removed by rainfall and through community and governmental clean-up initiatives.

The people of the Special Region of Yogyakarta endured the 2010 'Centennial' eruption of Merapi volcano (which is just 30 km north of Yogyakarta), during which time substantial ash fell on the communities,

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Fig. 1. Map showing the island of Java and direction of ashfall, from Mt. Kelud, towards Yogyakarta.

although it was rapidly washed away by monsoon rains (Damby et al., 2013). On that occasion, PMI Yogyakarta (local branch of the Indonesian Red Cross Society) distributed around 1 million basic face masks (Fig. 2). Since then, there has been little to no ashfall from Merapi volcano, so the sudden deposition of several centimetres of ash from Kelud was surprising and the effects on Yogyakarta – of an eruption of a distant volcano – had not been anticipated.

For those communities removed from the extreme dangers associated with proximity to volcanoes, but who experience ashfall, the primary concern is usually whether the air, which is contaminated with particles, is safe to breathe. The anxiety caused by ashfall is widespread across the demographics of a community and is not limited to those with existing respiratory diseases or other susceptible people (e.g., older people), especially because the ash is readily noticeable in the mouth and nose, through taste and texture (Baxter, 1986; Shore et al., 1986). Concern is probably also enhanced by news media communications which often focus on anecdotal reports of respiratory problems. Whilst the chronic health effects of inhaling volcanic ash are still uncertain, there is evidence for acute ash exposures exacerbating existing respiratory diseases such as asthma and bronchitis (Baxter et al., 1983; Horwell and Baxter, 2006).



Fig. 2. Basic face mask provided by the Indonesian Red Cross Society (PMI Yogyakarta) to the citizens of Yogyakarta during the Merapi and Kelud eruptions.

When ash falls, communities require rapid, accurate information on likely respiratory impacts from trusted sources, such as governmental agencies (e.g., civil defence/emergency management or health) but this is always hampered by the lack of immediate scientific information on the likely hazard of the ash. Every volcanic explosion is different, in terms of the health-pertinent characteristics of the ash generated (even from the same volcano and within the same eruption sequence). Whilst the International Volcanic Health Hazard Network (IVHHN, [www.ivhnn.org](http://www.ivhnn.org)) has developed protocols for the rapid characterisation of ash for health hazard assessment (Damby et al., 2013; Horwell et al., 2013; Le Blond et al., 2010), the reality is that this detail cannot usually be provided whilst ash is still falling. Given that such analyses will only provide an indication of the *potential* respiratory hazard, and epidemiological/clinical studies can take months to years, the World Health Organization/Pan American Health Organization take a precautionary approach and have developed generic advice for use, globally, by health/disaster management agencies and NGOs on community protection when ash is in the air. They recommend staying indoors, but if one must be outside, using a 'simple' mask, handkerchief or cloth (Pan American Health Organization, [http://www.paho.org/disasters/index.php?option=com\\_content&view=article&id=704:volcanic-eruptions&Itemid=800&lang=en](http://www.paho.org/disasters/index.php?option=com_content&view=article&id=704:volcanic-eruptions&Itemid=800&lang=en); World Health Organization, <http://www.who.int/hac/techguidance/ems/volcanos/en/>). There is uncertainty about whether this is the best advice, given that, around the world, the ability of houses to block ingress of ash particles varies considerably, and it is not clear what people should do who cannot remain indoors, e.g., outdoor workers, street children, or when an eruption is prolonged.

There is currently no specific evidence base on which to make informed decisions on effective respiratory protection (RP) for the general population exposed to volcanic ash (as opposed to industrial and healthcare settings where certain types of respiratory protection have been proven to be effective and their use is mandated and enforceable by regulators in advanced economies (e.g., Health and Safety Executive, 2013)). A handful of studies have considered the effectiveness of respiratory protection for general public use (i.e. not related to volcanic eruptions), and have tested the filtration performance of common masks or fabric materials against ultra-fine particles (sub-1  $\mu\text{m}$ ; equivalent to some influenza pathogens, which are much smaller than most ash particles) or fine-grained particles (1.0–2.5  $\mu\text{m}$ ; which simulate larger pathogenic particles such as viruses, urban pollutants, allergens and construction dust). Rengasamy et al. (2004) tested the filtration efficiency, against NaCl aerosol (0.02–1.0  $\mu\text{m}$ ), of five fabrics which people might commonly use to protect themselves from inhaling

viruses, when certified types of respiratory protection are unavailable: sweatshirt, T-shirt, towel, scarf and a cloth mask. They found a wide variation in penetration values (40–97% of monodisperse particles passed through the material compared with <5% for an N95 respirator). Bowen (2010) tested the efficiency of a surgical mask, a pre-shaped dust mask ('nuisance dust' mask) and a bandana, with an N95 respirator again used as a positive control, also against a saline aerosol with a median diameter of 1.6  $\mu\text{m}$ . Bowen examined protective efficiency (rather than penetration value) via a different method, and found that the N95 mask was 89% effective compared with 33% for the surgical masks, 11% for the bandana and 6% for the dust mask. Both studies indicate that only marginal protection can be assumed from these materials, especially when poor fit (leaking around the face seal) is considered. Therefore, communities wearing non-certified masks, or cloth, may have a false sense of protection.

