Impacts of the 2014 eruption of Kelud volcano, Indonesia, on infrastructure, utilities, agriculture and health


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CONTENTS

ABSTRACT .......................................................................................................................... IX

KEYWORDS ......................................................................................................................... X

ACRONYMS .......................................................................................................................... X

1.0 INTRODUCTION .......................................................................................................... 1
  1.1 NOTES ON THE REPORT ........................................................................................... 4
  1.2 RESEARCH METHODS ............................................................................................... 4

2.0 ERUPTIVE HISTORY AND EMERGENCY MANAGEMENT ...................................... 7
  2.1 HISTORIC Eruptions AND VolcanIC Hazards .......................................................... 7
  2.2 VolcanIC Hazards Management AT Kelux AND IN Indonesia .................................. 9
     2.2.1 Emergency Management ..................................................................................... 9
     2.2.2 Health Management ........................................................................................... 12
     2.2.3 Proximal Community Preparedness ..................................................................... 14
     2.2.4 Warning Communication .................................................................................... 15

3.0 FEBRUARY 2014 ERUPTION OF KeLux VOLCANO ........................................... 16
  3.1 Eruption Chronology ................................................................................................. 16
  3.2 VolcanIC Hazards AND General Impacts ................................................................ 17
     3.2.1 Tephra Dispersion .............................................................................................. 20
     3.2.2 Tephra Accumulation and Characteristics ......................................................... 23
  3.3 WARNING AND RESPONSE - PROXIMAL .............................................................. 25
     3.3.1 Official Warnings ............................................................................................... 25
     3.3.2 Evacuations ......................................................................................................... 28
     3.3.3 Shelter in Place .................................................................................................... 30
     3.3.4 Evacuation Destinations ..................................................................................... 30
     3.3.5 Return .................................................................................................................. 31
     3.3.6 Infrastructural Rehabilitation ............................................................................. 32
     3.3.7 Post-eruption Concerns ....................................................................................... 33
  3.4 WARNING AND RESPONSE - DISTAL .................................................................. 34

4.0 IMPACTS ON HEALTH AND THE HEALTHCARE SYSTEM ................................ 36
  4.1 Public health Impacts ................................................................................................. 36
  4.2 Public health Advice .................................................................................................. 37
     4.2.1 Use of Protective Masks ..................................................................................... 38
  4.3 Air Quality ................................................................................................................ 38
  4.4 Impacts on Healthcare System .................................................................................. 39

5.0 IMPACTS ON INFRASTRUCTURE AND UTILITIES ........................................... 40
  5.1 Summary of impacts .................................................................................................. 40
  5.2 Transport .................................................................................................................. 41
     5.2.1 Aviation ............................................................................................................... 42
     5.2.1.1 Adisucipto International Airport (Al), Yogyakarta ....................................... 44
     5.2.2 Roads .................................................................................................................. 45
     5.2.2.1 Proximal .......................................................................................................... 45
     5.2.2.2 Distal ............................................................................................................... 48
     5.2.2.3 Public bus operations – The Trans Jogja Bus Company ................................... 51
     5.2.3 Rail ........................................................................................................................ 52
     5.2.4 Ports ..................................................................................................................... 53
  5.3 Buildings .................................................................................................................... 54
     5.3.1 Indonesian Building Typology ............................................................................. 54
10.4 IMPACTS ON INFRASTRUCTURE AND UTILITIES .................................................. 101
10.5 IMPACTS ON AGRICULTURE ............................................................................ 101
10.6 MITIGATION MEASURES AND RESILIENCE .................................................. 102
11.0 LESSONS FOR FUTURE ERUPTIONS .............................................................. 103
  11.1 EMERGENCY PLANNING .................................................................................. 103
  11.2 EVACUATION AND RETURN .......................................................................... 103
  11.3 IMPACTS ON TOURISM, PUBLIC HEALTH, INFRASTRUCTURE, UTILITIES AND AGRICULTURE .......................................................... 104
  11.4 CLEAN-UP ....................................................................................................... 104
12.0 ACKNOWLEDGMENTS ....................................................................................... 105
13.0 REFERENCES ..................................................................................................... 106
FIGURES

Figure 1.1 Location of Java, Indonesia with Provinces and Kelud volcano..................................................1

Figure 1.2 The regencies in proximal (blue) and distal (yellow) areas to Kelud where the field visits occurred. Also shown are cities and locations in Central and East Java of significance to the report. ..................................................................................................................2

Figure 1.3 The three regencies (Malang, Kediri and Blitar) surrounding Kelud’s summit and neighbouring regencies. Also shown (in yellow) are the districts on the flanks of Kelud where we conducted field studies, observations and/or interviews...............................................................................................................................3

Figure 1.4 Location of villages (grey areas) surrounding the Kelud summit and the hamlets (orange points) within which were visited. The two dams and Kelud Volcano Observatory (KVO) shown on the map were also visited.................................................................3

Figure 2.1 (a) Volcanological Survey of Indonesia (VSI) scientists measure water levels at a drainage tunnel of Kelud crater lake in 1973. (b) Outlet tunnel of Kelud crater lake drainage system in 1973 (GVP 2014e)..................................................................................................................................................................................................................................................................................8

Figure 2.2 The growing lava dome at Kelud volcano in November 2007. The incandescent blocks extended into the crater lake below (GVP 2014e).............................................................................................................................................................................................................................................................................9

Figure 2.3 Incident command system at national, provincial and regional / city levels in Indonesia (BNPB 2010)..............................................................................................................................................................................................................................................................................11

Figure 2.4 Volcanic hazards map of Kelud volcano, East Java Province, Indonesia. Produced by the Centre of Volcanology and Geological Hazard Mitigation, CVGHM (Mulyana et al. 2004)........................................................................13

Figure 2.5 Bridge being constructed in the Blitar Regency in 2013 to aid future evacuations (BPBD Blitar Regency 2014b). ........................................................................................................................................................................................................................................................................15

Figure 2.6 Examples of kentongan (gongs) which are used as a means of communicating warnings on Kelud. (a) Metal kentongan at Kalikuning Hamlet, Tulakan District (Blitar Regency). (b) Wooden kentongan at Munjang Hamlet, Pandansari Village in Ngantang District (Kediri Regency)..................................................................................................................................................................................................................................................................................................................15

Figure 3.1 Images from the south of Kelud crater area (a) before (23 August 2012), and (b) after (19 May 2014) the 13 February eruption (GoogleEarth 2014). The lava dome was removed by the explosive eruption leaving a ~400 m diameter crater. In the second photo, PDC deposits can be seen, which extend over 2 km from the vent, particularly to the south. Thick tephra deposits are also visible, particularly extending to the north east towards Pandansari Village..........................................................17

Figure 3.2 PDCs destroyed previously forested areas to the south and south west of the vent. .................18

Figure 3.3 Volcanic ballistics with maximum lengths of (a) ~500 mm, and (b) 600 mm, both deposited 2-3 km away from the vent (BPBD Blitar Regency 2014a, KVO 2014). Ballistics of a similar size (up to ~500 mm) were reported up to ~5 km from the vent.................18

Figure 3.4 Tephra deposition. (a) In field at Munjang Hamlet in Pandansari Village, Malang Regency, 5 km northeast of the crater. Maximum clast sizes were ~80 mm in diameter. (b) On the car park at the Kelud Volcano Observatory in Ngancar District, Kediri Regency, 7.5 km west of the crater. Maximum clast sizes were also ~80 mm in diameter..........................................................................................................................................................................................................................................................19

Figure 3.5 Landsliding and gulling of tephra deposits ~2 km from the crater in September 2014, 7 months after the eruption. (a) Looking towards the crater from the nearest accessible point to the west. (b) Shows the unstable tephra deposits on the upper southern flanks of the volcano.................20

Figure 3.6 The eruption plume less than 2 hours after the eruption at 17:28 UTC, 13 February (00:28 WIB, 14 February). From Suomi NPP VIIRS, 375m resolution 11.45μm IR (BOM 2014)............................................................................................................................................................................................................................................................................21

Figure 3.7 MODIS/AQUA image showing height/temperature of the ash cloud and path of the CALIPSO Lidar transect through the cloud, at 18:10 UTC, 13 February 2014 (01:10 WIB, 14 February 2014) (BOM 2014). .............................................................................................................................................................................................................................................................................................................21

Figure 3.8 Tephra Dispersion. (a) HYSPLIT ash dispersion forecast at 23:00 UTC, 13 February (06:00 WIB, 14 February) (BOM 2014). (b) Bilateral distribution of ash fall from the 1919 eruption of Kelud. High altitude westward winds and low altitude eastward winds were responsible for two distinct lobes of thick deposition (Wilcox 1959). Similarities exist with the tephra dispersion and deposition in 2014, although with somewhat different directionality.................................................................22

Figure 3.9 General tephra dispersion and deposition following the February 2014 eruption of Kelud volcano (altitude values extracted from BOM 2014 and VAAC 2014). Note that diagram is not to scale. .................................................................................................................................................................................................................................................................................................................23

Figure 3.10 Kelud-1 and Kelud-2 ash samples..................................................................................................25

Figure 3.11 Seismicity in respect of volcanic alert levels in January and February 2014 (adapted from CVGHM 2014a)........................................................................................................................................................................................................................................................................................................26
Figure 3.13 Meetings held on 03 February 2014 to discuss evacuation plans and funding for different agencies. This was following the raise in alert level to Yellow / 2 on 02 February 2014 (BPBD Blitar Regency 2014b). ..............................................................................................................27
Figure 3.14 Some signs were erected during the alert level Yellow /2 phase to advise people to stay away from the crater area (BPBD Blitar Regency 2014b). This one warns of the danger area beyond. ..................................................................................................................27
Figure 3.15 BPBD Blitar Regency staff meeting to be read the latest guidance regarding evacuations following the rise in alert level to Orange / 3 (BPBD Blitar Regency 2014b) ..................................................................................................................28
Figure 3.16 Equipment, tools and machinery were prepared and tents set up ready for an emergency (BPBD Blitar Regency 2014b). .........................................................................................................................................28
Figure 3.17 BPBD Regency staff providing basic provisions to refugees such as food, drink, clothing and healthcare items (BPBD Blitar Regency 2014b). ..................................................................................................................................28
Figure 3.18 Evacuations in the districts surrounding Kelud during the February 2014 eruption. Blue lines represent likely route directions taken from the known origin and destination points of evacuees. Evacuations in other locations existed but the destinations here were unclear and are therefore not depicted on the map. ..................................................................................31
Figure 3.19 Sites of two military camps. (a) South of Munjang hamlet. The camp was located on the field to the left of the track (the new water tank installed by the military can be seen on the right). (b) Selorejo Village. This camp was sited on the car park adjacent to the warungs. ........................................................................................................................................33
Figure 3.20 Military, police and volunteers working together in Yogyakarta (BPBD DIY 2014b). .................................................................................................................................................35
Figure 3.21 Volunteers line up to eat at an emergency response kitchen in Yogyakarta (BPBD DIY 2014b). .................................................................................................................................................35
Figure 4.1 Surgical masks distributed during the Kelud eruption. (a) Masks distributed by PMI. (b) Mask distributed by BPBDs (BPBD DIY 2014b). .................................................................................................................................38
Figure 4.2 Total suspended airborne particulate levels, Yogyakarta Special Region Province (BPTKL-PPM 2014). .........................................................................................................................39
Figure 5.1 Major transportation routes of Java (Mau Ke Mana 2014) ..............................................................................................................................................41
Figure 5.2 Motorbikes in Java. (a) Motorbike adapted for transporting poultry. (b) Motorbikes and other traffic waiting at a railway crossing in Yogyakarta. .........................................................................42
Figure 5.3 Total airport closure times after the eruption (indicated by coloured portion of circles, with totally coloured circle representing 7 days closure) where known ......................................................................................44
Figure 5.4 Aircraft covered in ash on 14 February 2014 at Adisucipto International Airport, Yogyakarta (ABC News 2014b). .........................................................................................................................................45
Figure 5.5 Road and bridge impacts within ~2 km of the crater (taken 20 September 2014). (a) large ballistic impact crater in asphalt concrete road surface (3.6 m along the longest axis). (b) holes in asphalt concrete and reinforced concrete bridge (now covered in wood) after being penetrated by ballistics. (c) ballistics embedded within bridge surface and damage to edge of bridge. (d) Bridge structure and railing damage. (e) remaining section of the road near the crater, now cleared of ash. .........................................................................................46
Figure 5.6 Kostrad TNI-AD (the Strategic Reserve Command of the Indonesian Army) help vehicles cross the Sambong River at site of old bridge between Munjang Hamlet and Selorejo Dam on Wednesday 19 February 2014 following a lahar (Haryanti 2014a). The bridge at this site had yet to be rebuilt as of 21 September 2014 ........................................................................................................................................47
Figure 5.7 Sambong River crossing near Klangon Hamlet, Pandansari Village. (a) Temporary bamboo bridge over the Sambong River built ~2 weeks after the lahar and improving access for pedestrians and motorbikes to Klangon Hamlet (Adonai 2014). (b) Larger temporary army- bridge built nearly ~6-7 months after the lahar (photo taken on 21 September 2014). A new permanent bridge will be built when funds permit. ...............................................................................................................................................47
Figure 5.8 Road bridge over Konto River between Pare and Kanndangan. (a) Reports suggest that the surface of the lahar came within 0.5 m of the road deck. (b) Some scouring was evident on the up-stream side of the central concrete support pillar, possibly from debris entrained in lahars. ........................................................................................................................................48
Figure 5.9 Cars at Castle Bridge, Yogyakarta covered in plastic protective sheeting (BPBD DIY 2014b). .........................................................................................................................................................49
Figure 5.10 Motorbikes driving through ash in Yogyakarta (Washington Post 2014). Remobilisation of fine ash in the city meant that visual range was only ~3 m at times. ....................................................................................49
Figure 5.11 Traffic lights and solar panels in Yogyakarta. These panels (which are near horizontal in the tropics) were covered in ash resulting in batteries discharging. ........................................................................................................50
Figure 5.12 ‘Sand mine’ truck with wipers lifted from windscreen. This avoids ash collecting above the wiper blades and subsequent abrasion of window glass. ..............................................................................51
Figure 5.13 Trans Jogja bus in the depot at Yogyakarta. Air conditioning unit can be seen mounted on the front section of the roof. ......................................................................................................................51
Figure 5.14  Surabaya to Bandung train passing through ash deposited at Kalimenur, Yogyakarta Special Region Province on 16 February 2014, over two days after the eruption (Habibie 2014). .................................................................53

Figure 5.15  Examples of predominant building typologies in the Kelud proximal area: ..............................54

Figure 5.16  The underside of a timber supported roof: sometimes plastic is placed underneath the tiles to prevent leaks and in this case is badly damaged. Labels refer to the support types referred to in the text. ........................................................................................................... 55

Figure 5.17  (a) Typical timber supports and tiled roof in the Kelud proximal areas. Roof tiles are often are not attached to the underlying supports. Some roofs have a flared (Figure 5.15a) or hipped (5.17b) shape having two or four sides and being steeper pitch near the centre before shallowing out towards the edge of the roof. This supports air ventilation within the home and is typical of the more traditional Javanese home. ........................................................................................................... 55

Figure 5.18  Munjang Hamlet, Pandansari Village in Ngantang District, Malang Regency looking north east towards Lake Selorejo on (a) 18 February 2014 (Karmini 2014), (b) 22 February 2014 (iMKIRAN 2014), and (c) 21 September 2014. Kelud is 7 km behind where the photos are taken from. The red arrow shows the same point in all three photos. ..............................58

Figure 5.19  Damage to asbestos and tile roofing in the proximal areas. (a) The corners of terracotta clay tiles were often broken, and (b) asbestos sheets were penetrated by ballistics in some instances. Some roofs were damaged beyond repair and damaged asbestos sheets were removed and replaced with new sheets. (c) Many broken sheets were seen seen dumped near houses during the field visit in September 2014. ............................................................... 58

Figure 5.20  Ash loading damaged part of the corrugated iron roof on the milk collection building in Munjang Hamlet. (a) One of three remaining wooden support brackets supporting the roof eaves. Three brackets under the damaged part of the roof were missing. (b) The overhanging section of 10 iron sheets that were bent downwards, likely as a result of increased ash load. Inset shows a close up of the bend in the iron sheets on top of the exterior wall. ........................................................................................................... 59

Figure 5.21  Warung in Selorejo Hamlet which had to have its corrugated asbestos roof replaced after it sustained damage and collapsed after wet ash loading. ................................................................. 60

Figure 5.23a-g  Severe damage to the electricity distribution network from ballistics in the proximal area extending ~3 km from the vent. Photos taken in September 2014. ................................................................................................. 63

Figure 5.24  Porcelain insulators coated in ash at a substation in Yogyakarta following the Kelud ashfall. ........................................................................................................................................ 64

Figure 5.25  PLN workers clearing Kelud ash from transformers with high pressure water at substations in Yogyakarta. The cooling fans also required cleaning (photos courtesy of Sumarsono, PLN Yogyakarta). .......................................................................................... 65

Figure 5.26  Pipework in proximal areas. It is often PVC (a,c) although some older galvanised metal pipes exist (b). Most is laid alongside roads and over road banks even through village centres. ................................................................. 66

Figure 5.27  New water supply tank (measuring ~ 3 x 2 x 2 m) which was constructed by the TNI above Munjang Hamlet in Pandansari Village following the eruption. ......................... 67

Figure 5.28  Two water storage tanks in Kalikuning Village which many residents relied upon following the eruption. Other residents had to walk to nearby reservoirs. ......................... 68

Figure 5.29  Sedimentation of ash at the water’s edge at Selorejo Reservoir (7 months after the eruption). ........................................................................................................................................ 68

Figure 5.30  Roadside drains filled with ash in Munjang Hamlet. The top of the concrete channel is just visible to the left of the plastic water supply pipes. This led to localised flooding of houses. ................................................................. 70

Figure 5.31  Ash piled up at front of house in an attempt to stop surface water from entering. Wood and tiles were stacked up on the outside of door openings to minimise ash ingress when open. ................................................................. 71

Figure 5.32  Typical main road in Yogyakarta. Where kerbs exist to segregate traffic types, holes allow water to flow openly to sides of roads. ........................................................................ 71

Figure 5.33  Drainage sumps in roads leading to partially open concrete channels with some removable slabs. .............................. 71

Figure 5.34  (a) Damaged, and (b) new mesh satellite dishes (2 m diameter) in Munjang Hamlet. .............................. 72

Figure 5.35  Rust damage to satellite dish at Sugihwaras Hamlet, although it is unclear whether this was a result of ash. ........................................................................................................... 73

Figure 6.1  Household items and personal belongings covered in tephra due to roof damage allowing tephra to fall into the rooms below (Washington Post 2014). .............................. 74

Figure 6.2  A coordinated approach to clean-up was adopted in many areas. (a) Residents cleaning a street together in the Kediri Regency (Irvine-Brown 2014). (b) TNI staff help to clear streets in Pandansari Village, Ngantang District, Malang Regency (Washington Post 2014). .............................. 75
Figure 6.3 Clean-up using ongsrok, a common tool used for clean-up of ash consisting of a wooden pole and small plank of wood (Tempo.co 2014). ................................................................. 75

Figure 6.4 Kelud tephra outside houses in proximal areas, seven months after the eruption. (a) Piled tephra outside house in the Kediri Regency. (b) Bagged tephra at Selorejo Village in Ngantang District, Malang Regency. ................................................................. 75

Figure 6.5 BPBD DIY water tanker being used to clean ash from rooftops and trees (BPBD DIY 2014b). ........................................................................................................ 76

Figure 6.6 (a) Plastic fibre sacks used for the storage of Kelud tephra. Often, old rice and cement bags were used (b). .......................................................................................................... 77

Figure 6.7 Temporary storage sites for tephra filled bags. (a) Recreational area adjacent to the BPBD DIY offices. (b) Yogyakarta Kraton (palace) grounds (BPBD DIY 2014b) ............... 77

Figure 6.8 Kelud ash remaining at the UPN Veteran Yogyakarta on 18 September 2014. (a) Accumulation to ~20 mm depth in flower bed. (b) remaining ash within paving voids. (c) Ash layer on second storey windows. (d) ash readily remobilised by human disturbance. .......... 78

Figure 6.9 Workers cover the Borobudur Temple near Yogyakarta to protect it from tephra from Kelud (Washington Post 2014). ........................................................................ 79

Figure 6.10 Volunteer using paint brush to clean Buddha statue at Borobudur Temple. Not all statues and stonework were covered in plastic sheeting so clean-up took some time even after it was removed (Muryanto & Ayuningtyas 2014). .................................................. 79

Figure 6.11 Workers sweeping ash to the sides of runways and into drainage channels on 15 February 2014 using ongsrok and brooms, the first day of clean-up at Adisucipto International Airport (AIA), Yogyakarta (Haryanti 2014b). ........................................ 80

Figure 6.12 High pressure hose cleaning the runway at Adi Sumarmo International Airport, Surakarta on 15 February 2014 (Hindu 2014). ........................................................................... 81

Figure 7.1 4WD vehicle tours in and around the sand mines of Merapi volcano. ........................................... 82

Figure 7.2 Potholes and erosion of asphalt concrete road surfaces are exacerbated by additional vehicles such as 4WDs and sand mining trucks. ..................................................... 83

Figure 7.3 Sand mining upstream of the bridge at Kandangan (~20 km north of Kelud’s crater). .................. 83

Figure 7.5 Sand mining sorting and processing near Munjang Hamlet in Pandansari Village. (a) Using wooden sluices and diversion channels to separate material of different grain sizes within the Sambong River. (b) Using mechanical processors on the banks of the Sambong River. ................................................................. 84

Figure 8.1 Pineapple plantation on the western slopes of Kelud. ................................................................. 86

Figure 8.2 Typical agriculture types. (a) Cash crop based agriculture, ~8 km north east of Kelud’s summit near Munjang Hamlet. (b) Rice paddies, Yogyakarta Special Region Province. .... 87

Figure 8.3 (a) Large swaths of farmland covered in ash following the Kelud eruption (Haryanti 2014a). (b) The same area 7 months after the eruption. Munjang Hamlet can be seen in the middle right. Both photos are taken looking south west from the dam at Selorejo reservoir (~9 km from the summit of Kelud). The summit area of Kelud is visible in the background. .............................................................................. 88

Figure 8.4 Albasia trees with some leaves stripped by ashfall. However, some new leaf growth is evident. ........................................................................................................................................ 88

Figure 8.5 Sambong River below the Selorejo Dam, after the lahars. The river was substantially widened through the scouring effect of lahars. Evidence of former rice paddies can be seen on the left. .................................................................................... 89

Figure 8.6 Farmer cleaning corn covered with Kelud ash (Washington Post 2014). ...................................... 90

Figure 8.7 Cattle farming sheds on the slopes of Merapi volcano, Yogyakarta. These house small numbers of animals but provide both animal and feed protection from ashfall. ...................... 91

Figure 8.8 Crops abandoned due to ash contamination within 10 km of the vent. ........................................... 93

Figure 8.9 Cultivation of ash into topsoil using community owned machinery, near Kalikunging Hamlet. ...................................................................................................................... 93

Figure 9.1 Motorbike tours operating on the road section inaccessible to four-wheeled vehicles on the damaged section of road leading towards the summit area. ........................................... 96

Figure 9.2 Warungs and car park area set up immediately before the official road closure where the motorbike tours began. ................................................................................. 97
TABLES

Table 2.1  Historic eruptions of Kelud since 1900 (adapted from GVP 2014b, De Bélizal et al. 2012, Bourdier et al. 1997). .......................................................... 7

Table 2.2  Alert levels for volcanic eruptions at Kelud and elsewhere in Indonesia (adapted from ...........12 De Bélizal et al. 2012) ........................................................................................................................................................................ 12


Table 3.2  Water extractable major elements in ash from the February 2014 Kelud eruption and global median (Ayris and Delmelle 2012). ........................................................................................................................................... 25

Table 3.3  Water extractable minor elements in ash from the February 2014 Kelud eruption and global median (Ayris and Delmelle 2012). ........................................................................................................................................... 25

Table 4.1  Number of cases for different health impacts from Kelud volcanic ash (Health Agency DIY 2014). ‘Accidents’ likely refers to traffic-related incidents (see section 5.2.2.2). .................. 36

Table 4.2  A list of the 10 most common diseases affecting refugees from the 2010 Merapi eruption, in the Sleman Regency (BBTKL-PPM 2011). ................................................................................................. 37

Table 5.1  Key impacts from the Kelud 2014 eruption and hazards for each infrastructural sector .......... 40

Table 5.2  Damage to buildings from ash in the three proximal regencies to Kelud as at 03 March 2014 (IFRC 2014). Note that it is not clear what each of the PMI damage categories refers to. ........................................................................................................................................... 56

Table 5.3  Recommended doses of coagulant and disinfectant materials in water from excavated wells following the Merapi 2010 eruption (BBTKL-PPM 2011). ......................................................... 70
ABSTRACT

This report presents a summary of the impacts from the February 2014 eruption of Kelud volcano in East Java, Indonesia, on agriculture, buildings, utilities and public health. The VEI 4 eruption ejected around 150 million m$^3$ of pyroclastic material, creating a tephra plume some 20 km in height. Both proximal areas (i.e. the Kelud flanks extending ~30 km radially from the vent including the regencies of Kediri, Blitar and parts of Malang) and distal locations, with a particular focus on Yogyakarta Special Region Province (in Central Java, ~220 km west of Kelud), are considered. Information was collected immediately after the eruption through analysis of emergency management and other official reports, maps, news and media articles which were sourced online, and through a field visit and sampling conducted by a team member in April 2014. The majority of the information presented in this report was obtained by an extended field team who conducted a comprehensive impact assessment during a field visit to the affected area during the period 08-23 September 2014. Other aspects covered in this report include the chronology of the February 2014 eruption including alert level status, social and cultural considerations, evacuation prior to and during the eruption, the official response, mitigation and recovery efforts to date, and expected future hazards from the eruption.

Impacts on all sectors in the proximal area were severe with a range of hazards including ballistics, pyroclastic density currents, lahars, landslides and heavy tephra fall resulting in the destruction of some buildings, parts of the road transportation, electricity and water supply networks, and erosion or burial of some agricultural land. Total economic loss for agriculture alone is estimated at up to Rp 377 billion (~NZ$ 39 million), which accounts for around a third of the loss for all sectors. Despite the explosivity of the eruption, there were only four fatalities attributed to primary hazards. This is very low considering the high population (>200,000 people) who reside and work on Kelud’s flanks and is largely attributed to the effective emergency planning and efficient response and evacuations that occurred. There are some concerns held by emergency service officials relating to how quickly evacuees returned to the area. However, impacts were substantially reduced in proximal areas by various proactive and mitigative measures implemented by residents, largely in response to the volcanic alert status being raised before the eruption, but also upon returning to their properties afterwards.