Cherrie et al. (1987) investigated the performance of 'nuisance dust' respirators (used in some industrial settings and for DIY) and, finding their fit and effectiveness to be highly variable, mainly as a result of poor design, they designed their own simple 'mask'. It consisted of a handkerchief, folded in four, and held onto the face by part of the leg of a pair of ladies' tights. They measured 'total inward leakage' of test particles and found that the performance was comparable to the better nuisance dust masks measured, showing that a close fit to the face, with flexible material (of adequate filtration capacity), can be more effective than poorly-fitting, inflexible, pre-shaped masks.

In the volcanic setting, we currently have no information on the effectiveness of materials in blocking inhalation of ash particles. A first step, though, is to document the types of RP which are currently used, people's perceptions of their effectiveness, and from where/whom they are purchasing/receiving them. In this pilot study, a basic questionnaire survey, for the general public, was designed and implemented over the days following the ashfall on Yogyakarta, in February 2014. The aim was to record the types of RP that people wore, where they had got the RP from, why people wore RP and who advised them to wear it, and whether people thought their RP was effective (and, if not, what they did, if anything, to improve their level of protection). In addition, informal interviews were held, in September 2014, with a number of Yogyakarta agencies and NGOs responsible for health care and emergency management provision during both the Kelud 2014 and Merapi 2010 ashfall events. Some of the information from those interviews is published separately in a GNS (New Zealand geological survey) Science Report (Blake et al., 2015).

The results of this pilot have been used to inform the Health Interventions in Volcanic Eruptions project (HIVE, <http://community.dur.ac.uk/hive.consortium/>) which is now building the required evidence base on effective RP for community exposures to ash.

## 2. Methods

The basic survey was composed of five questions plus a description of the respiratory protection worn by the respondent (if any worn). The questions were:

- Why are you wearing protection?
- Where did you get the protection from?
- Were you advised to wear it and, if so, by whom?
- Did you do anything to better-secure the protection over your nose and mouth?
- Do you think the protection stops you from inhaling the ash?

A single question was asked to those not wearing any respiratory protection:

- Why are you not wearing anything to protect yourself from the ash?

In addition, age, occupation and level of education were recorded (Table 1). The answers were not pre-coded on the questionnaire, to allow detail to be given, but the responses were coded into categories during analysis (see Table 2). Several photographs of each person wearing their RP were also taken (sometimes demonstrating how the respondent applied the mask to their face), plus samples of RP were obtained, where possible.

Ethical approval was given by the Department of Geography, Durham University. All questionnaires were anonymous and no other identifying details were recorded, such as respondents' address. Consent was given verbally.

Questionnaires were administered within Yogyakarta city, primarily around Gadjah Mada University campus and surrounding suburbs, between 16 and 19 February (i.e. 61–127 h after the start of the ashfall). Given the location of where the survey was conducted, the primary employer was Gadjah Mada University and respondents mentioned that the University had advised all employees to wear masks. Subject recruitment was simply by stopping passers-by in the street and asking them to answer questions and have their photograph taken. No formal attempt was made at representative or quota sampling or to sample particular numbers of respondents with or without protection, but an attempt was made to garner opinion from a wide range of ages and occupations/educational attainment (Table 1). For that reason, 116 out of the 125 respondents were wearing RP and this gives little indication of the prevalence of RP use in the population, a point which was not assessed quantitatively in this pilot. Due to the low number of respondents, no statistical analyses have been attempted and the results are largely qualitative.

In addition to the survey, photographs were taken of the environment following the ashfall, starting the morning after the event, on 14 February, and continuing each day up until 19 February. Fig. 3 is a collage of photographs, showing how the ash affected the Yogyakarta environment as time passed. It can be seen that air quality conditions were very poor (in places) through 14–16 February (our first questionnaires were conducted on the 16th) but that rainfall on the 17th substantially improved the airborne particulate pollution. Nevertheless, substantial ash remained on the road for days and was readily re-suspended by vehicle traffic.

A number of governmental agencies and NGOs were interviewed in September 2014, under the auspices of a wider study conducted by the Universities of Canterbury and Massey and GNS Science, New Zealand

**Table 1**  
Demographics of respondents.

Survey facts	
Number of respondents	125
Number wearing masks	116
Number not wearing masks	9
Age range	18–80
Gender	35 female; 90 male
Occupation	Students (35) University staff (15) Shop/stall sellers (15) Shop owners (9) Teachers (4) Labourers (3) Other <sup>a</sup> (35)
Level of education	Senior high school (42) Undergraduate (40) Junior high school (12) Postgraduate (9) Primary school (9) Graduate (8) Other (5)

<sup>a</sup> People with occupations categorised as 'other' worked in a number of roles which could not easily be categorised (or insufficient information was available to categorise the type of work).



**Table 2**

Raw data from questionnaires: number of responses to each question.

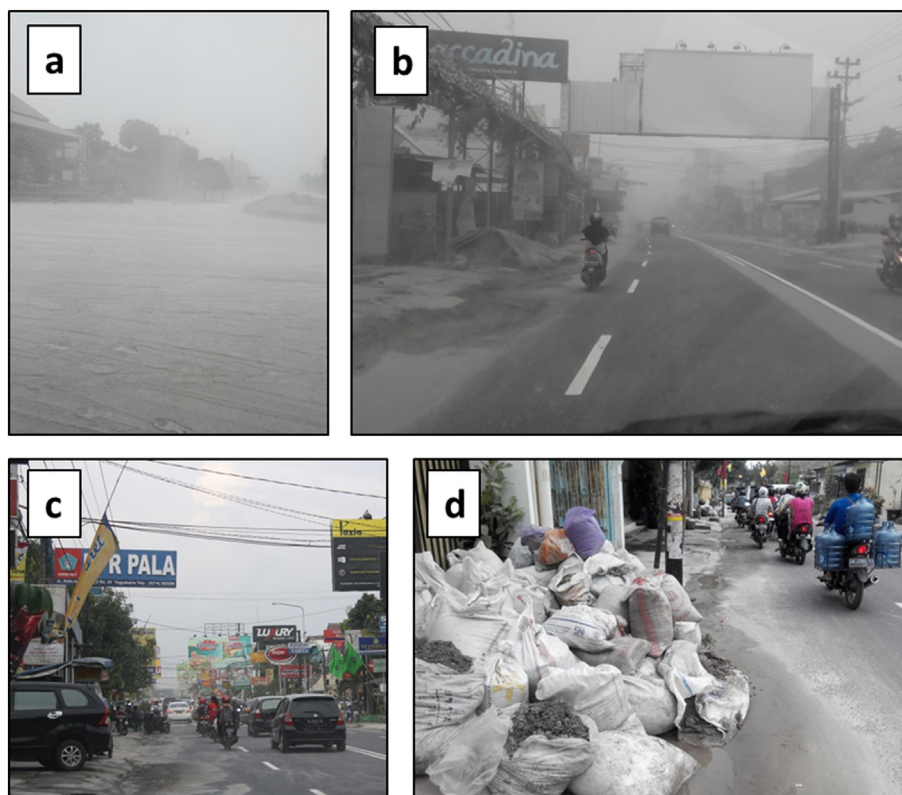
Q1. Why wear RP?	Q2. Where was RP from?		Q3. Were you advised to wear RP? By whom? <sup>a</sup>		Q4. Did you modify the RP?		Q5. Do you think the RP stops you from inhaling ash?		Documented types of RP		
Protect from ash	77	Supermarket/store	47	Self-initiative	99	No	79	Not good enough	24	Surgical	79
Avoid inhalation/stay healthy	28	Employer/University	21	Employer	12	Yes - no info	17	Yes	21	Nothing	9
Pollution from riding moped	6	Street stall	12	Doctor/Health officer/Pharmacy staff	3	Surgical mask and handkerchief/cloth	11	Quite protective	19	Fashion mask	9
Ash is dangerous	4	NGO distribution (Red Cross)	12	Head of neighbourhood	3	Surgical mask and bike helmet	4	Good enough	13	Handkerchief (slayer)	9
Q6. Why not wear RP? <sup>a</sup>		Friend	8	Internet	2	Double surgical mask	2	Effective	13	Scooter mask	5
Not much ash today	3	Market	6	Television	2	Wetted handkerchief	1	Very protective	8	Pashmina textile	3
Not comfortable wearing it	2	Other (had it already/found it)	3	Told by other people	2	Riding mask and handkerchief	1	Assume so	3	Veil	2
Don't have a mask	1	Neighbourhood leader	2	Wears anyway for medical/motorbike	2	Mask and hard cup	1	Not bad	1	High efficiency	2
Not disturbed by the ash	2	School	2	Parent	2					Elastic textile for mountaineering	1
I am mostly indoors	2	Hospital staff	1	Seen other people wearing them	1					Clothing	1
Don't want it to get wet	1										
Only used for outdoor activity	1										
Used to dust and smoke	1										

<sup>a</sup> Respondents could give more than one answer to this question.

(and under their ethical review procedures) (Blake et al., 2015). Permission to conduct the interviews was given by Muhamed Hendrasto, the Director of CVGHM (Center of Volcanology and Geological Hazard Mitigation, Yogyakarta) at the time of the surveys. Interviews were organised by the authors and Dr. Graham Leonard of GNS

Science and were with the following organizations, which we have anonymized:

- Organization 1 – University-run disaster management agency, Yogyakarta.



**Fig. 3.** Collage of photographs showing changing environmental conditions in Yogyakarta following the ashfall on the night of 13 February. a) 14 February; b) 16 February; c) 17 February (after rainfall); 18 February, showing sacks full of ash.

- Organization 2 – Charity looking after street children in Yogyakarta.
- Organization 3 – Governmental disaster management agency, Yogyakarta.
- Organization 4 – Health agency, Yogyakarta.
- Organization 5 – Public health NGO, Yogyakarta.