Distally, people in Yogyakarta Special Region Province received little to no warning of the eruption until ash began to fall at around 03:00 on 14 February 2014. However, a state of emergency was declared in Yogyakarta Special Region Province during the day following the eruption due to the severity of the impacts on various infrastructural sectors. There was generally a high degree of surprise that a volcano over 200 km away could produce enough ashfall to substantially disrupt infrastructure and daily activities in the city. The transportation network was heavily impacted by the ashfall with public bus services cancelled and an increase in traffic accidents rates despite far fewer vehicles in circulation. An aircraft suffered severe engine damage after flying through the ash cloud and seven airports throughout Java were closed for up to a week, four of them international which had knock-on effects globally. However, some infrastructure (diesel rail, high voltage electrical transmission, wastewater, stormwater and telecommunications) demonstrated resilience to ashfall.

The extent and severity of ash deposition in Yogyakarta Special Region Province necessitated a huge clean-up effort and a collaborative approach was taken which included contributions from governmental departments, emergency services, the military, students, volunteers and residents working together. Although ash was readily remobilised and persisted for months following the eruption, this approach was deemed successful. We conclude this report with a summary of key findings and lessons for future eruptions in Indonesia and worldwide.
KEYWORDS

Kelud, Kelut, volcano, East Java, Central Java, Yogyakarta Special Region Province, Indonesia, 2014 eruption, volcanic hazards, agriculture, infrastructure, health, utilities.

ACRONYMS

AIA  Adisucipto International Airport
AC  Air conditioning
BASARNAS  Badan SAR Nasional (National Search and Rescue Agency)
BBTKL-PPM  Balai Besar Teknik Kesehatan Lingkungan dan Pemberantasan Penyakit Menular (Centre for Environmental Health and Communicable Disease)
BLH  Badan Lingkungan Hidup (Regional Environment Agency)
BMKG  Badan Meteorologi, Klimatologi dan Geofisika (Indonesian Agency for Meteorological, Climatological and Geophysics)
BNPB  Badan Nasional Penanggulangan Bencana (National Agency for Disaster Management)
BOM  Bureau of Meteorology (Australia)
BPBD  Badan Penanggulangan Bencana Daerah (Provincial or Regional Disaster Management Agency)
BPPTKG  Balai Penyelidikan dan Pengembangan Teknologi Kebencanaan Geologi (Geological Disaster Technology Research and Development Agency)
CVGHM  Centre for Volcanology and Geological Hazard Mitigation (note. same as PVMBG)
DIY  Daerah Istimewa Yogyakarta (Yogyakarta Special Region Province)
DJPD  Direktorat Jenderal Perhubungan Darat (Directorate General of Land Transportation)
DJPL  Direktorat Jenderal Perhubungan Laut (Directorate General of Sea Transportation)
DJPU  Direktorat Jenderal Perhubungan Udara (Directorate General of Civil Aviation)
DREAM  Disaster Research, Education and Management Centre of Universitas Pembangunan Nasional (UPN) Veteran Yogyakarta
GVP  Global Volcanism Program
IFRC  International Federation of Red Cross and Red Crescent Societies
JANGKAR Kelud  Jangkane Warongs Redi Kelud (network of community and local government representatives in the three regencies surrounding Kelud who focus on volcanic risk reduction)
KVO  Kelud Volcano Observatory
NGO  Non-Governmental Organisation
OCHA  Office for the Coordination of Humanitarian Affairs
PAC  Polyaluminium chloride
PDAM  Perusahaan Daerah Air Minum (Water Utilities Company of Indonesia)
PDC  Pyroclastic Density Current
PHRI  Pergquiring Hotel dan Restaurant Indonesia (Indonesian Restaurant and Hotel Association)
PLN  Perusahaan Listrik Negara (State Electricity Company)
PMI  Pajang Merah Indonesia (Indonesian Red Cross Society)
PVC  Polyvinyl chloride
PVMBG  Pusat Vulkanologi dan Mitigasi Bencana Geologi (Centre for Volcanology and Geological Hazard Mitigation)
TNI  T entara Nasional Indonesia (National Armed Forces of Indonesia)
TSP  Total Suspended Particulate
UGM  Universitas Gadjah Mada (Gadjah Mada University)
UPN  Universitas Pembangunan Nasional (Veteran Yogyakarta)
UTC  Coordinated Universal Time
VAAC  Volcanic Ash Advisory Centre
WIB  Waktu Indonesia Barat (Indonesian Western Time)
1.0 INTRODUCTION

The island of Java in Indonesia (Figure 1.1) has a high concentration of active volcanoes (~45 in total), formed due to the subduction zone between the Eurasian and Indo-Australian plates. Increasing numbers of people inhabit such volcanically active regions due to a growing worldwide population and also fertile soils, water sources and beautiful scenery that often surround volcano flanks. In Indonesia alone, more than 5 million people live in close proximity to volcanoes (BNPB 2009).

Mount Kelud, a stratovolcano in East Java with a summit elevation of 1731 m, is located approximately 90 km south west of Surabaya, Indonesia's second largest city. Kelud has been the source of some of Indonesia's most deadly eruptions (GVP 2014a) and is the second most active volcano in the country (after Mt. Merapi), erupting more than 35 times in the last 1000 years (GVP 2014b). In September 2013, Kelud began to show signs of volcanic unrest as the temperature of crater lake water increased. This was followed by an increasing number of shallow volcanic earthquakes, which were later accompanied by deep volcanic earthquakes between January and early February 2014 (GVP 2014c). Inflation was also detected at one station (GVP 2014c). On 13 February 2014 a major (VEI 4) eruption occurred at 22.50, followed by an explosion at 23.30 (GVP 2014c). People began evacuating...
the area extending 5-10 km radially from the vent at 16:00 on 13 February, around 7 hours before the start of the eruption after the second to highest alert level was issued. Further evacuations occurred from 10 km of the vent upon issue of the highest alert level at 21:15, ~1.5 hours before the start of the eruption.

Proximal hazards during the February 2014 eruption included pyroclastic density currents (PDCs), in part likely caused in part by the collapse of the lava dome which formed in 2007 (GVP 2014d). Ballistic ‘missiles’ and syn- and post-eruption lahars also ensued, particularly in northern areas. Tephra was carried upwards in a 17-20 km high plume and, when falling, was generally directed towards the west of the volcano but affected proximal (Figure 1.2, Figure 1.3) and distal (Figure 1.2) areas up to ~600 km away in various directions from the vent. Parts of Pandansari Village (Figure 1.4), extending over 7 km northeast of the crater, were especially badly affected by tephra fall which accumulated up to 500 mm. Tephra accumulated up to 50 mm in parts of the Yogyakarta Special Region Province, which came as a surprise to many people as the province is over 200 km west of Kelud.

![Figure 1.2](image_url)  
**Figure 1.2** The regencies in proximal (blue) and distal (yellow) areas to Kelud where the field visits occurred. Also shown are cities and locations in Central and East Java of significance to the report.
Figure 1.3 The three regencies (Malang, Kediri and Blitar) surrounding Kelud’s summit and neighbouring regencies. Also shown (in yellow) are the districts on the flanks of Kelud where we conducted field studies, observations and/or interviews.

Figure 1.4 Location of villages (grey areas) surrounding the Kelud summit and the hamlets (orange points) within which were visited. The two dams and Kelud Volcano Observatory (KVO) shown on the map were also visited.
1.1 NOTES ON THE REPORT

The report focuses on the impacts observed following the 2014 eruption of Kelud volcano. Information was collected immediately after the eruption through analysis of emergency management and other official reports, maps, news and media articles which were sourced online. Although content from media articles is included for completeness, often in combination with information from other sources, the authors of this report don’t take responsibility its accuracy. Tephra samples (used for leachate analysis) and photographs were collected by a team member in April 2014. Further information was sourced from direct observations and interviews during an extensive field visit to the proximal (~30 km radially from the vent) and distal areas (with a particular focus on Yogyakarta Special Region Province) 7 months after the eruption, between 08 September and 23 September 2014. The report also outlines the chronology of the eruption including alert level status, social and cultural considerations, evacuations, the official response, mitigation and recovery efforts to date, and expected future hazards from the 2014 eruption. For background on common impacts and vulnerability associated with eruptions in general, the reader can also refer to Jenkins et al. 2014, Wilson et al. 2012 and Wilson et al. 2014.

Any reference to ‘Kelud’, ‘the crater’, ‘the vent’ and ‘the volcano’ refers to Kelud volcano in East Java. Reference to ‘the eruption’ and ‘the event’ relates to the 13-14 February 2014 eruption of Mt. Kelud. Due to the close proximity of Merapi volcano, many interviewees made reference or comparisons to previous eruptions here, particularly the 2010 eruption of Merapi. During the report, Merapi is specifically mentioned when referring to this volcano. If not, then the discussion relates to Kelud volcano and its impacts. The name Yogyakarta (when used alone in the report) refers to the entire Yogyakarta Special Region Province and not the city area within unless this is stated.

All areas of Java follow Indonesia Western Time (Waktu Indonesia Barat / WIB) which is Coordinated Universal Time / UTC +7 hours. We refer to WIB where no time zone is specified throughout the report.

A list of acronyms for organisations interviewed in the course of this project, and other common acronyms, is provided on page viii.

Any rainfall data throughout the report was not directly measured by the authors but was extracted from information provided by historical weather forecasts available on worldweatheronline.com (World Weather Online 2014). Although not a true representation of the rain which actually fell, it provides a means to identify general patterns that occurred. It also provides a comparative temporal measure for wet ashfall implications and the triggering of lahars in the days following the eruption.

1.2 RESEARCH METHODS

The team spent 11 days (8-18 September) in Yogyakarta. Five of these days were also occupied by other commitments at the Cities on Volcanoes 8 conference held at Universitas Gadjah Mada (UGM) although some interviews and discussions relevant to this report occurred then. Two members of the team travelled to Pare in the Kediri Regency, East Java Province on 19 September 2014 and spent the following 3 days (20-22 September) in all but the eastern sectors of Mt. Kelud. Information recorded in the field included evidence of physical impacts and, where possible, ash depth of any remaining deposits. Photographs were also collected at every site in order to facilitate a more detailed review after the field visit.

In all areas, the team conducted interviews with staff at various organisations involved with the official response and/or clean-up following the eruption, including emergency
management officials, health and agricultural experts, Indonesian Red Cross Society employees, university staff and utility sector managers. Interviews and discussions were also held with local residents: those who worked at restaurants and \textit{warungs}¹, charities, tourism companies and bus companies, and those who were farmers or ‘sand miners’. Throughout the trip, 32 interviews or formal discussions were held (see below for interviewees), all of which were aided by interpreters fluent in English, Bahasa Indonesian and Javanese. The interviewees were as follows, with bracketed text at the end of each numbered bullet point indicating how the material is subsequently referred to in the report.

1. Shop owner and resident of Batur resettlement village, Kali Gendol, Merapi, Sleman Regency, Yogyakarta Special Region Province (Batur 2014).
3. Staff at Badan Penanggulangan Bencana Daerah Kabupaten Blitar (the disaster management agency of Blitar Regency), Wlingi, East Java (BPBD Blitar Regency 2014a).
4. Staff at Badan Penanggulangan Bencana Daerah Istimewa Yogyakarta (The disaster management agency of Yogyakarta Special Region Province), Yogyakarta Special Region Province (BPBD DIY 2014a).
5. Research Student at Disaster Research, Education and Management (DREAM) Centre, Universitas Pembangunan Nasional (UPN) Veteran Yogyakarta (National Development University, Yogyakarta), Sleman Regency, Yogyakarta Special Region Province (Daniswara (pers comm, 2014)).
6. Dawet vendor. Drinks seller near BPBD DIY Office, Yogyakarta Special Region Province (Dawet (pers comm, 2014)).
7. Staff at the Direktorat Jenderal Perhubungan Darat (Directorate General of Land Transportation) and Direktorat Jenderal Perhubungan Laut (Directorate General of Sea Transportation), Kementerian Perhubungan (Ministry of Transportation), Yogyakarta (DJPD & DJPL 2014).
8. Staff at the Direktorat Jenderal Perhubungan Udara (Directorate General of Civil Aviation), Kementerian Perhubungan (Ministry of Transportation), Yogyakarta Special Region Province (DJPU 2014).
9. Staff at the Disaster Research, Education and Management (DREAM) Centre, Universitas Pembangunan Nasional (UPN) Veteran Yogyakarta (National Development University, Yogyakarta), Sleman Regency, Yogyakarta Special Region Province (DREAM 2014).
10. Workers at the ticket office and café, Kali Gendol, Merapi, Sleman Regency, Yogyakarta Special Region Province (Kali Gendol 2014a).
11. Worker for 4WD ticketing at Alien Rock, Kali Gendol, Merapi, Sleman Regency, Yogyakarta Special Region Province (Kali Gendol 2014b).
15. \textit{Warung} owners next to Konto River bridge, near Kandangan, East Java Province (Konto 2014).
16. Staff at the Kelud Volcano Observatory, Sugihwaras Village, Ngancar District, Kediri Regency, East Java Province (KVO 2014).
17. Staff at LSM Rumah Impian (The Dream House), Sleman Regency, Yogyakarta Special Region Province (LSM Rumah Impian 2014).

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¹ In Indonesia, a warung is a small family-owned business, often a shop, small restaurant or café.
18. Staff at Luwakmas Family Café and Restro, Sugihwaras Village, Ngancar District, Kediri Regency, East Java Province (Luwakmas Café 2014).
19. Tour Manager, Kakadu Tour and Travel, Yogyakarta Special Region Province (Mahjum (pers comm, 2014)).
21. Staff at Dinas Kesehatan Provinsi Daerah Istimewa Yogyakarta, Republik Indonesia (the provincial Health Agency), Yogyakarta Special Region Province (Health Agency DIY 2014).
22. Residents at a house being renovated in Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province (Munjang 2014a).
23. Farmer / Munjang resident in fields to south of Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province (Munjang 2014b).
25. Residents at house which was rebuilt following fire resulting from hot ballistic impact, Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province (Munjang 2014d).
26. Staff at PLN (the state owned electricity company), Yogyakarta Special Region Province (PLN 2014).
27. Staff at PMI (Indonesian Red Cross Society), Yogyakarta Special Region Province (PMI 2014).
28. Staff at PT. Jogja Tugu Trans (the Trans Jogja Bus Transport Company), Yogyakarta Special Region Province (PT-JTT 2014).
29. Translator and Guide, Kakadu Tour and Travel, Yogyakarta Special Region Province (Purwana (pers comm, 2014)).
30. Warung owners at Selorejo Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province (Selorejo 2014a).
31. Sand miner in Sambong River, below Selorejo dam, Pandansari Village, Ngantang District, Malang Regency, East Java Province (Selorejo 2014b).
32. Staff at Universitas Pembangunan Nasional (UPN) Veteran Yogyakarta, (National Development University, Yogyakarta), Sleman Regency, Yogyakarta Special Region Province (UPN 2014).
2.0 ERUPTIVE HISTORY AND EMERGENCY MANAGEMENT

2.1 HISTORIC ERUPTIONS AND VOLCANIC HAZARDS

There have been over 30 confirmed eruptions from Kelud volcano over the past 1000 years, with nine of these (Table 2.1) occurring since the beginning of the twentieth century and ranging in VEI from 1 to 4 (GVP 2014a). Around ten thousand people were reportedly killed by an eruption in 1587 (Wilcox 1959). The major identified hazards before 1990 were primary, syn-eruptive lahars incorporating pyroclastic ejecta and water from the crater lake, although Bourdier et al (1997) identified pre-1990 surge deposits on the summit ridges of the western flank. Hazards from tephra fall deposits are not noted in older literature, although ashfall more extensive than that in 1990 has been reported in eruptions since 1900 (Bourdier et al. 1997).

Table 2.1 Historic eruptions of Kelud since 1900 (adapted from GVP 2014b, De Bélizal et al. 2012, Bourdier et al. 1997).

<table>
<thead>
<tr>
<th>Start Date</th>
<th>Duration (approx)</th>
<th>VEI</th>
<th>Volume of tephra (millions m$^3$)</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 Oct</td>
<td>6 months</td>
<td>2</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>1990 Feb 10</td>
<td>1 month</td>
<td>4</td>
<td>150</td>
<td>32</td>
</tr>
<tr>
<td>1967 Dec 11</td>
<td>1 day</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967 Feb 18</td>
<td>1 day</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966 Apr 26</td>
<td>2 days</td>
<td>4</td>
<td>90</td>
<td>211</td>
</tr>
<tr>
<td>1951 Aug 31</td>
<td>1 day</td>
<td>4</td>
<td>200</td>
<td>7</td>
</tr>
<tr>
<td>1920 Dec 6</td>
<td>6 days</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1919 May 19</td>
<td>2 days</td>
<td>4</td>
<td>190</td>
<td>5,160</td>
</tr>
<tr>
<td>1901 May 22</td>
<td>2 days</td>
<td>3</td>
<td>200</td>
<td>Yes (no. unknown)</td>
</tr>
</tbody>
</table>

Following the destructive primary lahars of 1901 and 1919, the latter of which ejected about 40 million m$^3$ of water (Wilcox 1959) and killed 5,160 people (De Bélizal et al. 2012, Bourdier et al. 1997), an ambitious engineering project was undertaken in order to minimise the volume of water in the summit crater lake. A series of tunnels and shafts were dug through the western rim of the crater draining water into the Bladak River. A new tunnel was dug after the 1951 eruption (Figure 2.1), which deepened the crater by 70 m and another following the 1966 eruption (GVP 2014a, Bourdier et al. 1997, Sudradjat 1991). Loss of life from devastating lahars produced by the explosive ejection of crater lake water was significantly reduced since the construction of these drainage tunnels (see Table 2.1).

Precursors of the February 10 1990 eruption included seismic activity, variations in crater lake temperature, and bubbling noises in the lake (Bourdier et al. 1997, Lesage & Surono 1995, Sudradjat 1991). Seven discrete phreatomagmatic explosions followed, resulting in hazards due to PDCs in the summit area, and roof collapse under the load of tephra deposits on the lower slopes, predominantly affecting the western area (Bourdier et al. 1997, De Bélizal et al. 2012). Most of the 32 casualties resulted from the latter hazard, beyond the area evacuated before the onset of the eruption (Bourdier et al. 1997). Subsequent hazards were generated by secondary (rain triggered) lahars for several weeks.
Figure 2.1  (a) Volcanological Survey of Indonesia (VSI) scientists measure water levels at a drainage tunnel of Kelud crater lake in 1973. (b) Outlet tunnel of Kelud crater lake drainage system in 1973 (GVP 2014e).

Data from most of the eruptions in the twentieth century (i.e. those in 1901, 1919, 1951, 1966 and 1990) showed that they were comparable in erupted volume, duration (short) and eruptive style (explosive eruptions with rather steady, several hours long ejection of pyroclastic material through a crater lake) (Bourdier et al. 1997). Kelud appeared to have established a relatively regular eruptive behaviour over this century.

The 2007 eruption was dominated by a different style of volcanism, that of lava dome growth within the crater lake (Figure 2.2). During the 15 years prior to the eruption, the crater lake temperature was several degrees above the ambient air temperature of 19°C, but with near neutral pH (GVP 2014f). Eruption precursors were recorded in September 2007 when seismic activity increased sharply. Deformation and crater lake changes (physical and chemical) also began. In early October, seismicity decreased but physical variations of the crater lake suggested that the activity was increasing and authorities declared the maximum alert level on 16 October 2007. In mid to late October, seismicity again increased and then decreased (De Bélizal et al. 2012). In early November, the precursory unrest phase led to the extrusion of a lava dome in the crater lake. After ~5 months the lava dome growth ceased but had reached a visible radius of 250 m and a height of 120 m and filled much of the crater lake (GVP 2014e). Recorded seismicity decreased soon after the onset of dome growth. Tiltmeters also showed the absence of any significant deformation on the flanks of the volcano. Due to the reduced likelihood of a violent explosion, the alert level was lowered on 8 November. It was lowered again on 30 November, and to the lowest (normal activity) level in August 2008 (De Bélizal et al. 2012).

The 2007 eruption sequence surprised both the authorities and the population who had expected an explosive eruption (De Bélizal et al. 2012), as had occurred during the many historic eruptions of Kelud. Tourism and agricultural activities ceased on the flanks of Kelud for many months in anticipation of potential sudden signs of renewed activity (De Bélizal et al. 2012). Although there were some reports of a mildly explosive phase with light ash covering villages 15 km away (e.g. IOL 2007), most of the activity in 2007 was passive and neither water nor substantial ash were thrown forcefully out of the lake and onto the flanks (GVP 2014f).
2.2  Volcanic Hazard Management at Kelud and in Indonesia

2.2.1  Emergency Management

The emergency management system in Indonesia is based on a progressive and hierarchical framework that follows a top-down organisational approach. The Disaster Management Law No. 24 / 2007 requires the national government, through a Presidential Decree, to perform a rapid assessment based on the initial phase of the emergency and set the status and level of national and sub-national disasters, highlighting the level of government responsible and commanding authority. This is achieved through the analysis of certain indicators such as the number of victims, loss of properties, destruction of infrastructure, area affected and socio economic impacts. However, more than 7 years after the enactment of the Law, the mandated decree requires further development and ad-hoc decision making and coordination can result.

At Kelud, the system is designed to protect communities threatened by volcanic activity (De Bélizal et al. 2012). It is important to consider the different administrative divisions of Indonesia to better interpret the roles of the different groups involved in emergency management:

- **National** (Nasional) – The national government has the responsibility for national scale disasters, particularly to protect people from adverse impacts, to ensure the rights of the displaced population are equally met, and to assist with recovery. The national government is also responsible for allocating contingency funds. The President has the authority to declare national disaster status and appoint a commander to coordinate the responses from different organisations.

The key agency tasked with disaster management at the national level is the National Agency for Disaster Management, BNPB (Badan Nasional Penanggulangan Bencana). The BNPB, which was formed in January 2008 by presidential decree, are responsible for formulating policies in disaster management and managing displaced people through rapid, accurate, effective and efficient actions. They are also responsible for the coordination of disaster management among government offices and stakeholders (BNPB 2009). In implementing disaster management, BNPB works in cooperation with other ministries, agencies and institutions including the local volcano observatories, National Armed Forces TNI (Tentara Nasional Indonesia), police, Indonesian Red Cross Society (Palang Merah Indonesia), Ministry of Public Works, Ministry of Agriculture and universities.
• **Provinces (Provinsi)** – At a provincial level, the Governor acts as head to represent the central government. In Java, there are six provinces (Figure 1.1), two of which (Jakarta Special Capital Region and Yogyakarta Special Region) have special status. The other four are Banten, West Java, Central Java, and East Java. The Sultan of Yogyakarta is the de facto Governor of Yogyakarta Special Region since he is given priority when electing the Governor. Each provincial government has a separate Disaster Management Agency (BPBD).

• **Regencies (Kabupaten) and Cities (Kota)** – are autonomous areas, each having their own local government and legislative body. The difference between regencies and cities lies in their demography, size and economy with regencies generally comprising of larger rural areas. The three regencies, with cities of the same name, surrounding Kelud are Blitar (to the south), Kediri (to the north and west) and Malang (to the west) (see Figure 1.2). The regency and city governments have responsibility for responding to regency-scale disasters, which should be declared by the Head of the Regency, the *Bupati*. Depending on needs and the situation, regencies may have their own Disaster Management Agency, also called BPBD (Badan Penanggulangan Bencana Daerah), which is autonomous from the national and provincial disaster management agencies. It should be noted that when Kelud erupted, there was no BPBD in Kediri Regency.

The incident command system at national, provincial and regional/city levels is shown in Figure 2.3.

• **Districts (Kecamatan)** – are subdivisions of regencies or cities. Examples of districts include Ngancar (Kediri Regency) Wlingi (Blitar Regency) and Ngantang (Malang Regency) (see Figure 1.3).

• **Villages (Desa and Kelurahan)** – Both Desa and Kelurahan refer to village areas within a district. Desa has rural connotations and enjoys greater autonomy than Kelurahan. Pandansari is an example of a village (Desa) which is in the Ngantang District of Malang Regency (see Figure 1.4) (Turner et al. 2003, Edstrom 2002).

• **Hamlets (Dusun)** – Villages are divided into smaller areas known as Dusun, and translated in this report as hamlets. Munjang is an example of a hamlet within Pandansari Village (see Figure 1.4).

Staff at the Kelud Volcano Observatory, located 7.5 km west of the crater and immediately east of Sugihwaras, make regular visual observations of the volcanic activity (CVGHM 2014a) and send reports to the CVGHM (Centre for Volcanology and Geological Hazard Mitigation)\(^2\). In times of emergency, all staff at the observatory are in touch via ‘Handy Talkies’ and radios (i.e. handheld transceivers) which are used to keep every chief of settlement aware of volcanic activity (see Section 2.2.4) (De Bélizal et al. 2012).

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\(^2\) The CVGHM is also known by its Indonesian name, PVMBG (Pusat Vulkanologi dan Mitigasi Bencana Geologi)
Figure 2.3  Incident command system at national, provincial and regional / city levels in Indonesia (BNPB 2010).
The CVGHM analyse information received and provide advice to BPBD, and also BNPB who issue information about the status of alerts for selected volcanoes. Set criteria and implications exist for each alert level (Table 2.2) which have been standardised for all Indonesian volcanoes. Following a change in level, measures are implemented such as the preparation of emergency logistics and providing food, water and tents for evacuated people (De Bélizal et al. 2012) through BNPB, BPBDs and other agencies.

**Table 2.2  Alert levels for volcanic eruptions at Kelud and elsewhere in Indonesia (adapted from De Bélizal et al. 2012)**

<table>
<thead>
<tr>
<th>Level</th>
<th>Code</th>
<th>Name</th>
<th>Criteria</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Green</td>
<td>“Aktif Normal”</td>
<td>Usual activity; Monitoring of visual, seismicity and other volcanic event does not indicate changes</td>
<td>No eruption in foreseeable future</td>
</tr>
<tr>
<td>2</td>
<td>Yellow</td>
<td>“Waspada”</td>
<td>Be careful; Increasing activity of seismicity and other volcanic events, and visual changes around the crater</td>
<td>Magmatic, volcano-tectonic or hydrothermal disturbance, no eruption imminent</td>
</tr>
<tr>
<td>3</td>
<td>Orange</td>
<td>“Siaga”</td>
<td>Be ready; Intense increase in seismic activity, and obvious changes of visual observation of the crater</td>
<td>Eruption likely to occur within 2 weeks if trend of increasing unrest continues</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>“Awas”</td>
<td>Danger; Eruption is about to begin</td>
<td>The eruption is expected within 24 hours</td>
</tr>
</tbody>
</table>

In 2004, the CVGHM produced regulatory maps delineating the danger zones for many volcanoes. The hazard map for Kelud is shown in Figure 2.4. It illustrates areas that may be affected by tephra fall and PDCs and, among other details shows recommended evacuation directions and shelter points. However, there are some concerns from residents that the hazard map is now out of date, particularly as it does not accurately depict the true hazard that now exists from lahars in some areas (Indonesian Session 2014).

### 2.2.2 Health Management

Health information during and outside of emergencies is managed by the Health Agency (Dinas Kesehaten) (BPBD DIY 2014a). However, during an eruption after an emergency has been declared, health is delivered by several agencies with health-related information feeding into the incident command system. A disaster information system (118 advice line) is operated by the Health Agency and callers may be referred on to health clinics or hospitals (Health Agency DIY 2014). Health information is also disseminated through the media from the Governor of Yogyakarta who takes overall command of provincial agencies during a crisis (BPBD DIY 2014a, Health Agency DIY 2014).

Buffer stocks of masks are held by the disaster management agencies at national, provincial and regency levels (along with other supplies such as medicines and water treatment chemicals) (Health Agency DIY 2014). Masks are distributed to communities in need by the Community Health Centre (Puskesmas) and health workers, PMI, hospitals, Non-Governmental Organisations (NGOs), BPBDs and the Health Agency of Yogyakarta Special Region Province.

During non-crisis times, the Regional Environment Agency, BLH (Badan Lingkungan Hidup) monitors air quality. For Yogyakarta, monitoring is undertaken at seven sites. During states of emergency, the Centre for Environmental Health and Communicable Disease, BBTKL-PPM (Balai Besar Teknik Kesehatan Lingkungan Dan Pemberantasasi Penyakit Menular), a unit of the National Ministry of Health, monitor air and water quality. Particular attention is paid to microbiological risks present in refugee camps including from drinking-water, and other environmental health risks such as disease vectors. The BBTKL-PPM also sample ash during volcanic eruptions and analyse it for heavy metal content.
Figure 2.4 Volcanic hazards map of Kelud volcano, East Java Province, Indonesia. Produced by the Centre of Volcanology and Geological Hazard Mitigation, CVGHM (Mulyana et al. 2004).
2.2.3 Proximal Community Preparedness

In many towns on and around the flanks of the volcano, there is a strong sense of “community spirit” (KVO 2014). Interviews with emergency management officials and other organisations in the proximal areas during the field visit in September 2014 revealed that regular communication occurs between different groups such as observatory staff, BPBDs’ officials in the different regencies and residents. It is expected that this would aid community preparedness through people helping one another in times of heightened volcanic activity and through effective communication between leaders and efficient dissemination of warning messages.

Formal training of BPBD employees and volunteers in the three regencies surrounding Kelud (Kediri, Blitar and Malang) is co-facilitated by the BNPB and occurs more frequently during times of heightened volcanic activity (Indonesian Session 2014). Informal community awareness raising is achieved through small gatherings and through discussions between local residents such as meetings in warungs. This method of increasing knowledge and awareness related to Kelud (as opposed to large formal meetings) is preferred by many in the area (KVO 2014). JANGKAR Kelud (Jangkane Warongs Redi Kelud) is a platform of representatives from the community, teachers and local government in the three regencies surrounding Kelud who focus on risk reduction associated with Kelud volcano. They currently comprise of ~2000 people and pride themselves for acting as ‘one voice’, having no uniform and maintaining a focus on saving themselves, their families and all other residents during an eruption (Indonesian Session 2014, KVO 2014). The phrase ‘one voice’ suggests that consistent messaging in terms of alert level and volcanic activity information dissemination is seen to be of high importance in the area.

Interviews and discussions during the field visit in September 2014 revealed that emergency management officials and volunteers around Kelud appear to be viewed quite positively in local areas with one account suggesting that they have “one voice” and “act together to save people”. It was suggested that the larger number of different organisations and groups in Yogyakarta, some with contrasting priorities and additional political motives, can cause complexities in times of responding to crises. Cities such as Yogyakarta City may have further complexities during a volcanic eruption. For example, there are around 800 ‘street children’ in the city (LSM Rumah Impian 2014). Street children live nomadic lifestyles and spend most of their time on the city streets begging for money. However, according to staff at the charitable organisation, The Dream House they are not specifically considered a vulnerable group with respect to government disaster management (LSM Rumah Impian 2014).

The perceived time interval between eruptions and expected eruption style is another factor that could influence emergency management at Kelud. Discussions and interviews during September 2014 suggest that many people believe that the volcano only erupts every 20-24 years with just one short but explosive eruptive period. This may have affected responses during the February 2014 eruption as it may during future eruptions.

Following the increased volcanic activity at Kelud in 2007 and associated evacuations (many in the Blitar Regency residing within 10 km radius from the crater (KVO 2014, OCHA 2007)), various preparedness activities have taken place. Official disaster risk reduction training has been provided to residents and workers in ~35 villages in the three regencies around Kelud since 2008 and one training activity in 2013 included the BPBDs to specifically prepare for an eruption (Indonesian Session 2014). Regular disaster risk reduction training programmes are also delivered in more distal areas from Kelud such as Yogyakarta and such training includes first aid and disaster response (DREAM 2014). However, it is likely that these programmes in distal areas were aimed more at preparing for eruptions from volcanoes nearby, such as Merapi. There is also evidence that physical preparedness measures were undertaken in
2013. For example, BPBD Blitar Regency built and repaired bridges to be used for evacuation routes (Figure 2.5) (BPBD Blitar Regency 2014a, BPBD Blitar Regency 2014b).

2.2.4 Warning Communication

‘RAPI’, the amateur radio system for Indonesia is a popular method of information transfer (including latest volcanic activity and alert level statuses) between organisations, villages and residents. JANGKAR Kelud also broadcast information using the ‘RAPI’ system, enabling them to spread the same message (KVO 2014). Other means of warning communication in Java include sirens, neighbours and indirect methods using mobile phones and kentongan (gongs). Many types of kentongan exist in the villages on the flanks of Kelud (Figure 2.6). Every kentongan code has its own meaning and in the case of a volcanic disaster, it is beaten repeatedly and continuously with the same tone. This indicates that people should immediately evacuate to a pre-determined location (Mei et al. 2013).
3.0 **FEBRUARY 2014 ERUPTION OF KELUD VOLCANO**

3.1 **ERUPTION CHRONOLOGY**

A chronology of the February 2014 eruption of Kelud volcano is provided in Table 3.1.


<table>
<thead>
<tr>
<th>Date</th>
<th>Time (WIB)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2009 - 2 Feb 2014</td>
<td>-</td>
<td>Alert level Green / 1 status (<em>Aktif normal</em> Usual activity)</td>
</tr>
<tr>
<td>10 September 2013 - 9 February 2014</td>
<td>-</td>
<td>Crater lake water temperature increase</td>
</tr>
<tr>
<td>1 Jan 2014 - 2 Feb 2014</td>
<td>14:00</td>
<td>Alert level raised to Yellow / 2 status (<em>Waspadai</em> Be careful)</td>
</tr>
<tr>
<td>3-10 Feb 2014</td>
<td>-</td>
<td>Deep and shallow volcanic earthquakes increase (some 3 km below summit)</td>
</tr>
<tr>
<td>10 Feb 2014</td>
<td>16:00</td>
<td>Alert level raised to Orange / 3 status (<em>Siaga</em> Be ready), 5 km exclusion zone</td>
</tr>
<tr>
<td>10 Feb 2014</td>
<td>16:00</td>
<td>Some residents evacuate area up to 10 km from vent</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>00:00-22:49</td>
<td>Increase in number of VB, VA and low frequency (LF) earthquakes</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>21:15</td>
<td>Alert level raised to Red / 4 status (<em>Awas</em> Danger), 10 km exclusion zone</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>21:15</td>
<td>Evacuations within 10 km of crater in response to new alert status</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>22:46</td>
<td>Start of Eruption</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>22:50</td>
<td>Evacuation of some Pandansari residents in response to eruption</td>
</tr>
<tr>
<td>13 Feb 2014</td>
<td>23:30</td>
<td>Large explosion at vent, three seismic stations destroyed (one remaining)</td>
</tr>
<tr>
<td>14 Feb 2014</td>
<td>~03:00</td>
<td>Ash fall starts in Yogyakarta</td>
</tr>
<tr>
<td>14 Feb 2014</td>
<td>03:00</td>
<td>Volcanic activity at vent decreases</td>
</tr>
<tr>
<td>14 Feb 2014</td>
<td>(morning)</td>
<td>Military evacuate some Pandansari residents who sheltered overnight</td>
</tr>
<tr>
<td>14-15 Feb 2014</td>
<td>(daytime)</td>
<td>Some farmers returning in exclusion zone to check on properties, crops and livestock</td>
</tr>
<tr>
<td>15-20 Feb 2014</td>
<td>-</td>
<td>Amplitude of tremors decreased and white plumes (rather than grey) from vent</td>
</tr>
<tr>
<td>16 Feb 2014</td>
<td>-</td>
<td>End of ash fall in Yogyakarta (some may have been from substantial remobilisation)</td>
</tr>
<tr>
<td>17 Feb 2014</td>
<td>(daytime)</td>
<td>Many farmers returning to check on properties, crops and livestock</td>
</tr>
<tr>
<td>19 Feb 2014</td>
<td>(daytime)</td>
<td>Concern from Kelud Volcano Observatory over future lahars threat</td>
</tr>
<tr>
<td>20 Feb 2014</td>
<td>11:00</td>
<td>Alert level lowered to Orange / 3 status (<em>Siaga</em> Be ready), 5 km exclusion zone</td>
</tr>
<tr>
<td>20-28 Feb 2014</td>
<td>-</td>
<td>Further reduction in tremor amplitude</td>
</tr>
<tr>
<td>28 Feb 2014</td>
<td>16:30</td>
<td>Alert level lowered to Yellow / 2 status (<em>Waspadai</em> Be careful), 3 km exclusion zone advised</td>
</tr>
<tr>
<td>7 Aug 2014</td>
<td>12:00</td>
<td>Alert level lowered to Green / 1 status (<em>Aktif normal</em> Usual activity)</td>
</tr>
</tbody>
</table>
3.2 Volcanic Hazards and General Impacts

The VEI 4 eruption of Kelud on 13-14 February 2014, which started around 90 minutes after the highest alert status was issued, left a large crater around 400 m in diameter and destroyed the lava dome which emerged in 2007-2008, along with the parking area and stretch of crater road that previously extended up to the summit (GVP 2014d) (Figure 3.1). Around 1.5 hours after the start of the eruption, there were reports of an explosion that was heard over 200 km away, including in Surabaya, Surakarta and Yogyakarta (ABC News 2014a, BPBD DIY 2014b, Irvine-Brown 2014, SMH 2014). During the explosive eruption, PDCs extended up to ~2 km from the vent (Figure 3.2), particularly to the south and south west, destroying previously forested areas (Figure 3.1).

![Figure 3.1](image-url) Images from the south of Kelud crater area (a) before (23 August 2012), and (b) after (19 May 2014) the 13 February eruption (GoogleEarth 2014). The lava dome was removed by the explosive eruption leaving a ~400 m diameter crater. In the second photo, PDC deposits can be seen, which extend over 2 km from the vent, particularly to the south. Thick tephra deposits are also visible, particularly extending to the north east towards Pandansari Village.
Many ballistic bombs were ejected from the vent with some measuring up to 600 mm in length falling up to 3 km away (BPBP Blitar Regency 2014a, KVO 2014) (Figure 3.3). Lapilli and blocks which fell in the heavily impacted area of Pandansari Village (extending 7 km from the vent) had maximum sizes of 50-80 mm in diameter (Figure 3.4a) (Baku-APA 2014). Pumice clast sizes of around 50 mm were reported to the west of the crater, up to ~8 km from the vent, with clasts up to 80 mm found at the Kelud Observatory, 7.5 km west of the crater (Figure 3.4b).

Figure 3.2 PDCs destroyed previously forested areas to the south and south west of the vent.

Figure 3.3 Volcanic ballistics with maximum lengths of (a) ~500 mm, and (b) 600 mm, both deposited 2-3 km away from the vent (BPBD Blitar Regency 2014a, KVO 2014). Ballistics of a similar size (up to ~500 mm) were reported up to ~5 km from the vent.
In September 2014, PDC and thick tephra deposits were still evident extending ~2 km from the vent with little primary vegetation recolonising the area. There was evidence of landsliding and gullyng due to the newly exposed and unstable conditions (Figure 3.5).

There were at least four fatalities reported by the BNPB following the eruption as a result of primary volcanic hazards. One person died when crushed by a wall collapsing (possibly a result of tephra loading on the roof) whilst waiting for help evacuating, and the others due to respiratory problems associated with the inhalation of ash (Baku-APA 2014, BOM 2014, GVP 2014d, Jakarta Post 2014a). All victims were within 7 km of the volcano and within the area of heavy ash fall in the Ngantang District of the Malang Regency (Baku-APA 2014, Volcano Discovery 2014). Some reports (e.g. IFRC 2014, BNPB 2014a) suggested that there were seven fatalities, but the BNPB later revised the figure to four, claiming that some people had been counted twice under their different names (Jakarta Post 2014a).

Heavy rain, particularly torrential downpours from 16 February 2014 onwards (Pitaloka 2014a), mixed with the fresh pyroclastic deposits on the ground to form lahars. Lahars on Tuesday 18 February 2014 followed the courses of rivers in all three proximal regencies, causing damage to buildings, bridges and agricultural land (BNPB 2014b). These included lahars in the Ngobo, Mangli (Kediri Regency, 35 km WNW), Konto (Kediri Regency, 35 km N) and Bladak (Blitar Regency, 20 km SW) rivers (GVP 2014d). Most lahars were in proximal areas to Kelud, although it is possible that some lahars formed at distal locations such as on the slopes of Merapi volcano (~220 km to the west) as a result of the Kelud ashfall (De Bélizal 2014, De Bélizal (pers comm, 2014)). Additional fatalities may have resulted from the lahars with residents reportedly seeing a bloated body floating down the Brantas River in the strong current from a lahar in the Mojokerto area (Sudino & Rahmadi 2014).

In distal areas, such as Yogyakarta, the ashfall from the Kelud eruption came as a surprise to both residents and officials as they did not expect that ash originating from so far away would impact these areas. No warning of potential ashfall was received in these areas and the fact that the eruption occurred at night, with ash beginning to fall at around 03:00 on 14 February, also added to the surprise with many people awaking to
unexpected ash fall outside (BPBD DIY 2014a, Irvine-Brown 2014, Daniswara (pers comm, 2014)).

**Figure 3.5** Landsliding and gullying of tephra deposits ~2 km from the crater in September 2014, 7 months after the eruption. (a) Looking towards the crater from the nearest accessible point to the west. (b) Shows the unstable tephra deposits on the upper southern flanks of the volcano.

### 3.2.1 Tephra Dispersion

Ground reports indicate that ash plumes rose to an altitude of 17-20 km above sea level forming an umbrella cloud as wide as ~200 km across (CVGHM 2014a, Nakada 2014). Ash fell in areas NE, NW, and W of the vent, with many reports from as far as Yogyakarta (220 km WSW), Banjaranegara (320 km WNW), and Banyuwangi (228 km E) (BOM 2014, Dawet vendor (pers comm, 2014), KVO 2014). Trace quantities of ash even fell in Bandung, the capital of West Java 550 km away, and there were concerns that the ash would fall in the Indonesian capital of Jakarta 650 km away (Laia 2014, Jakarta Globe 2014). The volcanic eruption of Kelud was one of the best ever recorded by satellite observations, largely due to the eruption coinciding with the orbit of the NASA A-Train of satellites (BOM 2014). Figure 3.6 shows the eruption plume less than 2 hours after the eruption at 17:28 UTC, 13 February (00:28 WIB, 14 February).
Analysis at the time of the event indicated that the height of the ash cloud reached 55,000-65,000 feet (16.8-19.8 km) (BOM 2014, VAAC 2014). However, post-event analysis by the Darwin Volcanic Ash Advisory Centre (VAAC) (Figure 3.7) determined that the ash cloud in fact reached 85,000 ft (25.9 km) with the majority of the cloud at 57,000 feet (17.4 km) (BOM 2014).

![Image](image1.png)

**Figure 3.6** The eruption plume less than 2 hours after the eruption at 17:28 UTC, 13 February (00:28 WIB, 14 February). From Suomi NPP VIIRS, 375m resolution 11.45μm IR (BOM 2014).

![Image](image2.png)

**Figure 3.7** MODIS/AQUA image showing height/temperature of the ash cloud and path of the CALIPSO Lidar transect through the cloud, at 18:10 UTC, 13 February 2014 (01:10 WIB, 14 February 2014) (BOM 2014).
Figure 3.8a shows the HYSPLIT ash dispersion forecast at 23:00 UTC, 13 February (06:00 WIB, 14 February) that was generated operationally by Darwin VAAC during the eruption. Forecasting ash dispersion through modelling presents challenges in that powerful eruptions are able to overcome prevailing atmospheric winds, therefore accurate data for the ash source parameters is needed (BOM 2014). The HYSPLIT forecast of 13 February thus provided a different footprint to that captured by satellite during the eruption. However, the forecast was for around 5 hours after the time of the satellite image meaning that ash would have effectively had more time to disperse.

A similar pattern to the 2014 dispersion was observed following the 1919 eruption of Kelud (Figure 3.8b), with ash dispersing in two different directions. Relative to the 2014 eruption, the 1919 eruption occurred around 3 months later in the year on 20 May and was attributed to the different wind directions at different altitudes, a common occurrence in the season within Java, Indonesia (Wilcox 1959). Winds below 20,000 feet (6.1 km) were from the west while those above were from the east. The ash which reached high altitudes was carried westward at fairly high speed, and as it settled into the lower zone it was carried eastward, but at lower speeds so that the bulk of it fell to the ground west of the volcano (Wilcox 1959). The formation of two different lobes of ash deposition similar to the 1919 event was apparent from ground observations following the February 2014 eruption. However, thickest deposition appears to have occurred following a NE (for the low altitude dispersion) to WSW (for the high altitude dispersion) bilateral distribution, likely a result of the prevailing low altitude winds coming from the south during the event (CVGHM 2014a, KVO 2014).

Figure 3.8  Tephra Dispersion. (a) HYSPLIT ash dispersion forecast at 23:00 UTC, 13 February (06:00 WIB, 14 February) (BOM 2014). (b) Bilateral distribution of ash fall from the 1919 eruption of Kelud. High altitude westward winds and low altitude eastward winds were responsible for two distinct lobes of thick deposition (Wilcox 1959). Similarities exist with the tephra dispersion and deposition in 2014, although with somewhat different directionality.
3.2.2 Tephra Accumulation and Characteristics

Figure 3.9 shows the approximate tephra thickness in different locations, both proximal and distal to the volcano. This map includes lapilli (2-64 mm diameter) and ash (<2 mm diameter) sized tephra; volcanic bombs or ballistic clasts (>64 mm diameter) are not accounted for in the depths. The data relating to ash thickness collected during the field visit can be found in Appendix.

The total estimated tephra volume from the eruption is likely around 105 million m$^3$ (EDSM 2014), but potentially up to 160 million m$^3$ (Jakarta Post 2014b). Figure 3.10 illustrates the overall patterns of dispersion on tephra deposition in both proximal and distal locations following the February 2014 eruption. Within ~2-3 km of the crater, tephra accumulated up to a metre thick (Volcano Discovery 2014). Areas to the north east of the volcano in the Malang Regency were heavily impacted by tephra fall, and thicknesses were likely up to 500 mm (but more widely 200 mm) in parts of the Ngantang District, including Pandansari Village, 7 km away from the vent (Baku-APA 2014, KVO 2014, Munjang 2014a). Hamlets that were severely impacted include Munjang, Paid and Kotot (Munjang 2014a). Ash even accumulated to depths of ~300 mm within some Pandansari buildings that had experienced roof damage (Volcano Discovery 2014), although this thickness would generally not be consistent within the entire building due to different roof damage intensities and the concentration of ash below holes in roofs.

![Figure 3.10 General tephra dispersion and deposition following the February 2014 eruption of Kelud volcano (altitude values extracted from BOM 2014 and VAAC 2014). Note that diagram is not to scale.](image-url)
Around 6-8 km to the south and west from the vent, in the Blitar and Kediri regencies, some sites such as Kalikuning and parts of Wates including the Kelud Observatory (7.5 km from the vent) experienced depths of ~100 mm. Overall tephra here was generally coarser than what fell in the Malang Regency, mainly consisting of lapilli- (often referred to as "coarse sand") sized pumice clasts (BPBD DIY 2014a, Health Agency DIY 2014, KVO 2014, Purwana (pers comm, 2014)). Some individual clasts were up to ~80 mm in diameter in these locations (Kalikuning 2014, Karanganyar 2014, KVO 2014, Luwakmas Café 2014). However, further to the south, including Wlingi in the Blitar Regency, residents experienced no tephra fall despite the sky darkening overhead at times (BPBD Blitar Regency 2014a). This may have been a result of low altitude winds blowing from the south and ash remaining in suspension in the plume at higher altitudes.

In Yogyakarta, fine-grained tephra accumulated to average depths of 20-30 mm, and up to 50 mm in places (BPBD DIY 2014a, BPBD DIY 2014b, DJPD & DJPL 2014, Volcano Discovery 2014). Ash from the Kelud eruption was said to be more of a problem than that from the Merapi (2010) eruption in Yogyakarta as it covered a much larger area (BPBD DIY 2014a, Daniswara (pers comm, 2014), Mahjum (pers comm, 2014)). Merapi ash was mostly directed to the west in 2010. Due to the fine nature of the Kelud ash in distal locations, remobilisation by wind, traffic and other human activities was a particular issue. As a result, ash was prevalent in Yogyakarta for over one month (BPBD DIY 2014a) and some ash remained on the ground and other surfaces over 7 months after the eruption at the time of our field visit (see Figure 6.8). There was light rainfall in Yogyakarta on 14 February, although this was not enough to prevent further remobilisation. No major remobilisation issues were reported in the proximal areas where the ash was coarser and not as readily re-suspended. Ash from Kelud that fell farther afield in Java, particularly to the north west of Yogyakarta also accumulated to measurable depths. At Borobudur temple, around 25 km north west of Yogyakarta City, 3-5 mm of ash accumulated (Antara News 2014a).

Analysis of two samples of Kelud volcanic ash (Figure 3.11) for major (Table 3.2) and minor (Table 3.3) water extractable elements was conducted in the laboratory at Massey University, Palmerston North, New Zealand, following sampling from Yogyakarta. Samples Kelud-1 and Kelud-2 are markedly different with respect to their leachate composition. Kelud-1 de-ionised water leachate has a very high pH (10.1), which is dramatically different to the near-neutral value of 6.4 recorded for Kelud-2. This sample may have become contaminated with fragments of concrete; the sample contained visible larger fragments. The conductivity value for Kelud-2 is approximately half that of Kelud-1, corresponding to a lower soluble salt burden. For both samples, the most abundant water extractable elements are Ca, Na, S and Cl. Both samples are low compared to global median values, shown for comparison in Tables 3.2 and 3.3.
**Figure 3.11** Kelud-1 and Kelud-2 ash samples.

**Table 3.2** Water extractable major elements in ash from the February 2014 Kelud eruption and global median (Ayris and Delmelle 2012).

<table>
<thead>
<tr>
<th></th>
<th>Conductivity (µs/cm)</th>
<th>pH</th>
<th>Ca (mg/kg)</th>
<th>Mg (mg/kg)</th>
<th>Na (mg/kg)</th>
<th>K (mg/kg)</th>
<th>Cl (mg/kg)</th>
<th>F (mg/kg)</th>
<th>SO₄ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelud-1</td>
<td>158</td>
<td>10.1</td>
<td>1429</td>
<td>5.7</td>
<td>141</td>
<td>36</td>
<td>115</td>
<td>9.2</td>
<td>972</td>
</tr>
<tr>
<td>Kelud-2</td>
<td>82</td>
<td>6.4</td>
<td>404</td>
<td>14.7</td>
<td>87</td>
<td>11</td>
<td>108</td>
<td>9.9</td>
<td>916</td>
</tr>
<tr>
<td>Global median</td>
<td>2140</td>
<td>335</td>
<td>378</td>
<td>71</td>
<td>1162</td>
<td>129</td>
<td>4990</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.3** Water extractable minor elements in ash from the February 2014 Kelud eruption and global median (Ayris and Delmelle 2012).

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>As</th>
<th>Br (mg/kg)</th>
<th>Cr (mg/kg)</th>
<th>Cu (mg/kg)</th>
<th>Fe (mg/kg)</th>
<th>Pb (mg/kg)</th>
<th>Mn (mg/kg)</th>
<th>Ni (mg/kg)</th>
<th>Zn (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelud-1</td>
<td>61</td>
<td>0.02</td>
<td>15.6</td>
<td>0.11</td>
<td>0.35</td>
<td>0.57</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.15</td>
</tr>
<tr>
<td>Kelud-2</td>
<td>4.8</td>
<td>&lt;0.02</td>
<td>6.9</td>
<td>&lt;0.01</td>
<td>0.48</td>
<td>1.8</td>
<td>&lt;0.01</td>
<td>1.7</td>
<td>0.055</td>
<td>0.85</td>
</tr>
<tr>
<td>Global median</td>
<td>58</td>
<td>0.13</td>
<td>1.9</td>
<td>0.096</td>
<td>5</td>
<td>21</td>
<td>0.114</td>
<td>20</td>
<td>0.5</td>
<td>3.6</td>
</tr>
</tbody>
</table>

### 3.3 WARNING AND RESPONSE - PROXIMAL

#### 3.3.1 Official Warnings

As can be seen in Table 3.1, the alert level, which ranges from 1-4, was raised from Green / 1 (‘Aktif normal’ Normal activity) to Yellow / 2 (‘Waspada’ Be careful) on 02 February 2014. This was in response to the number of deep volcanic earthquakes fluctuating, but showing a general increase and often occurring at 2-8 km depth throughout mid to late January 2014 (GVP 2014d) (Figure 3.12).
As a result of the higher alert level, various meetings and discussions took place, including regional BPBD staff, military and police to decide on what steps to take regarding evacuations and for the allocation of funding to different agencies (BPBD Blitar Regency 2014b) (Figure 3.13). Some precautionary measures were taken such as erecting signs to warn people of the elevated alert level and potential dangers (Figure 3.14).

Figure 3.12  Seismicity in respect of volcanic alert levels in January and February 2014 (adapted from CVGHM 2014a).
Meetings held on 03 February 2014 to discuss evacuation plans and funding for different agencies. This was following the raise in alert level to Yellow / 2 on 02 February 2014 (BPBD Blitar Regency 2014b).