The interviews were conducted in Indonesian and English with simultaneous translation and were recorded with permission from the agencies. The recordings were then transcribed by the lead author and the salient points noted, without direct quotes being used. The interview findings are incorporated into the Discussion section.

### 3. Results of questionnaire survey

The results of the survey are given in Table 2.

#### 3.1. Types of RP worn by respondents

A wide range of RP types were worn in Yogyakarta. These can be divided into the following categories (Fig. 4) and are shown in photographs in Figs. 5 and 6:

- Disposable surgical masks: 65% of respondents were wearing surgical masks of the type easily procured from pharmacies and shops. People appeared to be wearing them specifically to protect themselves from the ash (as opposed to other cultures, such as in Japan, where people wear them in non-eruptive conditions to prevent spread of communicable respiratory viruses, as well as for other cultural reasons), although this needs further clarification. Surgical masks are designed to act as a barrier, minimising direct transmission of airborne infectious agents from healthcare professionals to patients (Lipp, 2003). Globally, disposable surgical masks are readily available and are also used to protect wearers from inhaling other people's airborne body fluids although they are not intended for this purpose. They are usually constructed of three layers with both outer layers being made of non-woven fabric and an internal layer being formed from a melt-blown material (often polypropylene) which acts as the filter (Chellamani et al., 2013). Different protective efficiencies of surgical mask are available, which vary in the pore diameter of the filtering material as well as the number of layers of material.
- Cloth (16%): These ranged from T-shirts/tops pulled up over the mouth and/or nose, pashmina scarves or veils worn by women,

and handkerchiefs/bandanas (locally known as 'slayer') or 'mountaineering snoods'/balaclavas and are bought from shops or roadside stalls.

- Scooter masks (7%): In Yogyakarta, many people (both men and women) travel by motorized scooter and wear RP to protect themselves from breathing in vehicle exhaust and road dust. The scooter masks (Fig. 5d) are rigid and substantial, having outer, elasticated woven material as covering layers (although the front layer has patterns stamped through it, penetrating through the layer) and an inner foam layer. They are easily available from roadside stalls (Fig. 7). Some people were wearing the scooter masks because they were on a scooter, and other people specifically to protect themselves from the ash.
- Fashion masks (7%): Again, to protect themselves from vehicle exhaust and road dust, many scooter users normally would wear 'fashion' masks which are made of soft, padded material (foam interior) and often have cartoon characters on the front, sometimes with furry or fleece material for the outer, front layer. Fashion masks are easily available from roadside stalls and were also being worn to protect from the ash (Fig. 5).
- High-efficiency mask (<2%): Two people wore non-disposable rubber masks with external filters which were bought from hardware stores. Nobody was observed wearing high-efficiency, disposable N95-style masks (which have been previously distributed in other volcanic eruptions, for example in Iceland and Alaska).

#### 3.2. Why wear RP?

Ninety-five percent of the respondents who were wearing masks said they were doing so to protect themselves from the ash, with some people specifically saying that they were doing so because the ash was dangerous or to stay healthy. The other 5% of the respondents were primarily wearing a mask to prevent inhalation of vehicle exhaust and road dust whilst on scooters.

#### 3.3. Where was the RP from?

Those wearing masks had procured (or were given) their masks from a wide range of locations (Fig. 8) but mainly (41%) from the super-market or a variety of different stores (e.g., pharmacies, hardware stores, scooter accessory stores or convenience stores). Some of the respondents (18%) had received masks from their employers (almost exclusively surgical masks), particularly those at the University. On this occasion, 15% of people had purchased their masks on street stalls or local markets and these were usually 'fashion' masks, bandanas/slayers and scooter masks. Eleven percent of respondents were given their masks by PMI Yogyakarta (local office of the Indonesian Red Cross Society); in this study, these were all disposable surgical masks rather than the basic mask shown in Fig. 1, which was apparently also distributed during the Kelud ashfall (PMI Yogyakarta, personal communication). Few people were given their masks by doctors/hospitals or community leaders.

#### 3.4. Who advised you to wear RP?

The vast majority of respondents wore masks on their own initiative (77%) and these tended to be the respondents who had purchased a mask from a shop/stall. Some respondents cited the experience of the 2010 Merapi eruption, which prepared them for how to behave in the Kelud ashfall. Nine percent of people were advised to wear a mask by their employer. It is not clear why this number is lower than the percentage who received a mask from their employer – 18%, see Section 3.3. It may be that people were simply handed masks by volunteers, for example, at the University, and did not specifically receive