Some signs were erected during the alert level Yellow /2 phase to advise people to stay away from the crater area (BPBD Blitar Regency 2014b). This one warns of the danger area beyond.

The crater lake temperature was rising during mid- to late- January but decreased slightly when measured on 10 February. The amplitude of volcanic earthquakes increased on 06 and 09 February (CVGHM 2014a) (Figure 3.12) and inflation was detected at one station 1.5 km from the crater (CVGHM 2014b) prompting the CVGHM to raise the alert level further to Orange / 3 (‘Siaga’ Be ready) on 10 February (GVP 2014d). This officially excluded visitors and residents from within a 5 km radius of the crater and all staff responsible for evacuations gathered and were informed of the latest guidance before assisting with evacuations (Figure 3.15). Equipment, tools and machinery were prepared and tents, including those for first aid and toilets, were set up in preparation for an emergency (Figure 3.16).
Following an increase in the number of shallow, deep and low frequency earthquakes, the CVGHM raised the alert to the highest level Red / 4 ('Awas' Danger) on 13 February at 21:15 local time (~1.5 hours before the eruption commenced). This extended the exclusion zone to a 10 km radius from the vent and the government ordered evacuations of communities accordingly (CVGHM 2014c, GVP 2014d, IFRC 2014).

### 3.3.2 Evacuations

During the ‘Siaga’ Orange / 3 alert phase at 16:00 on 13 February (~7 hours before the eruption), residents began to evacuate the area extending 10 km radially from the volcano (although only 5 km is enforced), some of which made their way to evacuation points and shelters. This included over 37,000 evacuees in the Blitar Regency alone and nearly 14,000 of them were provided with facilities and provisions such as food, drink, clothing and healthcare (BPBD Blitar Regency 2014b) (Figure 3.17). It was reported that some communities in the Kediri Regency received the information of the heightened alert status at ~20:00 via emergency sirens (Indonesian Session 2014). The relatively high number of early evacuees may be attributable to local knowledge suggesting that difficulties are encountered when trying to evacuate many people over a short period of time, emanating from governmental advice following the 1990 and 2007 eruptions (KVO 2014). There were also media reports of animals fleeing areas on the flanks of Kelud a few days prior to the alert level being raised which perhaps encouraged evacuations further (Pitaloka 2014b).
From 21:15 on Friday, ~1.5 hours before the eruption and in response to the highest alert level being issued, many people within 10 km of the crater commenced evacuations. It was reported that up to ~86,000 people evacuated solely in response to the highest alert level being issued (i.e. before governmental officials ordered evacuations or visible increases in volcanic activity) (Indonesian Session 2014, Kalikuning 2014, KVO 2014, Luwakmas Café 2014). Many were well informed about the volcano, potential hazards and evacuation routes and points, largely from the volcanic hazard map (published in 2004 and widely distributed after the 2007 eruption) (see Figure 2.4). Most residents knew that evacuation within 1-2 hours was deemed most appropriate and most evacuated using their own transport, particularly motorbikes. Evacuations were reportedly undertaken in a very calm manner with no panic or major traffic problems and the ‘RAPI’ radio system and JANGKAR Kelud members appeared to be very effective for helping disseminate information from village to village and assisting with evacuations. Some of the prompt evacuations may have been aided by the belief of some people that a major eruption at Kelud occurs every 20-24 years, and the fact that the last explosive (VEI 4) eruption occurred 24 years ago, in 1990. The regional BPBDs, police, military, National Search and Rescue Agency BASARNAS (Badan SAR Nasional), and volunteers helped with evacuations. This included over 400 volunteers from the PMI across the three affected regencies (IFRC 2014). No casualties were reported during the initial evacuation phase before the eruption occurred (Indonesian Session 2014). The timely pre-eruption evacuations likely avoided many casualties. For example, in Karanganyar residents indicated that they may have been killed by falling “fist-sized” rocks if they had stayed longer.

Despite a generally high evacuation response rate overall, the response in some villages, particularly in the Malang Regency was slow (Indonesian Session 2014). For example, the warning for residents at Selorejo Village (10 km north east of the crater), including many warung owners, came too late. Evacuations here appear to have been in response to the eruption itself with many quickly abandoning the area and leaving behind belongings including food and goods (Selorejo 2014a). Similarly, residents in the proximal village of Munjang, along with nearby farmers, sand miners and other workers, evacuated in response to the eruption. As they crossed the road bridge over the Sambong River (near the Selorejo Dam), some residents encountered very low visibility (~1-2 m visual range (Munjang 2014b)) due to falling ash fall and ballistics. Accounts of “people acting like monkeys” and head injuries to some residents in Munjang (Munjang 2014a) suggested that this caused evacuation difficulties, perhaps with them actively attempting to avoid falling ballistics.

The reasons for the late evacuation from some hamlets is unknown. However, in 2007 the residents of Munjang Hamlet and the wider Pandansari Village did not evacuate as most tephra fall occurred to the south of the crater, with only small pumice fragments impacting Pandansari (Munjang 2014a). It may be that some residents were expecting a repeat of similar events during the 2014 eruption. During the field visit in September 2014, there were relatively few vehicles present on the streets in the most proximal hamlets to the volcano such as Munjang and Kalikuning. Lower vehicle ownership may mean that some residents in the area were awaiting evacuation in vehicles provided by government officials or the military, thus leading to a slower response. There were various accounts that support this hypothesis such as some Kalikuning residents being evacuated in government cars, and BPBD staff and volunteers travelling from the Blitar...
Regency and Yogyakarta Special Region Province to Pandansari to help evacuate residents (BPBD Blitar Regency 2014a, Daniswara (pers comm, 2014), Kalikuning 2014).

As of 14 February 2014, the number of internally displaced persons was said to stand at 100,248 people (IFRC 2014). The approximate percentage of evacuees per regency can be estimated by data collected from the evacuation camps on 18 February (IFRC 2014):

- Kediri Regency: 48% of evacuees
- Malang Regency: 42% of evacuees
- Blitar Regency: 10% of evacuees

### 3.3.3 Shelter in Place

Despite the advice to evacuate villages located within the exclusion zone, some people chose to shelter in place during the night of the eruption. There are suggestions that hundreds of people, particularly many male farmers, remained in Munjang Hamlet sheltering within their homes. The four recorded fatalities likely occurred during this time. In the morning on 14 February, some of the remaining residents were evacuated by the military (Munjang 2014b), although some stayed throughout the duration of the eruption and recovery process (Munjang 2014a).

### 3.3.4 Evacuation Destinations

It is estimated that approximately 10% of evacuees travelled to family and friends living outside the exclusion zone and around 90% moved to evacuation points and internally displaced persons facilities set up by the government with the support of other agencies. These included temporary camps, schools, sports centres and other large buildings (KVO 2014). As of 14 February, the PMI reported that there were 172 facilities set up across the province to cater for basic needs (IFRC 2014). This included the set-up of kitchens and distribution of relief items (e.g. masks, sleeping mats, hygiene kits and tarpaulins) and provision of drinking water (IFRC 2014).

Destinations varied, largely depending on the location of the affected village in relation to the vent. Many residents from Pandansari either evacuated themselves or were taken in military vehicles to Pujon, Batu or Malang City, up to 20-25 km to the north east and east of the vent (Klangon 2014, Munjang 2014a, Munjang 2014b, Selorejo 2014b). Initially, some Ngantang residents evacuated to 10 km from the vent but after encountering ballistics in these locations, decided to evacuate further to ~15 km from the vent (KVO 2014). Other Ngantang residents were evacuated to the Blitar Regency on the other side of the volcano (BPBD Blitar Regency 2014a). Many residents of the proximal hamlets on the southern flanks such as Kalikuning and Karanganyar were evacuated to Nglegok to the south west, travelling ~4-9 km to reach the destination. In Ngancar District, to the west of the vent, some residents travelled ~10 km to reach their evacuation destinations (Figure 3.18).
Figure 3.18  Evacuations in the districts surrounding Kelud during the February 2014 eruption. Blue lines represent likely route directions taken from the known origin and destination points of evacuees. Evacuations in other locations existed but the destinations here were unclear and are therefore not depicted on the map.

3.3.5 Return

The return time of residents was by no means consistent and generally consisted of temporary return during the daytime, followed by more permanent return to the area. The 10 km radius area from the crater was declared a ‘red zone’ in the hours after the ‘Awas’ / Danger warning, prohibiting any activity or anyone from accessing it except emergency authorities (IFRC 2014). Some people returned to this area during the daytime from 1-2 days after the eruption onwards (and many from 4 days onwards), particularly the men who would check and clean their properties and tend to livestock and crops before returning to their temporary shelter or accommodation at sunset (Kalikuning 2014, KVO 2014, Sudino & Rahmadi 2014, Sunstar 2014). As a result, it appeared that officials and volunteers forced some evacuations during this time (Jakarta Post 2014a). By 18 February, 4 days after the eruption, the number of internally displaced people had reduced by at least 17,000 with 83,088 remaining in camps (IFRC 2014). After the CVGHM lowered the alert level to Orange / 3 status (‘Siaga’, Be ready) on 20 February, the exclusion zone was reduced to a 5 km radius from the vent. However, in addition to this exclusion zone, the CVGHM urged people not to carry out any activities along river banks, to be vigilant to the possibility of lahars and to remain on
high alert if returning to their homes (CVGHM 2014a, IFRC 2014). The CVGHM reported in The Jakarta Post on 20 February 2014 that “lahars could take the form of up to 105 million cubic meters of volcanic materials, carried by water, flowing down from the mountain” (Muryanto & Sustano 2014).

The CVGHM lowered the alert status to Yellow / 2 status (‘Waspada’ Be careful) 14 days after the eruption on 28 February 2014 (BPBD Blitar Regency 2014b, CVGHM 2014b). They advised of continued threat of phreatic eruptions, warning people to stay clear of heavily impacted areas within 3 km from the vent and to remain on alert for further lahars. Most residents had already permanently returned to their villages within 7-14 days following the eruption (KVO 2014, Luwakmas Café 2014, Munjang 2014a, Selorejo 2014b). However, some of those in the Ngantang District who had experienced serious damage to property remained in other locations for around 1 month (KVO 2014). The return of some residents occurred in stages, with many initially moving to villages closer to the volcano (than the original evacuation destinations) before moving to their home villages several days later (Selorejo 2014b). Despite some people being evacuated in government and military vehicles, return transport was not provided. However, many people had motorbikes and other vehicles parked at evacuation centres (Kalikuning 2014).

### 3.3.6 Infrastructural Rehabilitation

The East Java Province military commander was given responsibility to support the repairing of infrastructure, houses and facilities (IFRC 2014). As a result, the military established various camps within the proximal areas that experienced substantial infrastructure damage and disruption to livelihoods in order to provide relief to returning evacuees and support initial recovery efforts. This included one to the south of Munjang Hamlet (Figure 3.19a) where they provided food, shelter and distributed donations, some of which came from national television appeals (Munjang 2014b). Adjacent to this camp, the military helped restore water supply to the hamlet and wider Pandansari Village area by installing a new gravity-fed water tank (Figure 5.27). Another camp was established in a car park at Selorejo (Figure 3.19b) (Selorejo 2014a). The government took responsibility to cover the provision of temporary roofing, set up temporary sanitation, communication and other facilities until regular services were restored (IFRC 2014). The rapid provision of aid appears to have been well-organised and well-received by residents (Munjang 2014b, Selorejo 2014b).

After the lowering of the alert status to Green / 1 status (‘Aktif normal’ Normal activity) on 07 August 2014 (BPBD Blitar Regency 2014b, CVGHM 2014d), the CVGHM advised residents and tourists not to approach the crater rim and to continue to avoid the rivers that drain from Kelud. The Kediri Regency government erected signs warning of the dangers that remain around the crater area (CVGHM 2014d) (see Figure 3.5a).
Figure 3.19  Sites of two military camps. (a) South of Munjang hamlet. The camp was located on the field to the left of the track (the new water tank installed by the military can be seen on the right). (b) Selorejo Village. This camp was sited on the car park adjacent to the warungs.

3.3.7  Post-eruption Concerns

There appeared to be some concern from staff at various organisations as to how quickly people were allowed to return. Shortly before the alert status was lowered to Orange / 3 (‘Siaga’, Be ready) on 20 February, reports suggested that there were concerns about the future threat of lahars. Residents were urged to remain in shelters but many returned home anyway (Muryanto & Susanto 2014) particularly during the day. Concerns continued into March with an article published in The Jakarta Post (8 March 2014) stating that a police official was concerned over the reopening of a recreational park:

He said the reopening was too dangerous because the condition of the mountain remained unstable.
“The condition of the field is too risky,” deputy Kediri Police chief Comr. Alfian Nurizal said on Saturday
He said he would deploy personnel to secure the site, preventing visitors reaching the unstable crater or any other potentially dangerous areas. (Jakarta Post 2014c)

As of September 2014, some residents in Pandansari Village (Munjang 2014c) expressed concerns that all government assistance had now ceased. Despite most properties being rebuilt and critical infrastructure being restored, the loss of land due to lahars and impact of thick tephra on agriculture will likely present some difficulties for months or years to come.

There are further concerns about the threat of future lahars emanating from existing material remaining in the upper reaches of catchments on Kelud’s flanks. As the eruption occurred towards the end of the 2013-2014 wet season, the wet season at the time of writing (i.e. 2014-2015) may present further challenges. The BPBD of Blitar Regency
expressed particular concerns about further lahars in the Bladak and Putih rivers with fears that the sabo dams will be overtopped.

3.4 WARNING AND RESPONSE - DISTAL

There was no warning of the eruption in Yogyakarta (apart from some people reportedly hearing the initial explosion) until ash began falling at around 03:00 on 14 February. Little action appears to have been taken until that time with the exception of monitoring seismographs and the development of activities at Kelud (BPBD DIY 2014b). At 09:00 on 14 February, BPBD DIY and various stakeholders convened to discuss the possible impact on health, schools, transport and other utilities. This discussion involved the following agencies and groups:

- Public Works Agency
- Social Services
- TNI
- Police
- Department of Education
- Health Agency
- Balai Penyelidikan dan Pengembangan Teknologi Kebencanaan Geologi, BPPTKG (Geological Disaster Technology Research and Development Agency)
- Badan Meteorologi, Klimatologi dan Geofisika, BMKG (Indonesian Agency for Meteorological, Climatological and Geophysics)
- PMI
- Volunteers
- BLH.

These discussions, along with further talks with the Governor led to the declaration of a state of emergency for Yogyakarta Special Region Province later that day. This would cover a period of one week (14-20 February 2014), with the BPBD coordinating much of the response, as they did in the proximal regencies (BPBD DIY 2014a). This was different to the 2010 eruption of Merapi volcano where a national disaster was declared and the event was handled by BNPB. It is suggested that emergency management officials at different governmental levels may have different perceptions of volcanic risk, particularly associated with the threat posed by volcanic ash compared to other volcanic hazards such as PDCs which are often portrayed as dramatic and sensational hazards by the media. The provincial level government in Yogyakarta was relatively quick to declare a disaster status following the Kelud eruption based solely on the threat from volcanic ash. Similarly, the East Java Province also declared provincial level disaster status. However, at a national level, no disaster status was declared despite more four provinces being affected, large economic losses and impacts on national assets. Additionally, no disaster status was declared by the Central or West Java provincial governments, despite impacts on many districts, particularly from volcanic ash in Central Java.

The state of emergency in February 2014 in Yogyakarta Special Region Province involved school closures for four days including the weekend (later extended to five, from 14 to 18 February inclusive) (BPBD DIY 2014a, BPBD DIY 2014b, DJPD & DJPL 2014). Advice issued through the Governor also led to the immediate closure of several governmental offices. This included the Transportation, Communications and Informatics
offices in the city which were closed for one day, with the exception of a few staff on standby (DJPD & DJPL 2014). It appears that many people assisted with clean-up efforts, particularly on Saturday 15 and Sunday 16 February with little workplace activity during these times (see section 6.2.1).

Advice issued by the Governor through the incident commander, and broadcast by local leaders, radio and social media included the emphasis of these points:

- “If you don’t need to go out, don’t” (Health Agency staff reported to the Governor with the recommendation to stay indoors (Health Agency DIY 2014)).
- Schools will be closed for four days (later extended to five). A holiday was announced.
- Police have been dispatched to manage road traffic. (BPBD DIY 2014a)

In carrying out the emergency operation in Yogyakarta, BPBD DIY was assisted by resources and staff from the police, volunteers and the military (Figure 3.20). In turn, some resources such as food and drink were provided to assist the volunteers (Figure 3.21).

Based on an emergency response evaluation meeting held on 20 February 2014, it was decided that the emergency response in Yogyakarta should end. However, the government appealed for residents and organisations to continue with the ash clean-up effort thereafter (BPBD DIY 2014b).
4.0 **IMPACTS ON HEALTH AND THE HEALTHCARE SYSTEM**

The information in this section is based on interviews conducted with the Health Agency of Yogyakarta Special Region Province (Dinas Kesehatan Propinsi Daerah Istimewa Yogyakarta), The Centre for Environmental Health and Communicable Disease BBTKL-PPM (Balai Besar Teknik Kesehatan Lingkungan Dan Pemberantasan Penyakit Menular) of the National Ministry of Health, Indonesian Red Cross Society PMI (Palang Merah Indonesia), and the Yogyakarta Disaster Management Agency BPBD DIY (Badan Penanggulangan Bencana Daerah Istimewa Yogyakarta). The discussion of health impacts is mainly limited to those in Yogyakarta Special Region Province as we did not conduct interviews with health agencies in proximal areas.

4.1 **PUBLIC HEALTH IMPACTS**

The Health Agency of Yogyakarta Special Region Province provided data (Table 4.1) on the overall health impacts of the Kelud eruption on Yogyakarta Special Region Province (population approximately 3.5 million). This dataset was compiled from multiple agencies including community health centres (Puskesmas), hospitals and the police as part of the coordinated response to the provincial state of emergency. The data refer to a one month period following the eruption and to cases that were specifically attributed to volcanic ashfall from the Kelud eruption.

**Table 4.1**  Number of cases for different health impacts from Kelud volcanic ash (Health Agency DIY 2014). ‘Accidents’ likely refers to traffic-related incidents (see section 5.2.2.2).

<table>
<thead>
<tr>
<th>Disease/health outcome</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper respiratory tract infection</td>
<td>56</td>
</tr>
<tr>
<td>Accidents</td>
<td>50</td>
</tr>
<tr>
<td>Itchy skin</td>
<td>11</td>
</tr>
<tr>
<td>Eye problems</td>
<td>2</td>
</tr>
<tr>
<td>Asthma</td>
<td>2</td>
</tr>
<tr>
<td>Deaths</td>
<td>2</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>1</td>
</tr>
<tr>
<td>Dermatitis</td>
<td>1</td>
</tr>
</tbody>
</table>

The most common impact was upper respiratory tract infection, similar to the clinical effects that emerged from other populations exposed to distal ashfall (e.g. Mt. St Helens 1980 eruption; Nania & Bruya 1982). Overall incidence rates, for a population of approximately 3.5 million, appear extremely low. As a comparison, Table 4.2 presents the number of cases of health problems experienced by refugees in refugee camps set up following the 2010 eruption of Merapi volcano. This table is taken from a report on the environmental health impacts of the 2010 Merapi eruption, compiled by BBTKL-PPM (BBTKL-PPM 2011). These tables are not directly comparable, as the second table refers only to health problems experienced in refugee camps set up in the Sleman
Regency of Yogyakarta Special Region Province following the 2010 Merapi eruption. Health monitoring is relatively easy in such camps as refugees tend to seek medical assistance from established health services within. Monitoring is difficult outside camps, especially as people may not always seek health assistance from available health centres. Nonetheless the inclusion of the data for Merapi highlights the very low incidence of reported distal health impacts from the Kelud eruption.

**Table 4.2** A list of the 10 most common diseases affecting refugees from the 2010 Merapi eruption, in the Sleman Regency (BBTKL-PPM 2011).

<table>
<thead>
<tr>
<th>Disease</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper respiratory tract infection</td>
<td>9,419</td>
</tr>
<tr>
<td>Cepalgia (headache)</td>
<td>3,769</td>
</tr>
<tr>
<td>Common cold</td>
<td>3,710</td>
</tr>
<tr>
<td>Myalgia (muscle pain)</td>
<td>2,903</td>
</tr>
<tr>
<td>Primary hypertension</td>
<td>2,861</td>
</tr>
<tr>
<td>Acute pharyngitis</td>
<td>1,934</td>
</tr>
<tr>
<td>Allergic dermatitis</td>
<td>1,589</td>
</tr>
<tr>
<td>Dyspepsia</td>
<td>1,538</td>
</tr>
<tr>
<td>Cough</td>
<td>1,461</td>
</tr>
<tr>
<td>Eye irritation</td>
<td>1,413</td>
</tr>
</tbody>
</table>

**4.2 PUBLIC HEALTH ADVICE**

Public health advice was made available in Yogyakarta Special Region Province promptly following the arrival of ash in the area. As the ash fell, the relevant provincial government agencies, including the Health Agency of Yogyakarta Special Region Province, recommended that the Governor deliver emergency health advice. The Governor distributed such advice through various channels and key messages included:

- Stay indoors
- Avoid driving
- Protect water supplies (e.g. cover open wells)
- Wear protective clothing (masks, umbrellas, long clothing, glasses) if outdoors
- Children advised to wear masks indoors also.

Discussion with staff at the Health Agency of Yogyakarta Special Region Province suggested that they considered that the prompt provision of this advice, and that the general public appeared to heed it, were probably factors in the low occurrence of health problems following the eruption. As Nania and Bruya (1982) note, although accidents can be directly attributed to ash (particularly traffic accidents occurring in low-visibility conditions, and falls from roofs occurring during clean-up), the overall number of accidental injury cases following the 1980 eruption of Mt. St Helens was relatively low due to many people staying indoors.
4.2.1 Use of Protective Masks

During the Kelud eruption, approximately 500,000 masks were distributed in the Yogyakarta Special Region Province by community health centres (Puskesmas), health workers, PMI, BPBDs, the Health Agency, hospitals and NGOs. Disposable surgical masks (Figure 4.1) are officially recommended for the general population. They are considered cost-effective and popular. However, staff at the Health Agency of Yogyakarta Special Region Province reported that they did not know the effectiveness of these masks at removing airborne particles, and were also concerned about whether all surgical masks are manufactured to the same standard (Health Agency DIY 2014). High-efficiency masks were reportedly provided for BPBD DIY frontline response staff, but the interviewees were unsure of the specifications of these masks. In the event of mask supply shortages, the advice was to wrap a dampened cloth (such as a sarong or bandana) around the face, although this advice is not officially-sanctioned.

![Figure 4.1 Surgical masks distributed during the Kelud eruption. (a) Masks distributed by PMI. (b) Mask distributed by BPBDs (BPBD DIY 2014b).](image)

4.3 Air Quality

In the early hours of 14 February, BBTKL-PPM (as a first responder) sent a team out to conduct air quality testing. Testing was also conducted on 15 February, then on 17, 19, 21 and 24 February, after which time the key parameter measured (Total Suspended Particulate, TSP) was considered to have returned to baseline levels (Figure 4.2). Levels of the air quality parameters SO$_2$, NO$_x$ and ozone were also measured but were considered to be at normal levels. These data were supplied to the Health Agency of Yogyakarta Special Region Province and used as a basis for decisions such as school closures. It may be seen (Figure 4.2) that the eruption caused a spike in levels of total suspended particulates, particularly at sites in the Sleman and Bantul regencies. Levels returned to baseline levels after 3-4 days. Only a minor change was recorded at the Yogyakarta site.

For the Merapi 2010 eruption, extensive environmental monitoring was undertaken, particularly in relation to identifying health risks in refugee camps. The impacts of the Kelud eruption on the Yogyakarta Special Region Province were comparatively low, thus extensive environmental monitoring was not considered warranted (BBTKL-PPM 2014).
4.4 **IMPACTS ON HEALTHCARE SYSTEM**

In Yogyakarta, the eruption reportedly caused no particular problems for the functioning of healthcare systems, and no problems were reported for ambulance access. The Governor directed hospitals (and other public facilities) to clean up their own premises (see section 6.2.1).
## 5.0 IMPACTS ON INFRASTRUCTURE AND UTILITIES

### 5.1 SUMMARY OF IMPACTS

This section presents a summary of impacts from the Kelud 2014 eruption. Each infrastructural sector is examined in turn and the impacts in proximal (~30 km from the vent) and distal locations (with a strong emphasis on Yogyakarta) are distinguished where possible. Table 5.1 summarises the key impacts and associated hazard type which have been identified for each sector.

### Table 5.1 Key impacts from the Kelud 2014 eruption and hazards for each infrastructural sector.

<table>
<thead>
<tr>
<th>Infrastructure Sector</th>
<th>Impact Type</th>
<th>Responsible hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport - Aviation</td>
<td>Engine damage (aircraft entered ash cloud)</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Passenger airport closures (7 total, 4 international)</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Military air base closures</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td>Transport - Roads</td>
<td>Proximal road destruction</td>
<td>Tephra (blocks), PDCs, landslides</td>
</tr>
<tr>
<td></td>
<td>Road damage (attribution and source)</td>
<td>Tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Bridge destruction</td>
<td>Lahars</td>
</tr>
<tr>
<td></td>
<td>Bridge closure</td>
<td>Lahars</td>
</tr>
<tr>
<td></td>
<td>Bridge support damage (accord)</td>
<td>Lahars</td>
</tr>
<tr>
<td></td>
<td>Driving difficulties (low visibility, slippery surfaces)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>Increased accident rate despite less vehicles</td>
<td>Tephra (ash &amp; lapilli), water (rainfall &amp; clean-up)</td>
</tr>
<tr>
<td></td>
<td>Solar traffic light failure (panels covered)</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Braking problems (brake disks scratched)</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Engine air intake filters clogged</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Tether pressure issues</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Vehicle air conditioning filters clogged</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td>Transport - Rail</td>
<td>No reported negative impacts (increased services)</td>
<td>N/A</td>
</tr>
<tr>
<td>Transport - Ports</td>
<td>No reported negative impacts</td>
<td>N/A</td>
</tr>
<tr>
<td>Buildings</td>
<td>Building destruction</td>
<td>Lahars, tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Roof damage (tile, corrugated iron &amp; asbestos sheets)</td>
<td>Tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Roof damage (support structure)</td>
<td>Tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>HVAC contents damage</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>Window and door damage</td>
<td>Tephra (blocks)</td>
</tr>
<tr>
<td></td>
<td>Potential rotting (corrugated iron roof)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td>Electricity</td>
<td>Proximal distribution network destruction</td>
<td>Tephra (lapilli &amp; blocks), PDCs, landslides, lahars</td>
</tr>
<tr>
<td></td>
<td>Proximal power failure (up to one month)</td>
<td>Tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Hydro-electric operations disrupted (reservoir sedimentation)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>Distal power failure (localised, temporary)</td>
<td>Tephra (ash), water (rainfall)</td>
</tr>
<tr>
<td>Water supply</td>
<td>Proximal pipes broken and damaged</td>
<td>Tephra (lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Proximal water contamination</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td></td>
<td>Proximal water intake reduced (reservoir sedimentation)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>Increased turbidity in distal areas (unconvened units)</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td>Wastewater and Stormwater</td>
<td>Proximal open roadside drains blocked (flooding)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>No reported negative impacts in distal areas</td>
<td>N/A</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>Proximal television satellite dish damage (mesh type)</td>
<td>Tephra (ash, lapilli &amp; blocks)</td>
</tr>
<tr>
<td></td>
<td>Potential rotting of television satellite dishes (metal type)</td>
<td>Tephra (ash &amp; lapilli)</td>
</tr>
<tr>
<td></td>
<td>Minor distal communication problems</td>
<td>Tephra (ash)</td>
</tr>
<tr>
<td>Oil and Gas</td>
<td>No reported negative impacts</td>
<td>N/A</td>
</tr>
</tbody>
</table>
5.2 TRANSPORT

Transportation networks are frequently impacted following volcanic eruptions, sometimes in both proximal and distal locations from the vent (e.g. Mt. St Helens 1980 (Blong 1984), Hudson 1991 (Wilson et al. 2009), Chaitén 2008 (Wilson et al. 2012)). The February 2014 Kelud eruption was no exception and there were effects on all transportation modes to some degree on the flanks of Kelud and in distal cities over 200 km away. In this subsection, after a brief summary of Javanese transportation networks, we outline the major impacts on each major transportation mode in turn.

The road, rail and domestic airline network (Figure 5.1) are used extensively throughout Java, with key shipping ports for connections to other Indonesian islands located mainly on the northern coast.

![Figure 5.1 Major transportation routes of Java (Mau Ke Mana 2014).](image)

A wide variety of vehicles are used for road transport. Buses operate within and between the larger cities with minibuses servicing many of the smaller towns. Motorbikes are by far the most popular vehicle in Java (71% of motor vehicles in 2003 (World Bank 2013)) with many adapted to transport a variety of goods in addition to passengers (Figure 5.2). Taxis and cycle rickshaws, called becak are common in most cities. Private cars are becoming more popular, especially with the increasing purchasing power of Indonesians and liberalisation of import motor vehicle rules. However, vehicle growth outpaces the construction of new roads and congestion is common, particularly on the major roads through cities (World Bank 2013).

There are two major rail lines running the length of the island in addition to several minor lines. Air transport serves as an important way to connect the thousands of Indonesian islands and cities with passenger and flight numbers having increased drastically over the past two decades (Picquout et al. 2013), particularly since the advent of low-cost flights.

All transport modes in Java were affected by the Kelud eruption to some extent. The estimated cost of damage and losses associated with transportation in the Blitar Regency alone was Rp 76,500,000 (~NZ$ 1,597,000) (BPBD Blitar Regency 2014b). However, this only represents a small percentage of the overall loss, particularly as no
major airports operate within this regency and ash thickness in this regency was relatively low, particularly compared to parts of the Malang Regency.

![Figure 5.2](image_url)

**Figure 5.2** Motorbikes in Java. (a) Motorbike adapted for transporting poultry. (b) Motorbikes and other traffic waiting at a railway crossing in Yogyakarta.

### 5.2.1 Aviation

The Volcanic Ash Advisory Centre (VAAC) in Darwin, Australia issued a series of advisories in response to the Kelud eruption, some key points of which are summarised below:

- The initial volcanic ash advisory (IDD41295) (VAAC 2014) was issued at 17:21 UTC, 13 February 2014 (00:21, 14 February 2014 Indonesia Western Time / WIB). This summarised that a high level eruption with aviation colour code red had occurred.
- The next advisory was issued around half an hour later and estimated that the plume had risen to Flight Level 450 (45,000 feet / 13.7 km nominal altitude) and extended 50 nautical miles (93 km) to the west of the crater at 16:32 UTC, 13 Feb (23:32 WIB, 14 Feb). This was based on the hourly temperature from the MTSAT-2 IR satellite and the Surabaya 12:00 UTC atmospheric profile (BOM 2014, GVP 2014d).
- By 20:32 UTC, 13 Feb (03:32 WIB, 14 Feb), this plume had extended 240 nautical miles (444 km) west of the crater and details emerged relating to the plume also spreading at Flight Level 200 (20,000 feet / 6.1 km nominal altitude) and extending 80 nautical miles (148 km) to the north east (VAAC 2014).
- The upper plume had reached Flight Level 650 (65,000 feet / 19.8 km nominal altitude) to the west at 16:32 UTC (23:32 WIB), 14 Feb (VAAC 2014).

Shortly before 05:00 local time (WIB) on 14 February 2014, a Jetstar Airbus A320 aircraft carrying passengers from Perth, Australia to Jakarta, Indonesia entered the Kelud volcanic ash cloud. It was reported that the flight crew suddenly heard unusual faint noises with the captain observing green sparks outside the cockpit about 30

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3 Post-event analysis by Darwin VAAC indicated that the ash in fact reached a maximum height of 85,000 feet / 25.9 km (BOM 2014).
seconds later. A faint sulphuric smell and light haze also began forming in the flight deck (Foo & Tan 2014). The flight crew donned oxygen masks and changed direction after diagnosing that the plane had probably flown through volcanic ash (Foo & Tan 2014). They landed safely at Jakarta at 05:50. Reports soon after estimated that the cost of replacing the two damaged engines could be ~US$ 20 million (~NZ$ 25.8 million) (Thomas 2014). At the time of writing, the circumstances surrounding this incident were still under investigation and no International Civil Aviation Organisation incident report (ICAO ANNEX 13) was available (Goodwin (pers comm, 2014), EASA 2014).

As ash began to blanket parts of Central and East Java provinces, operations at seven airports (four international in Yogyakarta, Surakarta, Surabaya and Semarang, and three domestic in Bandung, Malang and Cilacap) were disrupted by closures which were ordered by the Department of Transportation (Figure 5.3) (BPBD DIY 2014b). Military air bases at some of the above airports and at Iswahyudi airfield in the Madiun Regency were also closed. It appears that these closures were ordered in response to the ashfall itself as few warnings prior to this were received in the distal areas from Kelud. Cancellations and delays affected many airlines in Indonesia and further afield including Australia (Australian 2014, Gough 2014). There were many impacts considered at airports including concerns of reduced traction for aircraft landing, damage to aircraft engines and reduced visibility (Australian 2014, DJPD & DJPL, Gough 2014, Sunstar 2014), all of which are common volcanic hazard impact types (Guffanti et al. 2009). Clean air announcements from Darwin VAAC were required before airports could reopen (DJPU 2014) but there were also many issues associated with ash on the ground. Four airports (those at Surabaya, Malang, Semarang and Cilacap) resumed normal operation late on Saturday 15 February (3News 2014) (~2 days after the eruption started) (Figure 5.3). Estimated losses at the airport in Surabaya alone were said to have totalled around Rp 3 billion (~ NZ$ 315,000) (Boediwardhana & Harsaputra 2014). Flights at Bandung resumed on Sunday 16 February (Gough 2014) (~3 days after the eruption started) and the international airports in Yogyakarta and Surakarta reopened on Wednesday 19 February (~6 days after) (BPBD DIY 2014a, DJPU 2014, KVO 2014) and Thursday 20 February (~7 days after) respectively (Figure 5.3) (Muryanto & Susanto 2014). As operations re-commenced at some of the affected airports, there were still some ongoing issues due to the challenges of scheduling and plane supply with other airports still closed (DJPU 2014).
5.2.1.1 Adisucipto International Airport (AIA), Yogyakarta

It was estimated that 20-50 mm of ash fell at AIA following the eruption of Kelud (DJPU 2014, Jakarta Post 2014b). As the ash started falling at ~03:00 WIB and the normal opening time of the airport is at 04:00 WIB, the decision was made to not open AIA to passengers at all on 14 February. People arriving at the airport were told that it was closed which led to traffic congestion in the area (DJPU 2014). The airport is used for both civilian and military purposes with a taxiway for each. Military planes are kept in hangers and did not come into contact with ash. At least two commercial planes however, were outside for the night of the 13 February (Figure 5.4) and ash infiltrated into the engines of the stationary planes despite being covered by plastic sheeting at some stage. Subsequently, the engines required dismantling, deep-cleaning and complete oil changes – a very expensive process which required specialist technicians (DJPU 2014). The Directorate General of Civil Aviation reported that there were no indications of any damage to paintwork on the two stranded planes or to airport line markings resulting from the ash.
The closure of AIA following the Merapi 2010 eruption was largely due to airborne ash and there was little accumulation at the airport as occurred in February 2014 from the Kelud eruption (DJPU 2014). The finer grained ash from Kelud at Yogyakarta meant that the ash was readily remobilised by wind and efforts to reopen the airport were hampered by this (see section 6.2.5). Over the course of AIA’s closure in February 2014 (based on the loss of five average operating days (DJPU 2014)) it is estimated that as many as 600 domestic, 750 military (including training flights) and 20 international flights were cancelled. The transportation of cargo was also affected as this is normally carried on the above flights.

5.2.2 Roads

5.2.2.1 Proximal
Severe impacts occurred to ~3 km of asphalt concrete road (within ~2 km radius of the vent) immediately following the eruption, particularly from ballistics, PDCs and landslides (Figure 3.3, Figure 5.5a-e). The largest ballistic impact crater on roads visible in this region was around 3.6 m in diameter (Figure 5.5a) and some ballistics completely penetrated bridges with subsequent holes to the ground below up to 1.1 m in diameter (Figure 5.5b). Around 1 km of road was completely destroyed by these volcanic hazards with the remainder buried by tephra to a depth of ~1 m in places. At the time of observation, 7 months after the eruption, these sections of road remain closed to everyday traffic and repair work had not commenced, presumably in part due to the continued instability of the land. Some asphalt concrete road surfaces within ~10 km of the crater (particularly to the north east) were damaged by vehicles driving over the roads that were covered in lapilli and ash (Munjang 2014a). This is perhaps due to an increased attrition rate caused by the direct impact of tephra on asphalt concrete and subsequent layer remaining on the road surface, which could lead to increased fluvial erosion and pothole formation.
Figure 5.5  Road and bridge impacts within ~2 km of the crater (taken 20 September 2014). (a) large ballistic impact crater in asphalt concrete road surface (3.6 m along the longest axis). (b) holes in asphalt concrete and reinforced concrete bridge (now covered in wood) after being penetrated by ballistics. (c) ballistics embedded within bridge surface and damage to edge of bridge. (d) Bridge structure and railing damage. (e) remaining section of the road near the crater, now cleared of ash.

Around 9 km NE of the Kelud crater, at least two bridges crossing the Sambong River were destroyed by a lahar. This lahar may have occurred as soon as 18 February 2014 (BNPB 2014b) four days after the eruption, immediately forcing the closure of some roads (Pitaloka 2014a). The bridge to the north east of Munjang Hamlet, which was frequently used by its residents and also used in the evacuation, was ~2-3 m long and was of standard concrete and metal construction with an asphalt concrete deck. Seven months after the eruption, this had yet to be rebuilt and vehicles were driving on the river bed to cross the river here (Figure 5.6). The bridge, of similar construction style,
adjacent to Klangon Village was ~35 m long (Selorejo 2014b). Within ~2 weeks of being destroyed by a lahar, it was replaced by a small bamboo bridge (Figure 5.7a) allowing residents to cross the river either by foot or motorbike. This was subsequently replaced by a more substantial bridge on loan from the Indonesian Army (Figure 5.7b) which took 6-7 months to install, enabling easy access for all vehicles to Klangon. This larger bridge will be replaced with a new permanent bridge when the government have funds (Klangon 2014).

Figure 5.6 Kostrad TNI-AD (the Strategic Reserve Command of the Indonesian Army) help vehicles cross the Sambong River at site of old bridge between Munjang Hamlet and Selorejo Dam on Wednesday 19 February 2014 following a lahar (Haryanti 2014a). The bridge at this site had yet to be rebuilt as of 21 September 2014.

Figure 5.7 Sambong River crossing near Klangon Hamlet, Pandansari Village. (a) Temporary bamboo bridge over the Sambong River built ~2 weeks after the lahar and improving access for pedestrians and motorbikes to Klangon Hamlet (Adonai 2014). (b) Larger temporary army-bridge built nearby ~6-7 months after the lahar (photo taken on 21 September 2014). A new permanent bridge will be built when funds permit.

The Sambong River (Figure 1.3) is a tributary of the larger Konto River which was also affected by at least one lahar. On the western side of Kandangan (~20 km north of the crater), the lahar was said to arrive very slowly and rose gradually until the surface came to ~0.5 m of the road deck (Konto 2014) on the major bridge carrying the main road between Pare and Kandangan (Figure 5.8a). A road-side warung and many houses lie just above the level of this bridge close to the river banks. It is unclear when this lahar
arrived but according to warung owners nearby, the bridge was closed by police for 2 hours (18:00-20:00) on Friday 14 February due to the possibility of structural damage. In fact, there was little damage to this bridge apart from scour damage to the upstream side of the central support at the base (Figure 5.8b) and some subsidence and erosion of the surrounding stone and concrete river bank structures, although it cannot be confirmed that these were a result of lahars alone.

Figure 5.8  Road bridge over Konto River between Pare and Kanndangan. (a) Reports suggest that the surface of the lahar came within 0.5 m of the road deck. (b) Some scouring was evident on the up-stream side of the central concrete support pillar, possibly from debris entrained in lahars.

Some residents, particularly in the Pandansari area to the north east of the crater evacuated as ash was falling and they experienced very low visibility (with a visual range of just a few meters (Gough 2014)) which made driving difficult. There were no reports of direct impacts to vehicles on the flanks of Kelud because most were either taken during evacuations or stored under shelters before the tephra fall arrived, as occurred in Kalikuning (Kalikuning 2014). Some areas, such as the road to the west of the Kelud Volcano Observatory were mainly affected by light pumice, which was not dense enough to cause any substantial vehicle damage (Luwakmas Café 2014). When returning to areas affected by ash fall around Kelud volcano, tephra had accumulated to depths of around 50-500 mm at 5-35 km from the crater across the north east to north west segment of the flanks (KVO 2014). Although traffic was reported to be light in some areas such as Kediri City (Irvine-Brown 2014), there were several accidents due to slippery roads in proximal areas, particularly involving residents on motorbikes which had increased stopping distances and skidded into one another (KVO 2014). In some instances, including in Selorejo, this resulted in personal injury. It was reported that most vehicle accidents occurred between residents on the first day of return, although this cannot be backed-up with accident data. The visual range in Kediri upon return may have been around 1 km (Baku-APA 2014), adding to the driving difficulties. There were no reports of engine or other mechanical damage to vehicles in this area, perhaps due to the grain size of ash being relatively large.

5.2.2.2 Distal
In Yogyakarta, the government advised people to stay off roads and to only drive or go outside when absolutely necessary and to turn their lights on if they had to drive (BPBD DIY 2014a, Mahjum (pers comm, 2014)). Most people obeyed this advice and many
were reluctant to drive in their vehicles anyway because of concerns about vehicle
damage including scratched windows and engine problems, difficulties driving in ash and
impacts on breathing and health (DJPD & DJPL 2014). Some cars were covered in
plastic sheeting as a protective measure (Figure 5.9) (BPBD DIY 2014b). As a result, the
roads in Yogyakarta were relatively quiet for up to a week after the eruption (DJPD &
DJPL 2014, Irvine-Brown 2014, Mahjum (pers comm, 2014)), although police were out
helping to manage traffic flow (BPBD DIY 2014a). Visibility in Yogyakarta was reduced
to a visual range of just 1-3 m at times (BPBD DIY 2014a, BPBD DIY 2014b, DJPD &
DJPL 2014). This was largely due to remobilisation from vehicles and worsened in areas
where ash was thicker, making it difficult to drive (Figure 5.10) (DJPD & DJPL 2014).
Outside of the city, visibility was also very low with a visual range of ~7 m near
Borobudur Temple reported (Antara News 2014a).

Another complication was from ash covering the solar panels of traffic lights. These solar
panels (Figure 5.11) are used to power the traffic lights and are near horizontal in the
tropics so collect ash easily. When covered, the batteries only last for ~1.5 days before
needing to be recharged (DJPD & DJPL 2014). The Directorate General of Land
Transportation took two key mitigative measures to prevent traffic lights from failing:

1. Near-discharged batteries were replaced with recharged ones
2. Solar panels were cleaned every day for ~5 days to prevent ash accumulation.
This prevented further traffic congestion at intersections. Visibility of functional traffic lights was not affected as the cover over each light prevented ash accumulation in front of the lights, stopping them from being obscured. There is no evidence that ash stuck and obscured road signs.

Despite lower traffic volumes and many people driving more slowly than usual within the city (DJPD & DJPL 2014), there were several traffic accidents, often from motorbikes skidding and colliding on the slippery roads (BPBD DIY 2014a, Mahjum (pers comm, 2014)). This appears to have been due to increased stopping distances rather than sliding on corners, and the failure to see the brake lights of motorbikes through the suspended ash (DJPD & DJPL 2014). The Directorate General of Land Transportation reported that some cars experienced braking problems due to brake disks becoming scratched. According to hospital figures that were retrieved from the Health Agency of Yogyakarta Special Region Province, there were at least 50 injuries as a result of ‘accidents’ (likely traffic-related) in Yogyakarta Special Region Province within one month of the eruption (see Table 4.1) (Health Agency DIY 2014). It was also reported that there were at least 12 injuries within 2 days of the eruption at Panembahan Senopati hospital in Bantul, in the south of Yogyakarta (Susanto 2014).

Water was used to clean vehicle windows rather than wipers as previous experience suggested that the use of wipers can result in scratched windows (DJPD & DJPL 2014). Such measures are also implemented at the sand mines on the flanks of Merapi volcano where truck drivers lift their wipers from the window before their trucks are loaded with tephra material (Figure 5.12). The windows are then cleaned with water and wipers put back into position before the trucks drive off. Following the Kelud ashfall, water was sourced largely from existing stocks of bottled water and from irrigation channels using buckets. Many people took a collaborative approach, cleaning their vehicles at the same time and helping one another. Discussions with the Directorate General of Land Transportation indicated that the cleaning of vehicles and related increase of water on roads may have led to a ‘sludge’ of ash forming on some road sections resulting in further nose-to-tail motorbike collisions. However, people reacted to this and cleaned roads of wet ash.

Figure 5.11   Traffic lights and solar panels in Yogyakarta. These panels (which are near horizontal in the tropics) were covered in ash resulting in batteries discharging.
There was rainfall in Yogyakarta within three days of the eruption but this was not enough to wash ash from roads and may have made surfaces more slippery (BPBD DIY 2014a). After one week, there was heavy rainfall in Yogyakarta and there were fewer accidents following this. In the weeks following the eruption, engine air filters became clogged and required cleaning or changing (DJPD & DJPL 2014).

5.2.2.3 Public bus operations – The Trans Jogja Bus Company

Trans Jogja Bus Company is a rapid bus transit system, operated by PT Jogja Tugu Trans within Yogyakarta using a fleet of 74 buses (Figure 5.13). School students and office workers are among the frequent users of the service. Typically, buses start operating at 05:00 each day. However, on the night of the eruption two buses were still out and were refueling when ashfall arrived. The remainder were in depots in the city but were not covered (PT-JTT 2014).

The decision was made not to operate in the ashy environment and the two buses that were out were called back to the depot. The decision to stop bus operations was based on concerns about “the sharp nature of volcanic ash compared to usual road dirt” and previous experience that the Chairman had gained working for the National Bus Company during the Merapi (2010) eruption (PT-JTT 2014). No Trans Jogja buses
operated for four days after the Kelud eruption. The two buses that drove back to the depot experienced engine and turbo-pressure issues around two months later which the staff attributed to driving through the ashfall.

From days 4 to 10 following the eruption, only 50% of buses operated at one time with the other 50% being cleaned and serviced by technicians and equipment supplied by PT Jogja Tugu Trans. There was also a corresponding ~50% loss of income for the company during this time. There was ~30-40 mm of ash at the sides of the roads at the start of this operational period and bus drivers travelled nearer the middle of the roads where possible to avoid thicker ash. Some bus drivers wore masks due to health concerns. There were reportedly no major problems related to reduced traction, window abrasion or route diversions during this time (PT-JTT 2014).

A total of 20 technicians were employed (10 from within and 10 from outside the company) with each technician responsible for three buses. Labour was relatively cheap (~Rp 50,000 (~NZ$ 5.20) per technician per day) as the staff understood it was an emergency and only required enough money to get by (PT-JTT 2014). It took around one hour to clean three buses when they returned to the depot. As part of the regular servicing, windows were washed and air filters (both engine and air conditioning) were cleaned with compressed air. Some air filters were replaced because they were blocked. Air conditioning filters needed particular attention as the units are located on the top of buses and therefore susceptible to ash. Vacuums (rented from Tourism Transport) were used to remove ash from the bottom of engine bays and radiator systems where it was prone to accumulation. Brakes were also vacuumed via a hole in the system due to concerns about ash sticking to brake components where it could then thicken and solidify (PT-JTT 2014).

Bus operations returned to normal ~10 days after the eruption following the heavy rain in Yogyakarta. However, in the months following the eruption, maintenance of buses by Trans Jogja was increased to once per two months (usually once per four months).

There were indications that national bus services were also disrupted by ashfall for a time with only the routes to East Java from Yogyakarta operating on the first day after the eruption (BPBD DIY 2014b)

5.2.3 Rail

Diesel trains run on all areas of the rail network that were impacted by ash from Kelud (the only electric trains in Java are found in Jakarta) (DJPD & DJPL 2014). Although there was evidence of rail tracks becoming thinly covered in ash from the Kelud eruption (Figure 5.14), there were no reports of rail services being delayed or cancelled specifically due to ash impacts. This is difficult to monitor in Java as delays and cancellations are relatively frequent, especially to the economy class services. However, rail appears to have been the least affected transportation mode with BPBD DIY staff claiming that it was “the only transportation sector able to penetrate volcanic ash disruption”.
After interviewing the Directorate General of Land Transportation, it appears that the serviceability on the rail network actually increased at times with extra trains running and some trains lengthened with extra cars in certain areas including Yogyakarta Special Region Province. This was a result of higher demand caused by cancelled flights and buses and trains were full with passengers despite the increased capacity (DJPD & DJPL 2014). A similar approach was taken during the Merapi (2010) eruption where train numbers on certain routes were increased and all trains were lengthened by two cars, although this was in anticipation of an exodus of people living on the slopes and in Yogyakarta (Picquout et al. 2013). Some train cars are air conditioned but there were no reported problems to these systems due to ash from the Kelud eruption.

The apparent resilient nature of the diesel rail system to ashfall coincides with the lack of reported impacts on similar networks worldwide following other eruptions, with the key exception of the 1980 Mt. St Helens event (Blong 1984). This contrasts with electric rail systems which appear more vulnerable to small ash accumulations (e.g. following the Shinmoedake 2011 eruption and Sakurajima eruptions in Japan in recent years (Magill et al. 2013)).

5.2.4 Ports

There were no major shipping ports that were impacted by heavy ash fall from the Kelud eruption, with the nearest (Tanjung Perak, Surabaya) located over 90 km to the north east. However, there are plans for a new port on the south Java coast near Yogyakarta (Daniswara (pers comm, 2014)) which, given the same wind directions as those on 13-14 February 2014 could be exposed to future ash fall.
5.3 BUILDINGS

5.3.1 Indonesian Building Typology

We have identified three key building typologies following the post-eruption field visits to the three regencies proximal to Kelud in September 2014, some of which are comparable to those observed in the Merapi area following the 2010 Merapi eruption (Jenkins et al. 2013):

1. Timber frame with timber weave infill panels, often supported by masonry block walls beneath; timber or bamboo roof supports covered by terracotta clay tiles (Figure 5.15a).
2. Block masonry walls (often rendered) within a reinforced concrete frame; timber or bamboo roof supports covered by terracotta clay tiles (Figure 5.15b) or sheet roofing.
3. Clay brick walls known as *batu batu* (sometimes rendered); timber or bamboo roof supports covered by terracotta clay tiles (Figure 5.15c).

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![Building typologies examples](5.15a)
**Figure 5.15** Examples of predominant building typologies in the Kelud proximal area:
(a) Building type 1: Timber frame with timber weave infill panels supported by masonry block walls below; timber roof supports covered by terracotta clay tiles (photo taken in Karanganyar Hamlet, Blitar Regency);
(b) Building type 2: Block masonry walls (rendered at front) within a reinforced concrete frame; timber roof supports covered by terracotta clay tiles (photo taken in Munjang Hamlet, Malang Regency);
(c) Building type 3: Clay brick walls; timber roof supports covered by terracotta clay tiles (photo taken in Munjang Hamlet, Malang Regency).

The majority of buildings have tiled roofs. Whether a roof will fail under ash loading or not depends upon, amongst other things, the roof pitch and spacing of supports, as well as the ash characteristics (e.g. density and moisture content). Tiles are supported by timber or bamboo rafters that run perpendicular to the walls, and the spacing between rafters is variable but generally between 150 and 300 mm. Underlying purlins are spaced 500 to 1000 mm apart, depending on the pitch and width of the roof, with tiles then directly supported by cut timber or bamboo horizontal battens that rest on the rafters,
spaced approximately 100 to 150 mm apart (Figure 5.16). Roof tiles in Indonesia commonly are not attached to the underlying roof supports, but rest on top (Figure 5.17a), which may allow for slipping of tiles down the roof under any increased load (see section 5.3.3.2 and Figure 5.18b). For flared or hip roofs (Figure 5.15a, Figure 5.17b), the two different pitches of the roof make the overhangs significantly more vulnerable to damage through overloading than the central steeper part of the roof.

Figure 5.16  The underside of a timber supported roof: sometimes plastic is placed underneath the tiles to prevent leaks and in this case is badly damaged. Labels refer to the support types referred to in the text.

Other less common building typologies exist including those with rubble stone masonry walls, some with timber cladding / weatherboard exteriors and some with a combination of different material types already discussed. Asbestos and metal sheet roofs are less common than the typologies discussed above for residential houses. However, this is a popular form of construction for warungs and livestock shelters. Asbestos sheets are supported only by rafters and purlins as battens are not required (as there are no tiles to hold in place). The spacing is often much wider than for tiles because the roof covering is lighter. Such roof coverings are more economic than tiles but do not support...
ventilation as well as tiles and typically have a low thermal capacity, offering little respite from heat.