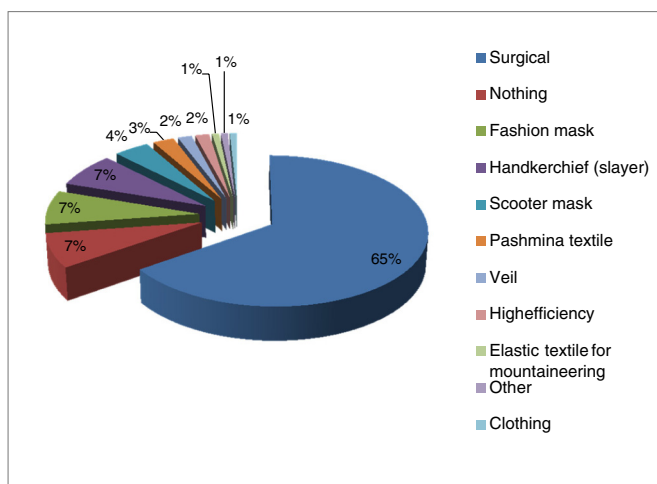
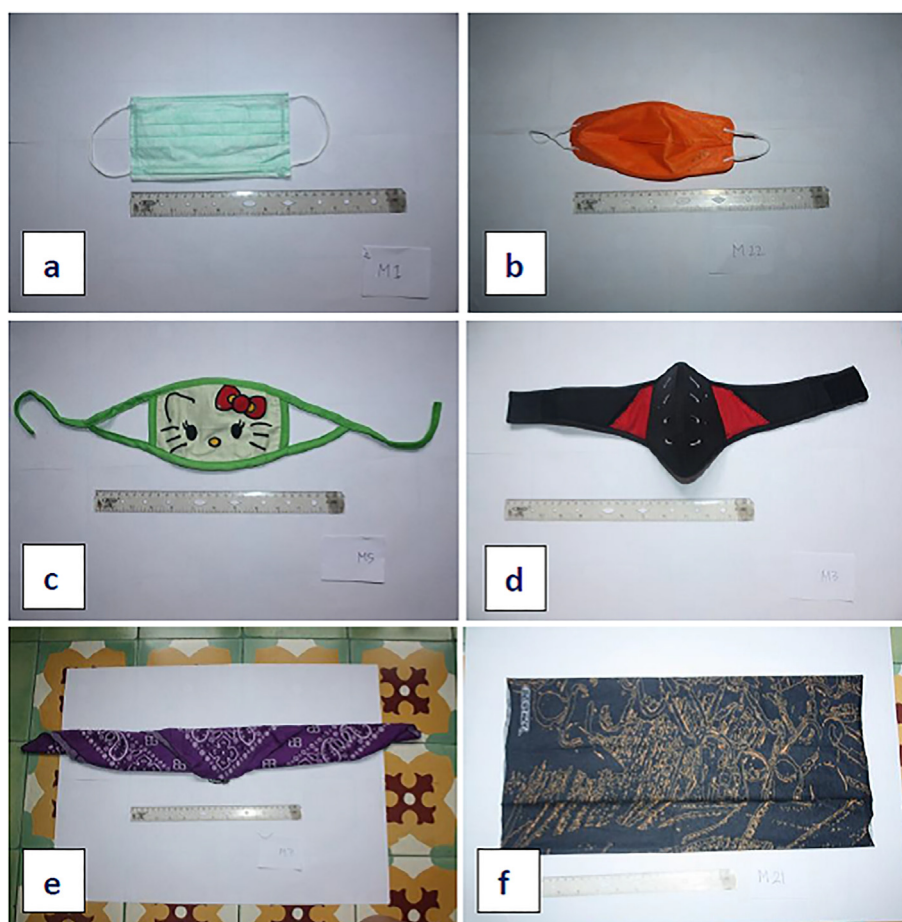


Fig. 4. Pie chart showing the range of RP worn by respondents (data include those not wearing RP too).



**Fig. 5.** Collage of photographs showing some types of RP worn in Yogyakarta. a) surgical mask; b) facemask; c) 'fashion' mask; d) scooter mask; e) bandana (also called slayer); f) mountaineering snood (stretchy fabric).

advice. A range of other advice sources were given, such as medical staff, community leaders, various media (social, internet, television) and word of mouth (parent/friend etc.), totalling 13%. Only 1% of respondents said that they used RP because they had seen others doing so,

but it is impossible to know whether those who seemingly used their own initiative were, in fact, influenced by others around them. None of the respondents said that an NGO or government agency advised them to wear a mask, despite distribution of RP from these sources



**Fig. 6.** Photographs of people wearing respiratory protection in Yogyakarta. From top left, clockwise: surgical mask; facemask; scooter mask; 'fashion' mask; veil; high-efficiency non-disposable mask; mountaineering 'snood'; bandana/slayer.





Fig. 7. Photograph of a street stall selling 'fashion' masks and scooter masks.

being so prevalent (and ongoing active education campaigns, see Discussion, below).

### 3.5. Did you modify your RP to increase protection?

Whilst most respondents (65%) did not modify their protection, a number (32%) said that they did (although they were not necessarily demonstrating this at the time of the survey). 15% (of the total respondents) did not give any further information but 17% of respondents felt the need to modify their surgical masks, in several ways (Fig. 9): some people wore a handkerchief, or other cloth, in addition to the mask; a few people wore a motorcycle helmet (which has a barrier across the mouth) on top of a surgical mask, or a scooter helmet with a strap which then held a bandana/slayer in place; a few people wore two surgical masks at the same time or a surgical mask and another type of mask. People also reported wearing the fashion masks with additional handkerchief, or wetting handkerchiefs to improve the filtering capacity of the material. Those that did alter their RP also mostly responded that they thought the protection of a single mask, alone (usually a surgical one), was not effective.