Many homes in cities such as Kediri, Blitar and Yogyakarta have air conditioning (AC); however, most homes in more rural areas do not have AC. Many homes within the proximal areas to Kelud have ventilation holes or grills within the walls and large gaps between the wall top and roof supports to allow free ventilation into the building. To support ventilation within the building, internal walls do not always extend to the roof.

### 5.3.2 Extent of Impacts

The majority of building damage occurred in the proximal hamlets, particularly where ballistics and heavy tephra fall occurred. Buildings in parts of the Kediri, Malang and Blitar regencies sustained damage during the eruption with the majority of the damage occurring on the north east side of Kelud. Hamlets within 7 km of the vent in these regencies received 100-500 mm of ash and ballistics up to 80 mm in diameter (see Figure 3.3). The PMI estimated that 26,507 residential buildings were damaged, of which 11,093 were considered totally damaged (IFRC 2014). The majority of damaged properties were located in the Kediri Regency (BNPB 2014c) (Table 5.2). A number of government offices, educational facilities, health facilities and places of worship were also damaged to varying degrees (BNPB 2014a). A lahar travelled down the Sambong River, most likely following the heavy rain from 18 February 2014 onwards, washed away two road bridges and two houses near Klangon Hamlet and left only the concrete foundations behind. Lahars also occurred in the Konto River and inundated five houses and one mosque in Kandangan (~20 km downstream from the Kelud vent) (BNPB 2014b).

### Table 5.2 Damage to buildings from ash in the three proximal regencies to Kelud as at 03 March 2014 (IFRC 2014). Note that it is not clear what each of the PMI damage categories refers to.

<table>
<thead>
<tr>
<th>Regency</th>
<th>Totally damaged</th>
<th>Moderately damaged</th>
<th>Minor damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kediri</td>
<td>8,622</td>
<td>5,426</td>
<td>5,088</td>
</tr>
<tr>
<td>Malang</td>
<td>1,514</td>
<td>1,066</td>
<td>1,378</td>
</tr>
<tr>
<td>Blitar</td>
<td>957</td>
<td>878</td>
<td>1,578</td>
</tr>
<tr>
<td>Total</td>
<td>11,093</td>
<td>7,370</td>
<td>8,044</td>
</tr>
</tbody>
</table>

At the time of our visit on 21 September 2014 the majority of houses in Munjang, Klangon, Kalikuning, Kalibladak and Karanganyar hamlets already had their roofs repaired and there was limited damage to observe (Figure 5.18c, see Figure 8.3b). In fact on 09 March 2014, less than 1 month after the eruption, the East Java Governor reported in the Jakarta Post that 99% of houses in the three regencies had already been fixed at a total cost of Rp 55 billion (~NZ$ 5.7 million) (Jakarta Post 2014d). The rebuild effort was supported by 6,000 personnel from the military and police.

### 5.3.3 Type of Impacts

By combining media images, field observations and discussions with residents we were able to infer the type and severity of damage.
5.3.3.1 Structural damage
In Munjang Hamlet, Pandansari Village, at least one wooden house and an adjacent cattle stall were completely burnt and destroyed by several hot ballistics (Munjang 2014d). Windows and doors facing the volcano were also damaged in some cases due to ballistic impacts, while those facing away remained undamaged (Munjang 2014a). This was the only burnt building we are aware of. In most instances the underlying roof support structure remained, although damage to these structures was observable in some media images (e.g. Figure 5.18b). Field observations suggested that roof damage was not preferentially orientated with all sides damaged in some cases.

5.3.3.2 Non-structural damage
The most common form of damage was broken roof tiles (Figure 5.18a, 5.18b) and corrugated asbestos sheets as a result of ash loading and/or ballistic impact. Tiles were either completely broken or had their corners broken off (Figure 5.19a) and asbestos sheets either had holes punctured in them (Figure 5.19b) or were broken into many pieces beyond repair and disposed of (Figure 5.19c). Houses in the Ngantang and Puncu districts had an estimated 60-90% of their roof tiles damaged (KVO 2014, JOAC 2014) with BNPB estimating that 2,000-3,000 new tiles were needed to repair the roof for each house (BNPB 2014c). Figure 5.18b suggests that some tiles slid from roofs because of their increased load, rather than collapsing through the roof supports into the building below. Roof damage meant that ash and roof materials were able to enter houses and cause damage to furniture which either had to be replaced or cleaned (see section 6.1).

In Munjang Village, the co-operative milk collection and distribution building showed evidence of roof damage from ash loading. This building is of masonry block construction with a corrugated iron sheet roof supported by cut timber supports. This is one of the few buildings in the village with an iron sheet roof. On the east side of the building the iron sheets overhang the building by 1 m and are supported by wooden brackets (Figure 5.20a). At the time of our visit, 10 roof sheets were bent downwards at the point where they overhung the building’s exterior wall (Figure 5.20b). Local residents had possibly salvaged the wooden supports as they were no longer attached to the wall and could not be seen on the ground below. The remaining nine sheets on the roof were partially bent and warped. It appears that the damage was caused by increased ash loading as there was still ~100 mm thick cemented ash and lapilli in places on the roof. There appeared to be no ballistic impacts on the roof. The iron was also corroded with visible rusting although we could not verify if this has occurred pre or post eruption.
Figure 5.18  Munjang Hamlet, Pandansari Village in Ngantang District, Malang Regency looking north east towards Lake Selorejo on (a) 18 February 2014 (Karmini 2014), (b) 22 February 2014 (iMKIRAN 2014), and (c) 21 September 2014. Kelud is 7 km behind where the photos are taken from. The red arrow shows the same point in all three photos.

Figure 5.19  Damage to asbestos and tile roofing in the proximal areas. (a) The corners of terracotta clay tiles were often broken, and (b) asbestos sheets were penetrated by ballistics in some instances. Some roofs were damaged beyond repair and damaged asbestos sheets were removed and replaced with new sheets. (c) Many broken sheets were seen dumped near houses during the field visit in September 2014.
Figure 5.20  Ash loading damaged part of the corrugated iron roof on the milk collection building in Munjang Hamlet. (a) One of three remaining wooden support brackets supporting the roof eaves. Three brackets under the damaged part of the roof were missing. (b) The overhanging section of 10 iron sheets that were bent downwards, likely as a result of increased ash load. Inset shows a close up of the bend in the iron sheets on top of the exterior wall.

5.3.3.3 Services
In Yogyakarta, where most homes have combined or split system AC, some units required cleaning or a quick service after the ash fall contaminated the filters, however no damage was reported. Although AC is less common closer to Kelud, there was evidence of preventative measures being taken to minimise the likelihood of damage in proximal areas. At one location we visited in the Ngancar district, staff covered exterior AC units with plastic and other building ventilation holes before the eruption. This was undertaken in response to the volcano alert level being raised during the previous week and was considered effective as a mitigation measure (Luwakmas Café 2014).

5.3.4 Building Rehabilitation

Clean-up of damaged residential buildings in the weeks to months following the eruption was mostly carried out by the home-owners themselves. As a first step, residents removed ash, tiles and asbestos sheets from roofs before discarding the broken material. Tarpaulins, which were donated by the Indonesian Government and PMI or purchased by residents, were then used to cover roofs and keep rain out until repairs could be completed (Figure 5.18b). In some cases there were not enough tarpaulins and residents had to quickly improvise with other materials as some rain fell on most afternoons in the days following the eruption (Sudiono & Rahmadi 2014, World Weather Online 2014).

In Munjang Hamlet the residents received new tiles from the government and military personnel to assist in replacing damaged tiles, although in some cases residents had to purchase the new tiles themselves. The new tiles (12 mm thick), which were sourced from Surabaya, are thinner than the old tiles (15 mm thick), potentially increasing the vulnerability of buildings to future ash and ballistic impacts. Undamaged tiles were reused and in order to reduce costs it is common in Java for people to replace damaged tiles with undamaged tiles from lower down on the roof (i.e. from the eaves).
Corrugated asbestos roof sheets were replaced with new sheets in most cases. At *warungs* in Selorejo Hamlet (north of the Selorejo reservoir) asbestos roofs were broken after rain on top of the ash caused increased loading and collapse. The owners of one *warung* (Figure 5.21) took out a loan to replace the roof by themselves at a total cost of ~Rp 3.5 million (~ND$ 360) (65 sheets at Rp 55,000 each) (Selorejo 2014a). In some cases, damaged sheets were able to be re-used in animal sheds, sometimes under new sheets or tiling (to stop leaks in poorly tiled roofs). For example, asbestos sheet roofing damaged by ballistics in Kalikuning had impact holes of more than 100 mm long but was later used in conjunction with newer sheeting on goat sheds elsewhere in the hamlet (Figure 5.22) (Kalikuning 2014). However, this method of roof waterproofing would increase the load on supports, perhaps making them more susceptible to collapse during future ash fall.

To conclude, there was widespread damage to tile and corrugated asbestos roofs in the proximal hamlets to Kelud as a result of ash loading and ballistic impacts. However, despite the damage, roofs could be quickly repaired with the help of the government, aid agencies and local residents. Further damage as a result of rainfall a week after the eruption was potentially minimised due to some residents returning to clean ash from their houses beforehand.
5.4 ELECTRICITY

Electricity in Indonesia is distributed by the government-owned corporation, State Electricity Company, PLN (Perusahaan Listrik Negara) using a high voltage (500-150 kV) transmission network and a low voltage (220 and 380 volts) distribution network. The majority of electricity in Java is generated at coal-fired power stations supplemented by geothermal and hydro-electric power stations. The reliability of electricity supply has improved in Indonesia in recent decades and the grid in Java is relatively well-developed compared to other islands. However, power outages are common nationally (Trading Economics 2009).

During other explosive eruptions worldwide, ash-induced insulator flashover has been a common problem on transmission networks, which is attributed to the high conductivity and low resistivity of volcanic ash, particularly when wet (Wardman et al. 2012).

5.4.1 Proximal

The majority of impacts to electricity supply in the proximal areas following the Kelud eruption appear to be due to impacts on the distribution network rather than any issues associated with transmission or generation (with the exception of Selorejo Dam). Prior to the eruption, a single electricity circuit followed the route of the crater road up the western flanks near to the summit area providing power to many of the warungs in addition to street lighting. The wires were supported by steel reinforced concrete poles measuring 300 mm diameter with a 180 mm diameter hollow centre. Within ~3 km of the vent this part of the network was destroyed beyond repair by PDCs, landslides and ballistics (Figure 5.23) during the eruption and there were no signs of rebuilding during the field visits seven months later, presumably due to the restricted access and continued land instability.

Some electricity poles further down the crater road (~6 km from the vent) were of metal construction and there was no observable damage from the eruption. Staff at the Kelud Volcano Observatory reported that Sugihwaras Hamlet, located ~8 km west of the vent near the observatory, lost electricity for two days following the eruption. Disruption to supply in Pandansari Village to the north east of the vent was more long-term. Many residents turned off their electricity before it was cut and before evacuating their properties. It took around one month for power to be restored in Pandansari (Munjang 2014a) and disruption was likely caused by a number of factors including ballistics, heavy tephra falls and lahars knocking down distribution network poles in the Sambong River valley. Additionally, accessibility issues in the area may have delayed workers restoring the service. According to residents, there were no electricity supply problems in Kalikuning and no other cases of disruption were reported from other villages or hamlets to the south of the crater, perhaps due to the smaller maximum clast size of ballistics and less infrastructure in the area. There were also no reports of insulator flashover in the proximal areas, most likely attributable to the generally coarser grain size of ash closer to the vent.

Selorejo Dam (a rockfill type dam) and reservoir, around 9 km north east of Kelud’s vent in the Ngantang District of the Malang Regency, provides hydro-electric power (in addition to drinking water, irrigation and a popular holiday location with many scenic and tourist activities). The power station at Selorejo has an installed capacity of 4.48
megawatts generated from one vertical Kaplan turbine. Heavy tephra fall led to sedimentation in the reservoir and damage to facilities at the site (Perum Jasa Tirta 2013), although the details and extent of damage is unclear. As a result of the sedimentation however, operations at the reservoir were halted and Perum Jasa Tirta I, the State Owned Enterprise responsible for the water resources and activities at Selorejo incurred high financial costs associated with the clean-up and repair efforts (Perum Jasa Tirta 2013). There were no operations occurring during our visit in September 2014, although this may have been due to low reservoir levels.
Figure 5.23a-g  Severe damage to the electricity distribution network from ballistics in the proximal area extending ~3 km from the vent. Photos taken in September 2014.
5.4.2 Distal

Most electricity generation sites are located in East Java Province and there are none in Yogyakarta Special Region Province (BPBD DIY 2014a). Electricity is supplied at high voltage (150-500 kV) into Yogyakarta and then distributed at a lower voltage through 20 kV transformers, and along overhead lines. Most insulators are porcelain and are strung both horizontally and vertically with some covered by a polyvinyl chloride (PVC) coating protecting them from animals. The Yogyakarta network operates on a ring system meaning that electricity can be distributed either way around providing some level of redundancy (PLN 2014).

Although there were no reports of problems for the high voltage transmission into Yogyakarta and no apparent cases of widespread electricity outages in the city caused by the Kelud ash (BPBD DIY 2014a, Mahjum (pers comm, 2014), PLN 2014), there were some isolated impacts that caused localised disruption and damage in the days following the eruption, particularly to the high-medium voltage part of the network (PLN 2014). At least seven large substation transformers and many smaller ones in Yogyakarta experienced either flashover or cooling fan disruption due to direct ash fall (Figure 5.24) and/or infiltration of ash. Flashover occurred despite the low soluble salt content of the ash (see section 3.2.2), which has previously been identified as one of the controlling factors that increases conductivity (Wardman et al. 2012).

The impacts resulted in temporary disruption due to the cleaning that was required. Firstly, high pressure water was used to wash all ash from transformer and substation components (Figure 5.25). Silicon was used for the secondary phase of cleaning at the substations to increase hydrophobicity. The cleaning process for each transformer took around 2-3 hours each time (PLN 2014). According to PLN, there were no reported problems of ash affecting the resistivity, and step and touch potentials of medium voltage substation gravel ballast. The gravel ballast was cleaned however, simply by spraying with water and washing the ash downwards. All cleaning approaches appear to have been reactive, waiting for damage or disruption to be reported before teams, tasked with cleaning substations as part of their usual role, were dispatched to the sites.

Figure 5.24 Porcelain insulators coated in ash at a substation in Yogyakarta following the Kelud ashfall.

Ash in most parts of Yogyakarta was only 20-30 mm thick, leading to several cases of ash accumulation on line insulators causing flashover, particularly following light rainfall. Examination of some insulators by PLN found that ash had accumulated on the inside of the protective PVC covers. Flashover was also reported elsewhere in Central Java.
Province but detailed information is limited, particularly as the extent and degree of ongoing ash remobilisation was not recorded (PLN 2014). There were no reported issues with pylons or lines (e.g. collapse) and no planned shutdowns occurred to clean ash from insulators or lines (PLN 2014). This differs from the Merapi eruption where shutdowns did occur, but it appears for Kelud that the fine ash was readily removed from the outside of insulators by wind and/or rain soon after the eruption. In addition to Yogyakarta and other parts of Central Java, there were some reports of electricity disruption following the Kelud eruption in other distal locations, including Surabaya located to the north of the vent (Irvine-Brown 2014).

**Figure 5.25** PLN workers cleaning Kelud ash from transformers with high pressure water at substations in Yogyakarta. The cooling fans also required cleaning (photos courtesy of Sumarsono, PLN Yogyakarta).
5.5 **WATER SUPPLY**

Proximal hazards have proven particularly damaging to water supply systems following other eruptions and volcanic ash can disrupt supply on a more widespread scale. Ash can damage components, block water intakes, affect water quality and turbidity and increase water demand during the clean-up phase, creating the potential for water shortages (Wilson et al. 2012).

5.5.1 **Proximal**

In the proximal areas to Kelud, water supplies are generally sourced from springs then piped using gravity-fed systems to households and communities (KVO 2014). Pipework is often laid overground along the edges of roads and is mainly PVC (Figure 5.26a, Figure 5.26c, Figure 5.30), although some older galvanised metal pipework exists (Figure 5.26b).

**Figure 5.26** Pipework in proximal areas. It is often PVC (a,c) although some older galvanised metal pipes exist (b). Most is laid alongside roads and over road banks even through village centres.

General effects on water supplies were described in the Jakarta Post (5 March 2014) as follows:

“The recent eruption of Mt. Kelud in Kediri, East Java, has disrupted springs in four districts causing local residents to suffer from clean water shortages. The disruptions have occurred in four districts, namely Ngancar, Plosoklaten, Kepung and Puncu.”
The Kediri Disaster Mitigation Agency spokesperson, Adi Suwignyo, said that besides covering the springs with volcanic materials, pipelines from the springs to water tanks were also damaged in the eruption.

According to Suwignyo, the residents have been forced to fetch water from other springs or rely on water provided through tank trucks" (Jakarta Post 2014e).

The major cause of damage reported to water supply systems in proximal areas was ballistic damage to pipes (KVO 2014, IFRC 2014), with lapilli and blocks 50-80 mm (longest diameter) falling up to 7 km from the vent in places (KVO 2014) (see Figure 3.4). Some water supplies were also contaminated by volcanic material entering the system (IFRC 2014). PMI provided drinking water through temporary kitchens and mobilised at least five tanker trucks to provide water to villages with supply problems for more than 2 weeks after the eruption (IFRC 2014, PMI 2014). The Water Utilities company of Indonesia, PDAM (Perusahaan Daerah Air Minum), mobilised staff rapidly to repair damage after the eruption. However, reports suggest that repair work was delayed due to disruption caused by heavy rain in the days following the eruption and fear of lahars in the area (Adonai 2014, Jakarta Post 2014e). In general, water supplies were affected for longer periods of time than electricity supplies.

Water supplies for Munjang Hamlet are sourced from a spring piped to a storage tank at a higher elevation which is then run (via 18 mm diameter mainly PVC above-ground pipes) to the hamlet. Most sections of pipe in Munjang Hamlet were reportedly damaged by ballistics from the eruption (Munjang 2014a, Selorejo 2014b). The TNI assisted residents by repairing the pipe network and by the time of the field visit in September 2014, this work was complete. The TNI also donated and constructed a new water tank (Figure 5.27), measuring approximately 3 x 2 x 2 m, which they installed above Munjang, next to the temporary military camp situated 6 km from the crater (see section 3.3.6, Figure 3.19a).

![Figure 5.27](image)

In the hamlet of Kalikuning (approximately 7.5 km south west of the Kelud crater), water supply pipes (some made of PVC and others galvanised metal) were damaged by ballistic block fall, and remained broken for approximately a week (Kalikuning 2014). During this time, some residents were able to rely on stored water, provided by two tanks within the village (Figure 5.28) but others had to walk considerable distances (an estimated 7-8 km) to the nearest water reservoir and carry water back in buckets. Repairs to the pipe network in Kalikuning were carried out by residents.
In addition to spring and tank water in the proximal areas, the large dam and reservoir at Selorejo, 9 km north east of Kelud’s crater, provides drinking water for further afield. Operations at Selorejo were disrupted following the eruption due to the sedimentation from heavy tephra fall in the lake (Perum Jasa Tirta 2013) (see section 5.4.1). Some ash deposition could be seen at the reservoir edge near the water intake and monitoring sites 7 months after the eruption when the water level in the reservoir had dropped (Figure 5.29).

Figure 5.29 Sedimentation of ash at the water’s edge at Selorejo Reservoir (7 months after the eruption).
5.5.2 Distal

Information on distal impacts of ashfall on water supplies was obtained for Yogyakarta only, from interviews with BPBD DIY staff (BPBD DIY 2014a), the Health Agency of Yogyakarta Special Region Province (Health Agency DIY 2014) and BBTKL-PPM (BBTKL-PPM 2014), along with information from limited media reports.

A reticulated water supply is provided to approximately 40% of the population of Yogyakarta by PDAM. This water is sourced from deep groundwater wells and some surface springs. The groundwater is naturally high in dissolved iron and manganese. The reticulated water supply is disinfected by chlorination (BBTKL-PPM 2014, BPBD DIY 2014).

Other residents and businesses in Yogyakarta rely on an extensive system of shallow wells for their water supplies (Health Agency DIY 2014). In the Sleman Regency, shallow wells are typically 5-6 m deep, 1-1.5 m in diameter and constructed of concrete. There is typically one well per household. Water is pumped up to the house, and is commonly boiled for disinfection purposes (Health Agency DIY 2014). An estimated 30% of the ~15,000 wells in Yogyakarta are open-air and uncovered (Wicaksono 2014).

The PMI and various reports (e.g. IFRC 2014, Wicaksono 2014) indicated that uncovered wells in Yogyakarta were contaminated by volcanic ash from the Kelud eruption, and well owners were urged by the agencies BPBD DIY and BLH (Environment Agency) to check the cleanliness of their wells.

The agency BBTKL-PPM conducted a water quality survey to assess impacts of the Kelud eruption in the Yogyakarta area (BBTKL-PPM 2014). Twenty locations (including surface waters, the PDAM deep well and shallow wells) were tested for physicochemical parameters (pH, dissolved solids, suspended solids/turbidity, colour and dissolved Al, As, B, Fe, Mn, NO₃, Se, Si and Pb). The scale of testing undertaken was much more limited than was the case for the 2010 Merapi eruption (BBTKL-PPM 2011).

The main effect on water quality noted in the shallow wells following the Kelud eruption was that some wells became ‘cloudy’ (i.e. turbid). No other effects on physicochemical parameters were noted. This concurs with our post-eruption ash leachate analysis which found that the soluble salt burden of the ash was generally low (see section 3.2.2). For turbidity removal, the chemical flocculant polyaluminium chloride (PAC) was distributed. This chemical is stocked in community health centres (Health Agency DIY 2014). For the larger-scale Merapi 2010 eruption, detailed advice on recommended doses of coagulant and disinfectant materials was available (Table 5.3).
Table 5.3 Recommended doses of coagulant and disinfectant materials in water from excavated wells following the Merapi 2010 eruption (BBTKL-PPM 2011).

<table>
<thead>
<tr>
<th>Clarity of water</th>
<th>Dosage of coagulant/litre</th>
<th>Dosage of disinfectant/litre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PAC (g)</td>
<td>Soda ash (g)</td>
</tr>
<tr>
<td>Clear</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Moderately clear</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Cloudy</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

1 Note that treatment with either PAC + soda ash or alum + quicklime is recommended.
2 This dose is for solid calcium hypochlorite Ca(ClO)\textsubscript{2}, dose will need to be recalculated if liquid bleach (sodium hypochlorite) is used.

5.6 Wastewater and Stormwater

Only limited information was obtained on ashfall impacts on wastewater and stormwater systems in the depositional areas. Readers are also referred to the sections 6.2.1 and 6.2.4, on clean-up of road networks.

5.6.1 Proximal

During the field team’s visit to Munjang Hamlet, it was observed that roadside drains were filled with ash (Figure 5.30), which led to localised surface water flooding problems. One village resident interviewed (Munjang 2014c) noted that houses in the neighbourhood have flooded, and that residents have built up ash in front of their houses (up to ~200 mm thick) in an attempt to mitigate flooding (Figure 5.31). Wood and tiles were stacked vertically in front of the doors to prevent ash from entering the house when open. Other measures by residents included piling ash along roadsides in an attempt to stop any rainwater flowing down the road from overspilling into neighbouring properties. Residents were reportedly hoping that the government would assist with clearing and removing ash from ditches.

Figure 5.30 Roadside drains filled with ash in Munjang Hamlet. The top of the concrete channel is just visible to the left of the plastic water supply pipes. This led to localised flooding of houses.
5.6.2 Distal

In Yogyakarta, construction of a new wastewater treatment plant for the city is currently underway, supported by the World Bank (BPBD DIY 2014a). In the meantime, most households use septic tank systems to dispose of domestic wastewater. There appear to have been no particular problems for septic tank systems as a consequence of the eruption, although we did not have an opportunity to interview the Provincial Public Works Agency.

The roadside drainage system in Yogyakarta largely consists of open depressions by the sides of roads. Where kerbs exist to segregate traffic (i.e. traffic flow in different directions and motorbike-only sections), holes in the kerb allow water to flow over the surface to the road sides (Figure 5.32). However, some roads have covered drainage sumps (Figure 5.33) which lead into partially-open channels running parallel with the road under pavements. Some of these have removable concrete slabs for easy access to the channels beneath. In most cases, both types link to larger open concrete channels which then lead into the rivers flowing through the city. The BPBD DIY staff did not report any problems in the province with ash entering and then blocking drains causing subsequent flooding. This may have been partially due to advice, provided by BPBD DIY, for people to take particular care to prevent ash from entering drains during clean-up (BPBD DIY 2014a).

Figure 5.31 Ash piled up at front of house in an attempt to stop surface water from entering. Wood and tiles were stacked up on the outside of door openings to minimise ash ingress when open.

Figure 5.32 Typical main road in Yogyakarta. Where kerbs exist to segregate traffic types, holes allow water to flow openly to sides of roads.
5.7 TELECOMMUNICATIONS

At Adisucipto International Airport (AIA), Yogyakarta (Figure 5.3) there were reports of problems with communications during the ash fall (DJPU 2014), however specific details about the types of problems are unknown. No other communication constraints with mobile phones, telephones, radio, television or fax were reported in Yogyakarta following the eruption or during the state of emergency declared soon after (BPBD DIY 2014a, BPBD DIY 2014b).

To the north east of Kelud in Munjang Hamlet all residential television satellite dishes were completely damaged by heavy ash fall and ballistic impacts (Figure 5.34a). The most common type of dish used is a 2 m diameter mesh satellite dish which due to Java’s latitudinal location (6-9° south of the equator) point towards the sky almost vertically (Figure 5.34b). As ash fell it accumulated inside the dishes caused the mesh to fail, rendering the dishes unusable. These satellite dishes are required to watch television in Munjang and some were replaced at a cost of Rp 900,000 (NZ$ 95) each (Munjang 2014c).

Figure 5.34 (a) Damaged, and (b) new mesh satellite dishes (2 m diameter) in Munjang Hamlet.
Other dishes are of a solid metal construction. In Sugihwaras Hamlet ~9 km west of the crater, rusting of some dishes was evident (Figure 5.35). However, it is unclear whether this was a result of (or exacerbated by) the Kelud ashfall.

![Figure 5.35 Rust damage to satellite dish at Sugihwaras Hamlet, although it is unclear whether this was a result of ash.](image)

In Kalikuning Village (south west of Kelud) ultra high frequency television antennae are used instead of satellite dishes and a local resident reported that there were no problems or damage with these. There were no reports of overloading of telecommunication exchanges or networks.

### 5.8 Oil and Gas

The major oil refinery in Cilacap, 360 km west of Kelud (see Figure 1.2), supplies around a third of Indonesia’s fuel needs at 348,000 barrels per day. Despite some ash fall from Kelud reaching the refinery and some reported concerns associated with this (Guardian 2014), operations appear to have continued as normal. However, it was reported that as a preventative measure, staff at Cilacap immediately prepared air filters for equipment there (Reuters 2014).

The Cepu oil-and-gas exploration block is located closer to Kelud, around 120 km to the north of the volcano. The area experienced minor ash fall but operations were not disrupted (Reuters 2014).

There were no reports of oil or gas supply and distribution being disrupted by the Kelud eruption, despite evacuations in the proximal areas. The existing stock of fuel by the large number of fuel suppliers and distributors, including many small kiosks selling bottled fuel for motorbikes, appears to have met any increased short-term demand for fuel brought on by evacuations.
6.0 **TEPHRA CLEAN-UP AND REMOVAL**

Previous studies of tephra impacted cities have identified efficient clean-up operations as a way to mitigate infrastructure impacts and as a fundamental aspect of post tephra fall recovery efforts and restoration of economic activities (Wilson et al. 2012).

6.1 **PROXIMAL**

In Munjang Hamlet within the Pandansari Village of Nangtang District, 7 km north east of the crater, ballistics penetrated some roofs leaving voids that allowed subsequent ash to enter rooms below (Figure 6.1). This necessitated the extensive clean-up of personal belongings and household items when people returned. Many chose to shake and hang belongings outside in order to remove the tephra (Figure 5.18b). Also in Munjang Hamlet, there were concerns that increased loading from any rainfall on tephra covered roofs could cause roof collapse. The majority of tephra was therefore cleaned from roofs when heavy rain was forecast (Munjang 2014a). When heavy rain arrived (~13 mm on Sunday 16 February and ~17 mm on Tuesday 18 February), it washed the remainder of tephra away without causing any noticeable additional impacts to roofs or buildings.

![Figure 6.1](image1.png)

*Figure 6.1*  Household items and personal belongings covered in tephra due to roof damage allowing tephra to fall into the rooms below (Washington Post 2014).

In the Kediri Regency, approximately 2,500 military and police personnel assisted the community with clean-up using whatever suitable tools were available (Antara News 2014b, KVO 2014). As occurred in some areas of Yogyakarta, it appears that a coordinated approach was adopted with many clean-up activities in proximal areas occurring at the same time and involving many people (Figure 6.2). By 04:00 on 14 February (around 5 hours after the eruption), tephra had been moved to the sides of some roads in the Ngancar District including the road leading to Kelud Volcano Observatory from Sugihwaras Village (KVO 2014). This was largely achieved using ongsrok, a wooden implement similar in design to a rake but with a wooden plank instead of metal teeth (Figure 6.3). Tephra was taken from road sides to be sold for construction material, which essentially offset the cost of clean-up (KVO 2014). The coarser properties of tephra in proximal areas meant that it was more suitable for construction purposes than that in distal regions (Purwana (pers comm, 2014)). Private property owners were responsible for removing tephra from their properties, and many
people still had piles of tephra outside their homes in September 2014, seven months after the eruption (Figure 6.4).

Figure 6.2 A coordinated approach to clean-up was adopted in many areas. (a) Residents cleaning a street together in the Kediri Regency (Irvine-Brown 2014). (b) TNI staff help to clear streets in Pandansari Village, Ngantang District, Malang Regency (Washington Post 2014).

Figure 6.3 Clean-up using ongsrok, a common tool used for clean-up of ash consisting of a wooden pole and small plank of wood (Tempo.co 2014).

Figure 6.4 Kelud tephra outside houses in proximal areas, seven months after the eruption. (a) Piled tephra outside house in the Kediri Regency. (b) Bagged tephra at Selorejo Village in Nangtang District, Malang Regency.
Less tephra fell in the Blitar Regency to the south of Kelud’s vent with some districts in the regency experiencing no tephra fall despite the sky darkening as the plume passed overhead (BPBD Blitar Regency 2014a). Clean-up activities in the Blitar Regency were coordinated by BPBD Blitar Regency. Residents mainly used manual clean-up methods, placing the tephra into bags. A maximum of one sack per household was collected by BPBD Blitar Regency.

6.2 DISTAL – YOGYAKARTA

6.2.1 Municipal Clean-up Response

On Friday 14 February around 20-30 mm (up to 50 mm in places) of fine grained tephra fell on Yogyakarta from the eruption of Kelud (BPBD DIY 2014a, BPBD DIY 2014b, DJPD & DJPL 2014). Official clean-up operations, under the control of BPBD DIY, did not begin until the morning of Saturday 15 February 2014. BPBD DIY and the Governor asked all parts of the community to join government workers to assist with clean-up operations (BPBD DIY 2014a, BPBD DIY 2014b). Two thousand military and police personnel were allocated solely to assist with clean-up efforts in the city. It was reported that tephra was still falling when clean-up began, although this could have been tephra remobilising out of trees (BPBD DIY 2014a). A major clean-up effort was conducted at the end of the weekend on Sunday 16 February. Clean-up was prioritised to remove ash from markets, shops, tourist locations, schools and at AIA (BPBD DIY 2014a, DJPD & DJPL 2014). Residents were advised by village leaders not to climb onto roofs but to clean ash from them by using shovels and hoses from the ground. BPBD DIY instructed those cleaning up that ash should not be swept into drainage networks because it could clog them. They also advised to keep water use to a minimum for the same reason and also to prevent surfaces becoming slippery. However, BPBD DIY water tankers were used to help clean ash from some areas, particularly hard to reach places such as rooftops and trees (Figure 6.5) (BPBD DIY 2014b).

Distal ash was mainly collected using manual clean-up tools such as brooms and shovels, and placed into 50 kg sacks (over 30,000 total) that were provided by BPBD DIY (BPBD DIY 2014a, DJPD & DJPL 2014, Mahjum (pers comm, 2014)). Most sacks used for clean-up in all areas were of plastic-fibre composition (Figure 6.6a) and often old rice and cement bags were re-used (Figure 6.6b). The full bags were then collected from the road side by more than 50 BPBD DIY trucks along with many trucks provided
by military, the Provincial Public Works Agency, and private operators, and taken to temporary storage sites. One such storage site was a concrete recreation area near the BPBD DIY offices in Yogyakarta (Figure 6.7a) (BPBD DIY 2014a) and another was located in the Yogyakarta Kraton (palace) grounds (Figure 6.7b) (BPBD DIY 2014b). Clean-up in Yogyakarta came to a total cost of around Rp 3 billion (NZ$ 315,000) with around Rp 1 billion (NZ$ 105,000) coming from the national government.

![Figure 6.6](image1) (a) Plastic fibre sacks used for the storage of Kelud tephra. Often, old rice and cement bags were used (b).

![Figure 6.7](image2) Temporary storage sites for tephra filled bags. (a) Recreational area adjacent to the BPBD DIY offices. (b) Yogyakarta Kraton (palace) grounds (BPBD DIY 2014b).

### 6.2.2 Disposal

Indonesian volcanoes greatly assist the livelihoods of many Indonesian people, and residents often utilise volcanic deposits for construction and agricultural purposes. If the physical characteristics such as grain size are suitable, ash can fetch up to twice as much money as sand when sold to the construction industry (Sunstar 2014). However, the grain size of Kelud ash in Yogyakarta was reportedly too fine to be used for building materials such as bricks, so there was little demand (Purwana (pers comm, 2014)). The Governor of Yogyakarta enquired about using the ash for agricultural purposes (BPBD DIY 2014a). However enough ash fell on agricultural areas that there was little demand for additional material anyway (Health Agency DIY 2014). Therefore sites for ash disposal had to be located ad hoc as no planning for such sites had been conducted prior to the eruption (BPBD DIY 2014b). Ash was used to fill depressions in four locations, 5-10 km from Yogyakarta City (BPBD DIY 2014a). A soil cap was used to permanently stabilise the disposed tephra which remained in the bags when dumped.
6.2.3 Non-municipal Clean-up Efforts

Not all clean-up was undertaken as part of that organised by BPBD DIY. At University Pembangunan Nasional (UPN) Veteran Yogyakarta for example, clean-up was undertaken by the university’s maintenance team (UPN 2014). Here, volcanic ash was moved to one location using water and brooms and then placed into 25 kg bags (100-150 bags in total). Bags were temporarily stored at the UPN general waste storage area before disposal at Piyangsan (municipal landfill) on the university’s usual waste collection and disposal day. Clean-up at UPN took about one week, and the removal of ash from buildings was helped by the heavy rain which washed remaining ash from roofs (UPN 2014). Not all ash was removed and some remained at the campus and in the surrounding area during the field visit on 18 September 2014 (Figure 6.8). As a consequence it was reported that UPN’s campus became dusty on windy days, even seven months after the eruption.

Borobudur, the world’s largest Buddhist temple and UNESCO World Heritage Site in the Magelang Regency (around 25 km north west of Yogyakarta City) (Figure 1.2), was partially covered with plastic sheets (Figure 6.9) to protect the temple’s stones from corrosion and aid with clean-up (Antara News 2014a). This protection method was prompted because of previous experiences of site clean-up, particularly after the 2010 eruption of Merapi volcano. Following the Merapi 2010 tephra fall, water drainage systems from the temple had to be cleaned. This required careful removal of 55,000 stone slabs and the total rehabilitation effort took one year (Wahyuni 2011). Clean-up of Kelud ash was undertaken by conservation office staff, military, and 200-300 volunteers.
consisting of Buddhist devotees, tourist guides, local traders, students, and tourists (Antara News 2014a). Not all stone-work was covered so clean-up took some time even after the plastic sheeting was removed. Paint brushes and sharpened bamboo sticks were used to dislodge and remove ash from the intricate detailing of some statues (Figure 6.10) (Muryanto & Ayuningtyas 2014).

Figure 6.9  Workers cover the Borobudur Temple near Yogyakarta to protect it from tephra from Kelud (Washington Post 2014).

Figure 6.10  Volunteer using paint brush to clean Buddha statue at Borobudur Temple. Not all statues and stonework were covered in plastic sheeting so clean-up took some time even after it was removed (Muryanto & Ayuningtyas 2014).

6.2.4  Clean-up Challenges

Clean-up in Yogyakarta was initially very difficult because the fine grained tephra meant it was easily remobilised by vehicles (DJPD & DJPL 2014). This necessitated the spraying of tephra with water from hoses and water cannons to consolidate it before it was collected and removed in bags (BPBD DIY 2014a, BPBD DIY 2014b). However, difficulties were experienced when too much water was added causing tephra to become cemented and stick to paved surfaces (UPN 2014). Light rainfall (~2-8 mm per day) until 17 February may have added to these difficulties. Knock-on issues also occurred to the transportation sector where patches of wet ash on roads resulted in slippery surfaces leading to further accidents (see section 5.2.2.2). Ash adhered to the leaves of trees and was later dislodged and remobilised by wind, settling onto previously cleaned surfaces (BPBD DIY 2014a, DJPD & DJPL 2014). As such, clean-up was easier in Yogyakarta than in the surrounding villages because there are fewer trees for ash to
accumulate on in the urban area (DJPD & DJPL 2014). Overall clean-up was aided by the heavy rain (~15 mm) which arrived on Tuesday 18 February in Yogyakarta, causing most remaining ash in trees and on roofs to fall to the ground (BPBD DIY 2014a, DJPD & DJPL 2014, UPN 2014). If this rain had arrived earlier in the clean-up process, before the majority of ash had been removed, it may well have led to blocked drains and flooding. Heavy rain arrived earlier (~11 mm on 15 February) in Semarang, located ~230 km NW of Kelud. However, as only light ashfall occurred in the city, the rain helped to clean ash from the streets without any flooding problems reported (Suherdjoko & Ayuningtyas 2014).

6.2.5 Adisucipto International Airport (AIA), Yogyakarta

Staff from the Provincial Public Works Agency were in charge of cleaning up AIA following the Kelud eruption (DJPU 2014) and were assisted by around 1,400 military personnel and police at times (Muryanto 2014). The runway, along with all airport buildings had to be completely cleaned before the airport could re-open (DJPU 2014). Clean-up operations began on 15 February and it was hoped that the airport would re-open on Tuesday 18 February, but clean-up operations took longer than expected and re-opening was delayed until Wednesday 19 February (Muryanto & Susanto 2014) (see section 5.2.1). In an effort to remove ash from the runway as quickly as possible, it was initially swept into drainage channels on the first day of clean-up, largely using ongsrok tools (Figure 6.11). The following day, ash was removed from the drainage channels and placed into bags, which BPBD DIY then collected for disposal. Shovels were used to remove the bulk of the ash, before brooms were used for the last few millimetres (DJPU 2014). Seven water cannons were sourced from the Yogyakarta Fire Department. These were only used for clean-up at night as they were required for other purposes elsewhere during the day. The water cannon belonging to AIA was not used for clean-up purposes as it was thought to be too powerful, potentially damaging paved surfaces. Water for cleaning AIA was extracted from two nearby rivers (the Tambakbayan and Kuning rivers) using the Fire Department’s water pump (DJPU 2014).

Figure 6.11 Workers sweeping ash to the sides of runways and into drainage channels on 15 February 2014 using ongsrok and brooms, the first day of clean-up at Adisucipto International Airport (AIA), Yogyakarta (Haryanti 2014b).
6.3 **DISTAL – SURAKARTA**

6.3.1 **Surakarta City**

Clean-up in Surakarta (also named Solo) City was conducted by military, police and local residents under the coordination of BPBD Surakarta City. Priorities were to use water and brooms to clean-up five main streets (Jalan Slamet Riyadi, Ahmad Yani, Adi Sucipto, Jend Sudirman and MT Haryono). Following clean-up of these streets the coordinated clean-up operation then moved into surrounding areas (Suherdjoko & Ayuningtyas 2014). Locals in Surakarta manually cleaned up ash on 14 February 2014, placing it into bags and selling it for construction material and as fertiliser for crops. This was reportedly priced at about Rp 680,000 (NZ$ 70) per small truck load (NY Daily News 2014).

6.3.2 **Adi Sumarmo International Airport, Surakarta**

At Adi Sumarmo International Airport in Surakarta six fire brigade units were used to clean ash from the runway using a high pressure hose (Tempo.co 2014) (Figure 6.12). Rainfall caused clean-up complications because the ash turned to mud and then became cemented to the runway surface. It was reported that clean-up was approximately 25% complete by 15 February (Tempo.co 2014) and about 70% complete by 18 February with the airport re-opening upon clean-up completion on Thursday 20 February (Antara News 2014c).

![Figure 6.12](image.png)  
**Figure 6.12** High pressure hose cleaning the runway at Adi Sumarmo International Airport, Surakarta on 15 February 2014 (Hindu 2014).
SAND MINING

Sand mining involves the quarrying of volcanic deposits from river beds, often those that have been transported down by fluvial processes (both high river flow and lahars) from the flanks upstream. Sand mining occurs in many areas of Java and provides a large source of employment and income for both local residents and workers of companies involved with the extraction, transportation and sale of material. Lahars on the flanks of a volcano may involve material that was erupted elsewhere. For example, it is hypothesised that there has been an increase in lahars on Merapi volcano as a result of the deposits from the Kelud 2014 eruption (De Bélizal 2014, De Bélizal (pers comm, 2014)).

Sand mining is encouraged by the government (although sometimes limited through licensing) particularly as it, in addition to the economic benefits, can allow river beds to be returned to their previous dimensions and potentially reduce inundation of properties and land from future high flows or lahars (Batur 2014, BPBD Blitar Regency 2014a). Large numbers of people (both local residents and from further afield in Java) can become involved working in the sand mining industry. On Merapi volcano for example, there may be up to ~5,000 workers in the various mines at peak times (up to ~400 people per mine) (De Bélizal (pers comm, 2014)). In some situations, such as on the slopes of Merapi volcano, after extraction, material is transported by truck for up to 7-8 hours to be sold (Kali Gendol 2014a). Extracted material ranges in quality and size, from several metre blocks which are often used as building stone or for sculptures, to sand- to clay-sized material used for construction including as a component for clay brick making and concrete. Taking costs (e.g. fuel, tax, workers pay) into consideration, each truck load of material may produce a profit of Rp 500,000 (~NZ$ 51) (Kali Gendol 2014a). The quarries are also exploited for tourism in some areas with 4WD vehicle tours on the slopes of Merapi volcano (Figure 7.1) visiting certain sites.

![Figure 7.1](image_url) 4WD vehicle tours in and around the sand mines of Merapi volcano.

Increased traffic (sometimes over 1,000 trucks per day (De Bélizal 2014, Kali Gendol 2014b), often on small village roads, can have a detrimental effect on the road surface with large potholes and complete erosion of asphalt concrete occurring (Figure 7.2). Unless frequent repair work and maintenance is undertaken, severe damage to road...
surfaces can occur within one month in some cases (De Bélizal (pers comm, 2014)), impacting on access and volcano evacuation routes (De Bélizal 2014). Although lahar warning systems are often set up to warn sand miners of lahars forming and potentially making their way downstream, these may not always work and fatalities and loss of equipment can result. Several people have died in recent years whilst mining the sediments of the Gendol River on the flanks of Merapi volcano due to embankment collapses and lahar inundation (Batur 2014, De Bélizal et al. 2013, Suherdjoko 2010). Trucks and excavators were also lost during some of these events (Batur 2014).

Figure 7.2 Potholes and erosion of asphalt concrete road surfaces are exacerbated by additional vehicles such as 4WDs and sand mining trucks.

Sand mining was observed in river beds on the northern, western and southern flanks of Kelud during the field visit in September 2014. West of Kandangan (~20 km north of the crater), a lahar had passed under a major road bridge (see section 5.2.2.1), leaving thick deposits upstream of a weir and irrigation diversion channel. These deposits were being extracted and transported away from the area (Figure 7.3).

Figure 7.3 Sand mining upstream of the bridge at Kandangan (~20 km north of Kelud’s crater)

Approximately 7 km south west of the crater, small scale manual sand mining was occurring in the Bladak River bed (just north of Kalibladak Village) (Figure 7.4) both above and below the upper sabo dam there. Mining is actively encouraged by the government in this river, particularly between and above the series of large sabo dams.
as there is concern about future lahars in the next wet season (BPBD Blitar Regency 2014a) (expected October 2014 – March 2015).

Figure 7.4 Sand mining in the Bladak River (below the upper sabo dam).

The recent lahar deposits (which were ~2-3 m deep in places (Selorejo 2014b)) in the Sambong River in Pandansari Village to the north east of the crater were being sorted into different grain sizes as each is suitable for different uses. This was being done within the river bed itself using diversion channels, mini-wooden sluices and pools (Figure 7.5a) and sometimes also by mechanical means on the immediate banks of the river (Figure 7.5b). The sediment from the Sambong River is mainly sold within the Kediri and Malang regencies (Selorejo 2014b).

Figure 7.5 Sand mining sorting and processing near Munjang Hamlet in Pandansari Village. (a) Using wooden sluices and diversion channels to separate material of different grain sizes within the Sambong River. (b) Using mechanical processors on the banks of the Sambong River.

In the past, lahars originating from Kelud have reached the Brantas River system, ~70 km away. However, only sand-sized material arrives into the Brantas River from the various tributaries and mining is not conducted here for environmental reasons (BPBD Blitar Regency 2014a).
Miners in the Blitar Regency receive warnings of potential lahars from the upper flanks of Kelud which allows them to move out of valleys and prevent damage to trucks. There is a high point (G. Gedang; see Figure 2.4) to the south of the crater where many of the upper reaches of the rivers on the southern flank of Kelud can be seen clearly and this is continuously manned by a spotter (BPBD Blitar Regency 2014a). This is particularly important as sometimes it can be raining in the upper reaches but not further downstream where sand mining may be occurring. Information is passed down through ‘Handy Talkies’ (radios) and mobile phones and the spotters themselves know routes down the volcano which avoid rivers (BPBD Blitar Regency 2014a).

It can be concluded that sand mining volcanic deposits has brought many employment opportunities and economic benefits in the proximal Kelud areas. Many farmers have switched to sand mining due to the loss of crops from burial by volcanic deposits and the loss of land resulting from lahar erosion. Sand mining may also reduce the impact of further lahars. However, despite the establishment of lahar warning systems, the increase in the number of people working in river beds close to the Kelud crater increases exposure to future hazards and may affect future evacuations.
8.0 IMPACTS ON AGRICULTURE

8.1 CONTEXT

Nearly half of the population of Indonesia live rurally with a large proportion working in agriculture. The rice industry alone employs 7.1% of the country’s workforce and agriculture comprises 14% of the nation’s Gross Domestic Product (GDP) (Barichello & Patunru 2009). Farming practices across the Central and East Java provinces are dictated by the timing of the wet (October – March) and the dry (April- September) seasons. This dual-cycle seasonality, combined with rich volcanic soils (dominated by Andosols) and high temperature and humidity year-round allows tropical agriculture to thrive (Nitis 2006).

On the flanks of Kelud within ~5 km radius of the summit, forests dominate the uneven landscape. Within ~3 km of the summit, these forests are protected by government legislation but outside of this zone, trees can be felled and some production forests exist in this area. Beyond ~5 km, agriculture becomes more widespread and generally consists of high intensity horticultural farming. Pineapple plantations (Figure 8.1) are particularly popular on the western and southern slopes, and the fruit are profitable enough to be transported and sold in neighbouring Central Java (at approximately Rp 15,000 (NZ$ 1.50) per pineapple) (Purwana (pers comm, 2014)). However, the majority of farming in the overall region is subsistence. In some areas, each family has a clove tree, often a rice paddy, and access to wild plants such as lemongrass, that grow abundantly in the area. In farmland adjacent to the Sambong River near the Selorejo reservoir and Klangon Hamlet (9 km north east of the crater), rice paddies dominate as the river provides suitable irrigation. The river is also used for catfish and koi farming with some of these fish sold in local markets and the larger fish transported to markets as far away as Yogyakarta (Purwana (pers comm, 2014)). In Munjang Hamlet (7 km north east of Kelud’s summit) cash crops including chillies, tomatoes, potatoes, cassava, and onions are grown (Figure 8.2a) (Munjang 2014b). Crops differ somewhat on the southern flanks of Kelud. In addition to subsistence farming, there is a large commercial coffee plantation near Karanganyar Hamlet (10 km south west of the crater). Around the Kalikuning and Kalibladak hamlets (~7.5 km south west of the crater), the main crops are sugar cane, rubber and albasia, with some coconuts also grown (Kalikuning 2014).

Figure 8.1 Pineapple plantation on the western slopes of Kelud.
High-intensity horticultural farming is the dominant agricultural type in the Yogyakarta Special Region Province (~200 km west of Kelud). The main crop in the province is rice (Figure 8.2b), with secondary crops including tobacco, durian, chilli, tomatoes, and maize (Agricultural Agency DIY 2014). Farms in the area are usually subsistence, family owned and relatively small (~10 hectares). These are often fertilised with animal manure, with artificial fertilisers rarely applied (Agricultural Agency DIY 2014). Access to farming machinery for cultivation is limited and resources are often shared across numerous farms.

Figure 8.2 Typical agriculture types. (a) Cash crop based agriculture, ~8 km north east of Kelud’s summit near Munjang Hamlet. (b) Rice paddies, Yogyakarta Special Region Province.

8.2 IMPACTS ON CROPS AND OTHER VEGETATION

Field observations, interviews with emergency managers and agricultural agencies, and ash leachate analysis (see section 3.2.2) suggest that the majority of losses sustained were due to the physical nature of the deposits (loading, abrasion, lahars), rather than any issues related to leachable elements present on the ash (see section 8.4).

8.2.1 Proximal

Around 70% (~2,580 hectares) of protected forest within a 3 km radius of Kelud’s vent was severely damaged by the eruption (Antara News 2014d). Many volcanic hazards were responsible for this devastation including PDCs, lahars, landslides, ballistics, secondary fire and thick ash fall (Figure 3.1, Figure 3.2). Further afield, volcanic ash also covered large swathes of productive farmland, with 4,136 hectares covered in the Malang Regency and 13,194 hectares in the Kediri Regency (Jakarta Post 2014f). Interviews confirmed that most crop damage within a 15 km radius of the volcano was due to thick ash accumulation (up to ~500 mm thick in places) which broke and/or buried plants. The extent of ashfall following the eruption can be seen in Figure 8.3. Crop damage was more severe within 5 km of the vent where large clove trees had branches snapped and leaves stripped by falling tephra. In the area around Munjang Hamlet, many coconut trees suffered due to leaf breakage (Munjang 2014a, Munjang 2014c). Ashfall caused leaf abrasion of coffee crops near Karanganyar Hamlet to the south west (Karanganyar 2014). Rubber and albasia trees appeared to be more resilient to ash
loading and abrasion than other crops in the region (Kalikuning 2014), although this is based on visual observations 7 months after the eruption and an account from one farmer. There was evidence of leaves being stripped from albasia trees, visible ~2 months after the eruption with some signs of new growth (Figure 8.4). This suggests that albasia recover quickly from ash damage. There were no reports of any acid damage to foliage, which correlates with the low acidity of leachate.

Figure 8.3  (a) Large swathes of farmland covered in ash following the Kelud eruption (Haryanti 2014a). (b) The same area 7 months after the eruption. Munjang Hamlet can be seen in the middle right. Both photos are taken looking south west from the dam at Selorejo reservoir (~9 km from the summit of Kelud). The summit area of Kelud is visible in the background.

Figure 8.4  Albasia trees with some leaves stripped by ashfall. However, some new leaf growth is evident.
Some rice paddies along the Sambong River valley were completely destroyed by erosion from lahars which occurred from 18 February onwards, following heavy rain. These lahars scoured away and overtopped the banks leaving the riverbed several meters wider (Figure 8.5). Remaining rice paddies were buried by 2-3 metres of lahar deposits in some instances (Selorejo 2014b). Lahar deposits also partially buried and swept away masonry irrigation structures near Klangon Hamlet and parts of one structure were fluvially moved ~80 m downstream at one site. This meant that new temporary irrigation pipework had to be built quickly to address the change in river course and to keep remaining rice paddies functional (Klangon 2014). However, it is likely that the 2014-2015 wet season will cause further lahars by incorporating the remaining pyroclastic material from the upper reaches of rivers on Kelud. This could potentially result in further agricultural damage.

Figure 8.5  Sambong River below the Selorejo Dam, after the lahars. The river was substantially widened through the scouring effect of lahars. Evidence of former rice paddies can be seen on the left.