### 3.6. Is your RP effective?

An issue arose with not having pre-coded the potential questionnaire answers for this question in that people gave a wide range of responses, which were not easily coded during analysis. Almost a quarter of the respondents (23%) were clear that they thought their existing RP choice was not effective. The remaining responses can be categorised as follows: Not bad (1%); quite protective (19%); yes/effective/good enough/assume so/very protective (57%). Although many people seem to be satisfied that the protection offered by their RP is effective, 42% can be said to believe that their chosen RP does not give total protection. Such replies require future investigation, particularly to find out why they wear RP nonetheless.

### 3.7. Why are you not wearing any RP?

We could not assess the percentage of people in the whole community wearing RP but, from our observations, a large proportion of the public were wearing RP during the survey period. Amongst our respondents, the

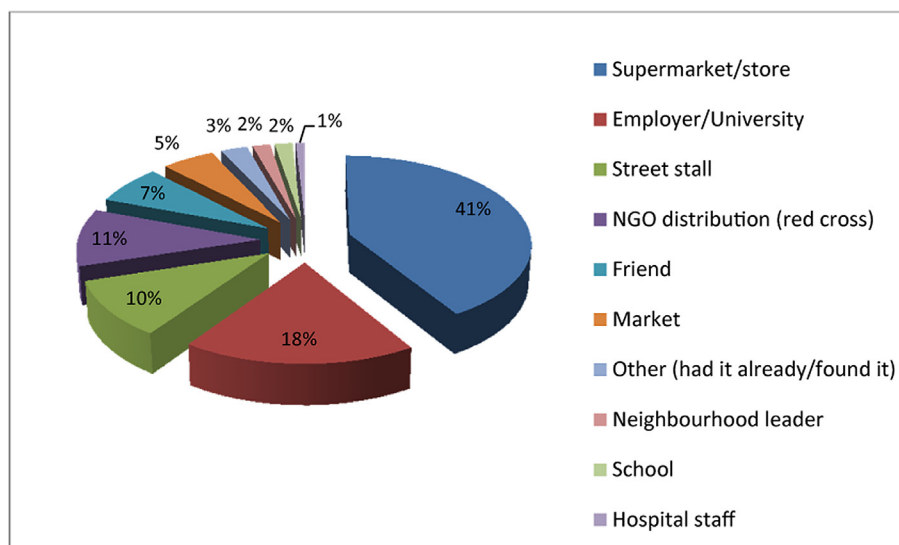


Fig. 8. Pie chart showing the retailer where masks were procured from or person/organization donating the masks.



**Fig. 9.** Photographs of people attempting to improve their respiratory protection. From left: slayer/handkerchief worn with scooter helmet holding it against chin; surgical mask worn with scooter mask on top; surgical mask worn with veil on top; wetted bandana/slayer.

nine who were not wearing any form of RP when questioned gave a variety of reasons for not doing so. The most popular answer was that there was not as much ash, at the time of the interview, as there had been previously (as it had rained). Two people simply did not find RP to be comfortable; two people said they spent most of their time indoors; two people said they were not disturbed by the ash, which was also supported by another person who said they were used to breathing dust and smoke and stayed healthy despite this. Only one person said they did not have a mask and another said they only used it for particular outdoor activities. Finally, one person, who was cleaning ash from the street with a water spray, said that he did not want his mask to get wet.

#### 4. Discussion

The aim of this urgent, responsive pilot survey was to document, for the first time, the types of respiratory protection used by the general population (in a specific area) when volcanic ash is in the environment. Whilst the questionnaire was very rapidly designed and implemented, and with such a small cohort that it cannot represent the Yogyakarta population as a whole (~4 million people in the metropolitan area), together with the agency interviews (the details of which are incorporated into the Discussion, below) the findings of this study give a first account which has proved invaluable for the design of a much larger study in the area. The Health Interventions in Volcanic Eruptions (HIVE, <http://community.dur.ac.uk/hive.consortium/>) project includes a questionnaire being answered by 600 respondents in Yogyakarta Municipality and Sleman District, including a further 200 questionnaires on children's protection, based on Protection Motivation Theory (Rogers, 1983), to understand the factors which influence whether people will wear RP or not.

##### 4.1. Types of RP used and their procurement and distribution

The survey demonstrated the wide range of RP used, from various types of cloth through to high-efficiency masks, when ash is airborne in Yogyakarta. The cloth used reflects, to some extent, the culture and environment, with veils being worn by Muslim women, and the general community already trying to protect themselves from severe air pollution caused mainly by vehicle traffic. Many people wore the 'fashion' masks or scooter masks, available for purchase on street stalls, to protect themselves from inhaling vehicle exhaust, dust and ash. These masks are specifically sold to prevent inhalation of fine particles and gases but it is clear from the packaging that they have not been through any regulatory testing for their efficiency.

Most people in the survey used surgical masks, which are readily procured or distributed by NGOs, agencies and employers. The agencies and NGOs, including the children's charity that we interviewed, all distributed surgical masks. Organization 2 issued children with surgical masks with fabric tie straps, but did not show them how to tie them to the back of their heads, assuming that they would know, and they also did not check that they were worn properly. They told the children that they should use them "until dirty". They had five boxes of 50 masks and distributed them twice, before stocks got too low (they rely on

sponsors for donations of masks). In Yogyakarta, there is difficulty in officially recognising street children as a vulnerable group because the government is trying to remove them from the streets. Most masks are not designed for children to wear (because they are mostly for industrial/healthcare use), so the fit of masks to children's faces is likely to be poor, especially if they are not shown how to use the mask. Children are usually regarded as a 'sensitive group' in terms of susceptibility to potential disease from particulate exposures (e.g., see the US EPA AirNow website, <https://airnow.gov/index.cfm?action=pubs.aqguidepart>) so urgent assessment is required on how to protect children adequately during eruptions, when conventional masks may not be suitable.

A disaster management agency, Organization 3, had limited stocks of disposable surgical masks for mass distribution at the time of the Kelud eruption, stockpiled for use in outbreaks of influenza pandemics. However, both Organizations 3 and 4 reported that 500,000 surgical masks were distributed in Yogyakarta by Organizations 3, 4, 5 and hospitals during the Kelud ash crisis. Organization 5 obtains surgical masks from their headquarters in Jakarta, who also stockpile masks for outbreaks of infectious disease. During the 2010 Merapi eruption, the 1 million masks distributed by Organization 5 were provided by another regional office, in Singapore. We do not know if all of the surgical masks were from the same manufacturer or were of the same quality and filtration efficiency. It is possible that agencies are unknowingly distributing masks of different quality. This issue becomes a question for further research.

A manager from Organization 5 said that, within Yogyakarta, their masks are distributed in the community to the public by volunteers, but that the public can also voluntarily come to health centres around the city. Organization 3 also provided more sophisticated, high-efficiency masks (e.g., N95 disposable respirators, which seal well around the face – if worn properly – and often have a valve on the front to reduce humidity, hence improving comfort) to their officers and for those involved in search and rescue and clean-up operations (a manager at Organization 5 corroborated that their staff and volunteers were heavily exposed and also wore high-efficiency masks).

A manager at Organization 1 told us that it was harder to get hold of surgical masks outside of the city, where there was less distribution by governmental agencies. This gap has implications for rural areas which require further exploration. However, during the 2010 eruption, there was better preparedness because local people are used to Merapi's 'cycles' (see Surono et al., 2012 for overview), so when its eruption status was increased, agencies at provincial and district level (who usually hold buffer stocks of masks), and local emergency managers, coordinated with people in the villages, asking them what stocks they required and sending masks if necessary (in the trucks also deployed for evacuation). During the Kelud ashfall, available masks were distributed by community teams (including through Organization 1) with help from village chiefs and health workers and anyone else dealing with the logistics of the eruption in the villages.

NGOs also distributed masks, but stocks were insufficient (although there is actually a surgical mask factory in Yogyakarta, according to a manager at Organization 4). Instead, people were advised (by Organization 5 and other organizations) to use cloths/sarongs (which were also





**Fig. 10.** Photographs demonstrating instances where masks were worn poorly, potentially reducing their effectiveness. From top left, clockwise: slayer/handkerchief with no attempt to hold material against chin; facemask seal disrupted by glasses; 'fashion' mask with gaps around upper face; facemask which has not been opened fully; surgical mask not worn over the nose; surgical mask with gaps around the side; fashion mask not worn over the nose.

distributed by Organization 5 when mask stocks were low), but without information on how to wear them. According to managers at Organizations 1 and 3, people were told by Organization 4 that cloth was more effective if made wet but were also advised to stay indoors if possible. However, a manager at Organization 4 told us that wetting cloth was common knowledge and that their official advice was to stay indoors and to wear a surgical mask outside, although they also suggested umbrellas, rain coats and glasses/goggles. Organization 5 also advised people to wet both cloths and masks, but also said that wetted protection would last less long (because it would get more dirty). Only 1% of the survey respondents in Yogyakarta wetted a cloth (and none wetted masks). This raises another issue which will be addressed by the HIVE research as, although widely recommended by NGOs and health agencies, we do not know of any scientific evidence to support the improved effectiveness of materials through wetting.

Few of the respondents had received their RP (or advice to wear RP) from community leaders, although it seems, from the interviews, that this may be more prevalent outside of the city. The HIVE project will attempt to explore the links between community leaders and guidance given on RP, and whether or not they use any evidence-based research to inform their advice.

#### 4.2. Perceptions of mask effectiveness by the public and agencies

During eruptions, disposable surgical mask distribution is the norm around the world (although high-efficiency masks have been distributed in Iceland and Alaska). In Japan, however, the use of RP has not been encouraged at all during the frequent eruptions of Sakurajima volcano. Moreover, there is little, if any, knowledge (from aid agencies or the public) of the actual effectiveness of standard surgical masks and this concern was expressed by Organization 5 during interview, and by the public in the surveys, which showed that a substantial proportion of the respondents were not convinced of the effectiveness of the RP that they were wearing. This highlights the need to conduct and disseminate research that enables people to gain confidence in the information that they receive about the protective capacities of different types of masks. Standard disposable surgical masks have low protective efficiencies against particulate pollution (Langrish et al., 2009), and are un-regulated for dusty industries, yet (as far as we are aware) their use and efficacy are rarely questioned during ambient particulate pollution episodes.

The economic and logistic grounds for distribution of surgical masks are clear in that they are mass manufactured, cheap, lightweight and pack very flat, so they can be easily stockpiled by the million. As discussed, they are stockpiled in any case for medical use (e.g., outbreaks of infection), so are usually available or can be acquired at short notice. The fact that there are no studies showing that such masks are effective at blocking ash particles from entering the respiratory system should be a major cause for concern. The HIVE project will seek to fill this knowledge gap by conducting laboratory experiments on the filtration efficiency (against volcanic ash) of the range of RP documented during this study, as well as human volunteer studies to test the fit of these different forms of RP on a range of facial shapes and types (including adults with small faces – to emulate children – and facial hair).

Agencies/NGOs/employers are in a position of responsibility in relation to public health protection and need to consider the ethics surrounding surgical mask distribution in the absence of being able to make evidence-based decisions (for now). Awareness of lack of knowledge surrounding these issues was apparent in the interviews: a manager at Organization 3 asked us which side of the surgical mask was most effective at blocking particles, and if all surgical masks were made to the same standard, and a manager at Organization 4 told us that they were not sure if surgical masks were effective. A manager at Organization 5 told us that many types of surgical mask were used and there was no standard that was adhered to. Despite this, the agencies, such as Organization 5, promote surgical mask use. A manager at Organization 4 reported to us that public advice on mask wearing is disseminated as soon as there is ashfall. Messages are sent by the provincial Department of Health, then distributed by the Governor of Yogyakarta, who takes overall command of provincial agencies during a crisis, then through official media (e.g., radio, television). Organization 5 promotes mask use through youth volunteers raising awareness in schools, actively encouraging students to wear surgical masks. A manager at Organization 3 also said that they believe that surgical facemasks are cost effective, and popular, indicating that other priorities may influence their decision-making besides the actual effectiveness of the masks.

#### 4.3. Mask fit and adaption

Whilst the particle filtration efficiency of masks (and other forms of RP) is critical in their efficacy, the fit of the RP on the face is also

crucial, as even the most efficient materials will be severely compromised if the masks let air (and particles) in around the sides. It was noticeable, from the photographs taken during the survey (Fig. 10), that masks were often very-poorly fitted, with large gaps visible around the nose and side of the mask, in particular, or were sometimes worn incorrectly, without opening the mask properly or sometimes not covering the nose. Disruption of the mask edges by glasses or facial hair was also common. For home-made interventions, the most common issue observed was cloth (e.g., slyer/bandana) tied around the face but open at the chin, likely rendering it almost entirely ineffective.

It is possible that some people may be completely unaware that particle ingress is likely when there is a poor fit. This false sense of security may encourage people to venture outdoors when ash is in the air, rather than seek shelter indoors, thereby actually increasing their exposure. Such behaviour also indicates the importance of raising awareness of the potential health impact and characteristics of particles, including their size, in volcanic ash, and how its potential impact might vary for different segments of the population.

Some people were aware of the inadequacy of their chosen protection method and had made attempts to improve the level of protection through self-developed interventions (as shown in Fig. 9). Their actions depict people exercising agency, or the capacity to take action to protect themselves, even though its efficacy may be questionable (Dominelli, 2012). This awareness by some people in the community is in stark contrast to others who have poorly-fitting protection and implies different levels of concern, or perhaps knowledge of the hazard, which could relate to education level (most people adapting their protection had at least senior high school education).

## 5. Conclusions

This pilot study was the first to document the respiratory protection used by the public following a volcanic eruption. The Yogyakarta public use a wide variety of self-developed and procurable/donated interventions. Whilst people clearly wear the protection out of concern for their respiratory health, many wear their protection poorly, likely allowing particle ingress. Others feel their protection is inadequate and some take measures to improve the protection. The agencies involved in mask distribution all donate surgical masks to the public and some actively encourage their use through educational campaigns. However, there is currently no evidence base to support their effectiveness in blocking volcanic ash particles, creating a situation where those in positions of responsibility for public health protection are potentially generating a false sense of security, as we currently do not know what level of protection these masks afford. This might encourage people to spend time outdoors, thereby potentially increasing their exposure and susceptibility to health problems. The Health Interventions in Volcanic Eruptions (HIVE) project will now consider important ethical questions, such as whether offering some protection is better than using no protection, even if its effectiveness is poor or unknown, as well as quantifying the efficacy of the range of respiratory protection identified in this study.

## Abbreviations

RP	Respiratory protection
HIVE	Health Interventions in Volcanic Eruptions research consortium project ( <a href="http://community.dur.ac.uk/hive.consortium/">http://community.dur.ac.uk/hive.consortium/</a> )

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