Some rice crops were flowering at the time of the eruption, leaving them more vulnerable to ash loading by potentially ruining the upcoming harvest. Some rice paddies particularly those nearer the crater in Pandansari Village were abandoned due to the thickness of the ash deposits (up to 500 mm thick in places), with some farmers in the region believing it will be three years before the area can be successfully cultivated again for all crops (Munjang 2014a, Munjang 2014c). Conversely, the timing of the eruption actually prevented sugar cane losses as the crop had not yet been planted (Kalikuning 2014). A secondary effect of the loss of rice paddies was the influx of lizards, mice and rats, which usually survive by living in the rice paddies, into the surrounding towns (Munjang 2014c). This in turn may increase the risk of vector-borne diseases for people coming into closer contact with wild animals (BBTKL-PPM 2011).

The incorporation of ash into the soil reportedly caused an increase in tomato yield for some farmers near Munjang Hamlet, where farmers reported larger fruit (up to 60 mm diameter) and more frequent harvests (up to seven in the months after the eruption, instead of the usual three or four in the same timeframe). The same farmers also reported that these results were achieved using less fertiliser (i.e. chicken manure) than
usual (Munjang 2014b). Some farmers in the area expect increased productivity and yield for such crops after the wet season when ash is further incorporated into the soil.

8.2.2 Distal

As with other groups, farmers in Yogyakarta Special Region Province did not receive any warning for the Kelud ashfall. This meant that the immediate priority when ashfall arrived was the protection of human health, followed by the protection and cleaning of affected crops (Agricultural Agency DIY 2014). The main issues faced by farmers in the area were the adherence of the fine ash deposits to leaves and structural breakages due to the weight of the ash on the vegetation (Munjang 2014a). Tobacco, chillies and tomatoes were most vulnerable to adherence and some of the upcoming harvest had to be abandoned. The deposit also adhered to corn, but was easier to wash off without damaging the crop (Figure 8.6). Rice paddies in distal areas were relatively unaffected by the ash, especially after juvenile plants had been flooded with irrigation water as a preventative measure (Mahjum (pers comm, 2014)). These findings compare well to observations made by Wilson et al. (2007) following the 2006 eruption of Merapi volcano who suggested that taller growing plants, such as chillies, tomatoes and tobacco are most vulnerable to tephra fall but that they offer a degree of protection to low growing plants and root vegetables. Wilson et al. (2007) also concluded that plant maturity is an important factor with rice being most vulnerable in late stages but corn being vulnerable in early to mid stages of plant growth. These observations correlate well with impacts seen following the Kelud 2014 ash fall.

![Figure 8.6](Farmer cleaning corn covered with Kelud ash (Washington Post 2014)).

8.3 IMPACTS ON LIVESTOCK

Livestock farming is not the main form of agriculture in distal or proximal areas. In Yogyakarta, small numbers of cattle are housed in feedlots or cattle farming sheds (Figure 8.7). Such structures are usually community owned and offered adequate protection from ashfall. However, some of the animal housing did have asbestos roofs, which are brittle and can fail when impacted by ballistics or thick ashfall. Areas with metal roofing are likely less vulnerable as such roofs are more resilient to ash loading.
In the proximal areas to Kelud, many families own a small number of cattle or goats for family use or for selling milk to the local co-operative. Many farmers that were evacuated came back during the daytime in the days following the eruption to care for these animals. The local government owns some of the cattle and deer on the flanks of Kelud. Farmers thus feel more inclined to evacuate as the government would be responsible to look after any livestock left behind (KVO 2014). Several asbestos roofed duck farms are in operation in the Blitar Regency. Despite these large, old, flat roofed structures being vulnerable to ashfall loading, no to little damage occurred as ashfall in the area was relatively minor.

There were no reports of animal fatalities directly related to the eruption, however some farmers chose to sell or kill animals due to the ash placing pressure on feed supplies and concerns about declining health (BPBD Blitar Regency 2014a). The Agricultural Agency of Yogyakarta Special Region Province reported that the main issue faced by livestock farmers was the provision of non-contaminated feed (Agricultural Agency DIY 2014).

8.4 IMPLICATIONS OF ASH LEACHATE COMPOSITION

While leachable element analyses of fresh volcanic ash can be useful for assessing health and agricultural hazards (Stewart et al. 2013), it is important to bear in mind that ash leachate composition may vary considerably during the course of an eruption, and also with respect to sampling location (Stewart et al. 2014). Thus the two Kelud ash samples analysed (Tables 3.2 and 3.3) provide only a snapshot into the potential health hazards for both animals and humans in the depositional area. On the basis of these samples, levels of F and S appear too low to pose a health risk to grazing animals, and we identify no other constituents of concern in the ash leachate. Levels of F are also too low to pose a threat to water supplies (e.g. by deposition of ash into open water supplies).

While the addition of leachable elements from ashfall can provide immediate stimuli to plant growth (e.g. Lansing et al. 2001), the relatively low soluble salt content of the Kelud ash suggests that this is unlikely to be a beneficial consequence (Stewart et al. 2014).
We note that in general, thin ashfalls containing high levels of available nutrient elements such as S may reduce the need for normal fertiliser applications, and may also provide a mulching effect. As ashfall depth increases, these beneficial effects may be increasingly offset by harmful effects such as impedance of gas exchange processes.

8.5 **Financial Implications**

Estimates for the financial implications for the agricultural sector from the Kelud eruption were wide ranging, from between Rp 1.1 billion (~NZ$ 115,000) (IFRC 2014) and Rp 377 billion (~NZ$ 39 million) (Jakarta Post 2014f), although the latter later estimate is seen as a more likely value accounting for the range of crops, livestock and other production. Damage specifically to fruit trees was estimated to contribute around Rp 24 billion (~NZ$ 2.5 million) towards these losses (Sudiono & Rahmadi 2014) and the total loss of protected forestry was estimated at Rp 19 billion (~NZ$ 1.9 million) (Antara News 2014d). The Association of Indonesia Milk Processing Cooperatives claimed that the eruption caused losses of hundreds of billions of rupiah with PT Nestlé Indonesia suggesting that milk suppliers in East Java were particularly severely impacted (Boediwardhana & Harsaputra 2014). Some reports (e.g. Sunstar 2014) highlighted the positive impacts of ashfall, emphasising the possible benefits it could have on future soil fertility.

8.6 **Recovery Strategies**

The Dinas Pertanian Republik Indonesia (National Ministry of Agriculture) set aside Rp 103 billion (NZ$ 10.7 million) specifically for agricultural aid and recovery. This was mostly distributed in the form of seeds in proximal areas (Jakarta Post 2014f).

8.6.1 **Proximal**

Farmers in the proximal areas had a good understanding of the potential impacts that could be expected from ashfall and the different mitigation options available. Workshops and community meetings had been held since 2008, training farmers what to do pre- and post- eruption to minimise agricultural losses. Due to this training, farmers in the area abandoned the majority of the contaminated harvest (Figure 8.8) and began to cultivate ash into the soil in some locations (Figure 8.9) often with the intention to replant come the next wet season (October 2014 onwards). This was conducted without seeking further governmental advice. Based on official advice, the vast majority of ash-affected crops within a 10 km radius of the vent (including chillies, tomatoes, onions and tobacco) were disposed of. The loss of harvest and need for complete replanting of the area placed major economic strain on farming families in the area (KVO 2014).

Due to the relative value of pineapples, many were harvested from the plantations on the slopes of Kelud in the four days prior to the eruption after the alert level was raised from Yellow / 2 (‘Waspada’ Be careful) to Orange / 3 (‘Siaga’ Be ready) indicating that an eruption could be expected within days to weeks and bringing into force a 5 km radius exclusion zone around the crater (GVP 2014f, IFRC 2014, KVO 2014). Farmers in the area had a good understanding of the alert system and reacted accordingly as the majority of the pineapple crop was reaching maturity (KVO 2014). Although some
pineapple fruits were left on crops into April 2014, no fruits were observed during the field visit seven months after the eruption in September 2014, suggesting that some were harvested after the eruption or the following planting season had been missed.

Figure 8.8 Crops abandoned due to ash contamination within 10 km of the vent.

Figure 8.9 Cultivation of ash into topsoil using community owned machinery, near Kalikunging Hamlet.

Along the Sambong River where rice paddies were completely buried by lahar deposits, some farmers have resorted to sand mining (see section 7) which many see as more beneficial than farming, particularly as it is more profitable, can occur every day all year-round and requires less decision-making (i.e. farmers do not need to decide which crops to plant where and when). However, some have contrasting opinions and claim that farming is a more diverse job, offering flexibility in terms of cultivating different crops at different times (Klangon 2014, Selorejo 2014b).

In November 2014, following the start of the wet season and with soil on the upper flanks of Kelud becoming wetter, The Kediri Regency Administration embarked on a large-scale seed sowing and planting programme in an attempt to help reforestation of the area. In addition to planting new trees, one tonne of red calliandra seeds were due to be sown at the time of writing, chosen because calliandra plants have “strong roots, are
easy to grow and help fertilise the soil” (Antara News 2014e). Due to the uneven terrain within ~3 km radius of the summit, there were plans to use catapults and a helicopter to help disperse the seeds in hard-to-reach areas. It is expected that the revival of new forest will help stabilise the soils and help secure new fresh drinking water sources for the local residents (Antara News 2014e).

8.6.2 Distal

The Agricultural Agency of Yogyakarta Special Region Province and researchers at Yogyakarta universities worked collaboratively to assess the impacts and provide recommendations to farmers following the eruption (Agricultural Agency DIY 2014). Initially the main advice given to rural communities was to protect their respiratory health by using masks when outside and to clean ash off any food before consuming. After the eruption some city officials suggested that collected ash could perhaps increase agricultural productivity and increase soil fertility (BPBD DIY 2014a). The Governor of Yogyakarta sought further information on whether the ash would be beneficial for agriculture. However, as there was little demand for further ash and no one knew what should be tested for in order to provide further information, the ash was not used or saved for future use. Compared to the 2006 and 2010 Merapi deposits, the Kelud ash was much finer grained (<1 mm) in this area and therefore more easily cultivated into the soil than proximal areas (Agricultural Agency DIY 2014). Some farmers felt that it was unlikely to be beneficial and chose to remove the deposits where possible. Others still felt that the deposit was likely to be a source of fertility and chose to incorporate the ash into the soil. Many were expecting an improved yield from upcoming harvests following the wet season (i.e. from October 2014 onwards) (Agricultural Agency DIY 2014).

The rice crop was relatively resilient to the ashfall, only needing re-irrigating in places, as rainfall after the ashfall removed the majority of the deposit from plants. The resilience of rice crops appears to be a result of the season at which the ashfall occurred. If the event had occurred later in the year, but still prior to the wet season beginning in October, there would have been limited water available to irrigate the fields and wash crops. Government subsidies were not provided in distal areas, as most farmers did not describe production losses in the area as substantial (Agricultural Agency DIY 2014).

8.7 Loss Reduction

Whilst limited conclusions about the relationships between impacts, loss and recovery can be drawn from a single study, general trends were identified. Aspects that minimised agricultural losses included:

- The resilience of juvenile rice and mature corn crops to ashfall compared to other crops reducing overall agricultural loss. Whilst juvenile rice plants needed re-irrigating and mature plants were more vulnerable to ash adhesion when flowering, the crop appeared to incur relatively minor losses across all impacted areas.
- The low intensity, sheltered style of livestock farming meant that providing uncontaminated feed was less challenging than in a traditional pastoral setting due to a low livestock population which is distributed widely, resulting in low demand for feed. In proximal areas there was often only one or two animals per
household, and in Yogyakarta animals were often housed in feedlots offering a degree of feed protection from ashfall.

- The frequency of volcanic events in Java, preparedness, general past experience and the well-publicised volcanic activity and eruption impacts in rural areas around Mount Sinabung (Sumatra) in the months prior to Kelud, meant that farmers had a good understanding of the options available to them before and after an eruption. For example, when the alert level for Kelud was raised many farmers on the slopes chose to harvest early.

- Actions taken by farmers in the region included abandoning crops within 10 km of the vent due to contamination and structural breakages from ashfall and ballistics, removal of the deposit, cultivation of the ash into the soil, and re-seeding of crops. These proactive responses likely accelerated recovery in the area.

- Rainfall helped prevent large-scale wind remobilisation of the ashfall deposit and rinsed some ash off affected crops. Whilst the wet season had not yet occurred at the time of the study, it is likely that this will further increase ash incorporation and weathering into the existing soil structure. However, associated lahars may increase erosion of agricultural land.
9.0 TOURISM AND TRADE

9.1 PROXIMAL

During the field visit in September 2014, we visited a homestead and café, around 9 km west of the crater in the Ngancar District of the Kediri Regency. Since the eruption, there had been less people visiting the restaurant but the numbers of guests staying overnight in the accommodation were about the same as before the eruption (Luwakmas Café 2014).

Although many of the warungs and other infrastructure such as roads, electricity and car parks closer to the vent had either been destroyed or damaged by the eruption, new tourism opportunities had arisen 7 months after the eruption. As discussed in section 5.2.2.1, the section of road that previously extended ~3 km from the vent remained closed to everyday traffic due to damage from ballistics, PDCs and landslides. This closed section began at the bridge which was heavily penetrated by ballistics (Figure 5.5b) and thus too dangerous for four-wheeled vehicles to cross. However, an organised group of around 40 motorbikes had set up a tour operation immediately beyond the bridge, driving back and forth up the next section (~1.5 km) of damaged road (Figure 9.1), transporting groups of tourists who could then walk freely as far as the cordon at the end of the damaged road section ~1 km from the crater. Paper tickets were given to each passenger allowing them to make a return journey when they had finished sightseeing activities near the summit. At the official road closure where the motorbikes began their journey up, a vehicle parking area and new warungs (Figure 9.2) selling pineapple, drinks, snacks and tourist gifts had been set up, making the most of the new increased number of tourists at this site, some of which arrive on tours from the major cities in Java.

Further disaster-based tourism opportunities may arise in the coming months, particularly if the upper parts of the volcano are made more accessible to vehicles. For example, 4WD tours such as those that operate on the flanks of Merapi volcano (see section 7) may begin at Kelud.

Figure 9.1 Motorbike tours operating on the road section inaccessible to four-wheeled vehicles on the damaged section of road leading towards the summit area.
Trade in the proximal areas was affected by the evacuations and direct damage to warungs, factories and other businesses, particularly from ballistics and heavy ashfall causing roof collapse. Reports suggest that food stocks also ran low in some areas, particularly in parts of the Malang Regency to the north east of the crater where many perishable goods were spoiled by coatings of ash and crops were badly damaged (Sudiono & Rahmadi 2014).

Figure 9.2  Warungs and car park area set up immediately before the official road closure where the motorbike tours began.

9.2  DISTAL

In the days following the eruption, trading activity in Yogyakarta was severely impacted by the volcanic ash as many people chose to stay at home. Most shops, markets, banks and shopping centres in the city closed (BPBD DIY 2014b, Irvine-Brown 2014). Sales figures on Friday 14 February, the day after the eruption were estimated to be ~60% lower than usual. However, the selling price of some items soared due to supply difficulties (BPBD DIY 2014b).

East Java Province is home to several industrial estates, including Rungkut and Gresik which are sited near Surabaya, ~90 km north east of Kelud. The distribution system for the Unilever Indonesia plant was interrupted as several affected areas remained inaccessible. Semen Indonesia reported that there were no issues with production at the Tuban plant located further afield in East Java (~150 km north of the crater) following the eruption (Boediwardhana & Harsaputra 2014).

Borobudur Temple, ~25 km north west of Yogyakarta City in the Magelang Regency, was affected by the fine distal ashfall and remobilisation of ash from the Kelud eruption. To enable preservation measures and clean-up, local authorities closed the temple to the public on Friday 14 February (Antara News 2014a). Other temples were also closed including the Hindu Prambanan Temple and Ratu Boko Temple in Yogyakarta, all partially reopening to the public 5 days later on Wednesday 19 February (Anatara News 2014a, Muryanto & Susanto 2014). It is estimated that the closure of Borobudur alone may have resulted in ~25,000 less visitors, also affecting goods traders in the area (Antara News 2014a). On partial re-opening, a discount of 30% was applied to entrance
tickets at the three temples when clean-up processes were ongoing (Muryanto & Susanto 2014). Visitor numbers at the temples and other tourist attractions in and around Yogyakarta were still recovering to normal figures for at least a week after the eruption (BPBD DIY 2014b).

The Yogyakarta branch of the Indonesian Hotel and Restaurant Association, PHRI (Perhimpunan Hotel dan Restaurant Indonesia), reported that volcanic ash from the Kelud eruption caused thousands of tourists to cancel their visits to Yogyakarta. This was likely exacerbated by the closure of AIA Yogyakarta and other airports within Java. The PHRI estimated financial losses of Rp ~2 billion (NZD ~210,000) per day for hotels in Yogyakarta (including costs associated with cancellations and physical damage) (Muryanto & Susanto 2014).
10.0 KEY FINDINGS

The short-lived VEI 4 eruption of Kelud on 13-14 February 2014 produced many volcanic hazards including PDCs, ballistics (some hot enough to trigger fire), landslides and lahars close to the volcano itself, in addition to tephra which was transported by winds up to 600 km from the vent. Wind was bi-directional with low-level winds carrying ash to the north east and high energy, high altitude winds transporting ash far to the west. Tephra did not dissipate proportionately away from the vent with relatively thick tephra accumulating in proximal areas ~0-10 km to the north east and in a zone ~200-250 km west of the vent. Tephra accumulations of 200-500 mm in some proximal villages lead to severe consequences. Other villages, located at a similar distance from the vent but on a different side of the volcano, received little to no tephra fall. Impacts to critical infrastructure, utilities and health were extensive in many proximal and distal regencies examined as part of this report, with building and agricultural impacts also occurring proximally. The total economic impact of the eruption is difficult to calculate, although soon after the eruption, the PMI estimated it could be in the region of Rp 1.2 trillion (~NZ$ 121.5 million) (IFRC 2014). Although much economic and practical support was provided by various organisations and the government to aid with initial recovery, affected communities may suffer some hardships in the years to come.

10.1 PROXIMAL EMERGENCY RESPONSE

In proximal areas, the already established and strong relationships between staff at organisations such as the three BPBDs, Kelud Volcano Observatory and community groups (including representatives of the risk reduction platform, JANGKAR Kelud), appear to have aided the rapid dissemination of consistent warnings and information. The range of communication methods in place through the emergency management structure, JANGKAR Kelud motives for saving lives, and various devices such as the ‘RAPI’ amateur radio system, ‘Handy Talkies’, mobile phones, sirens and gongs likely further supported warning dissemination. Much of the general population reacted quickly upon receiving official advice, not hesitating to evacuate. In fact, many people evacuated in response to the second highest alert level being issued, some from outside the designated 5 km evacuation zone boundary for which this alert refers. Further evacuations occurred following the highest alert level being issued with over 100,000 evacuees in total travelling ~4-25 km to reach their evacuation destinations. Strong community bonds, respect for the volcano, good understanding of alert statuses/warning information and evacuation planning, and a widely held belief that Kelud volcano erupts explosively every 20-24 years, appear to have overruled any doubts people had about evacuating which may have arisen following the multiple evacuations and unusual lack of volcanic explosivity in 2007. The quick response of inhabitants likely reduced loss of life, and the four fatalities from the direct primary hazards that occurred is considered very low considering the scale of the eruption and number of inhabitants affected.

It should be noted that despite the general success of initial response, not all hamlets in the proximal areas received warning messages in advance of the eruption with some evacuating as soon as ash and ballistics began to fall, forcing them to immediately abandon the area and leave unprotected belongings, food and other items behind. A few residents purposefully chose to remain, sheltering from ballistics and tephra fall in houses before being evacuated by the military the following morning. Evacuated
residents and farmers were keen to return to evacuated areas very soon after the eruption to check on properties, livestock and crops. Some made temporary returns within 1-2 days of the eruption during the day, returning to evacuation centres by night. More permanent return of evacuees occurred when the alert status was lowered four days after the eruption, although there was much concern about how soon people were allowed to return, especially with the instability of the upper crater areas and threat of new lahars.

10.2 DISTAL EMERGENCY RESPONSE

In distal areas, such as the highly populated areas of Surakarta and Yogyakarta, little to no warning of the Kelud eruption and potential impacts was received or disseminated until ash fell, around four hours following the eruption. This was likely aggravated by the time of day (with the ash arriving at 03:00 local time) and the lack of knowledge and misunderstanding of potential impacts from a volcano located ~200 km away, or from Kelud volcano specifically. Volcanological disaster management in Yogyakarta was likely focused on hazards and mitigation strategies for recent and future eruptions of Merapi volcano, which is located within viewing distance of many and has been a source of many hazards there in recent years. Additionally, the risk posed by volcanic ash generally receives less attention than that for other volcanic hazards such as PDCs and lahars in the area. Distal volcanoes to Yogyakarta such as Kelud perhaps receive less focus in terms of preparedness measures as they are out-of-sight and often more ‘out-of-mind’ than Merapi. However, ash from the 2014 Kelud eruption caused more problems in Yogyakarta than that from the 2010 Merapi eruption, particularly as it was more widespread and of finer grain size (hence readily remobilised). A state of emergency for Yogyakarta Special Region Province was declared in the day following the eruption. Interviews and discussions with staff at various organisations and members of the public in distal areas revealed that the Kelud ash fall and associated impacts came as a huge surprise to most.

10.3 IMPACTS ON HEALTH

Of the four fatalities from direct primary hazards within the proximal area, three were from respiratory problems associated with the inhalation of ash. Although further respiratory problems and other health effects in proximal areas may have resulted, reliable data to draw accurate conclusions was not available at the time of writing.

Respiratory problems (in the form of upper respiratory tract infections) were the most common recorded health impact in Yogyakarta with at least 56 cases reported by the Health Agency of Yogyakarta Special Region. There were at least 50 hospital admissions related to accidents (likely traffic-related) from Kelud ash in the province for the month following the eruption. Such figures appear extremely low compared to other eruptions, although it is likely many cases went unrecorded or unreported. However, people quickly responded to ash fall and official advice was quickly issued by the Health Agency of Yogyakarta Special Region Province and communicated through the Governor, with many staying indoors and using masks while outdoors. This likely substantially reduced the number of health impacts in Yogyakarta.
10.4 Impacts on Infrastructure and Utilities

Impacts on the local infrastructure and utilities in the three regencies on the flanks of Kelud varied spatially and with hazard intensity. There was complete destruction to some buildings and parts of the transportation, water supply and electricity networks from the immediate proximal hazards including ballistics (and related fire), PDCs and thick tephra accumulation. Lahars in the days following the eruption caused further destruction, completely removing bridges, electricity poles and buildings and some surface flooding due to blocked drains occurred in village centres. Severe impacts occurred in many of the hamlets within ~7-10 km of the vent with tephra accumulation of up to ~500 mm and ballistics of ~80 mm diameter in places causing major roof damage (particularly to roof tiles and asbestos sheeting) and requiring extensive clean-up. Some tiles were replaced with thinner tiles, potentially increasing the vulnerability of buildings in future eruptions.

In Yogyakarta, flashover and/or cooling fan disruption were experienced at seven or more substation transformers causing localised electricity outages. There was substantial disruption to the road network in the city, particularly due to reduced traction and low visibility, making it difficult to drive. This forced the cancellation of bus services and governmental advice was issued for people to stay off the roads. Despite fewer vehicles, the number of accidents increased. Effects to aviation were global as four of the seven Indonesian airports that were closed usually service international flights. The closure (some for up to a week) caused flight cancellations and disruption throughout Java and further afield including Australia. One aircraft flew through the Kelud ash cloud around six hours after the eruption and sustained heavy repair costs as a result.

10.5 Impacts on Agriculture

In distal areas, overall impacts on agriculture were relatively minor. Although some crops had to be cleaned and a few abandoned, most appear to have been relatively unaffected by ash. Impacts on agriculture on the upper Kelud flanks however, were severe with thousands of hectares of protected forest and productive farmland damaged. Trees close to the vent were destroyed by PDCs, ballistics and landslides and a governmental scheme has since embarked on re-vegetating this area. The majority of crop damage appears to have been due to thick ash loading with some abrasion and stripping of leaves. Rice paddies affected by thick tephra deposits close to the vent were particularly impacted with many fields abandoned. However, the incorporation of ash into soil reportedly helped yields for some crops such as tomatoes in the following months, with an increase in fruit size and number of harvests. Agricultural impacts were most likely the most costly impact type associated with the eruption with an overall estimated loss of up to Rp 377 billion (~NZ$ 39 million).

In the days following the eruption, lahars physically removed some low-lying farmland and irrigation structures through the erosion, scouring and overtopping of river banks. Adjacent fields were often affected by lahar and fluvial deposits and remained so during our field visits seven months after the eruption. The concerns over future lahars in the coming (October 2014 – March 2015) wet season likely meant farmers were not willing to attempt recovery of this farmland at this stage. However, ‘sand-mining’ of lahar deposits, often encouraged by the government, provides an alternative source of income and may reduce the threat from future lahars. There were no direct fatalities of livestock.
attributed to the eruption although pressures on feed supplies meant that some farmers chose to kill off or sell animals.

10.6 Mitigation Measures and Resilience

There were several mitigative measures that were implemented before the eruption occurred. For example, many pineapples were harvested in response to the second highest alert level being issued, residents covered parked vehicles, AC units and building ventilation inlets to prevent ash infiltration, and electricity was turned off in many houses immediately before evacuations. Various mitigation strategies occurred during the eruption as well including the replacement of vehicle filters to prevent further damage and general ash avoidance to reduce potential health impacts. In fact, some preparedness techniques that were implemented, although important as a preventative measure, turned out not to be necessary despite the extent of ash fall. For example, the oil refinery at Cilicap prepared air filters, although there is no evidence to suggest that these were actually required during the event.

Despite extensive building damage in proximal areas, roof structures appeared relatively resilient to tephra loading and many resisted total collapse, even with 200-500 mm thick deposits with most damage only occurring to the tiles and asbestos sheeting on roofs. Resilience to ash fall was evident in the diesel rail system where the number of train services and capacity was increased to cater for the higher number of passengers resulting from aviation and road transportation disruption. Although damage and disruption did occur to parts of the electricity network in Yogyakarta and other parts of Central Java, it was relatively localised and there were no reports of problems for the high voltage transmission network despite ash fall of around 20-30 mm. There were also few reports of communication issues in distal areas.

A proactive and collaborative approach was largely taken for tephra clean-up and recovery. Various people including workers and staff from the BPBDs, Provincial Public Works Agency, military, police, fire brigades, volunteers and many residents worked together to clean vehicles, public and residential buildings, trees and streets, and clear ash from roofs when rain was forecast. Spraying fine-grained ash with water and clearing immediately after was deemed effective for minimising ash remobilisation. The collection and disposal of tephra also appears to have been relatively effective, perhaps helped by the use of some material for construction purposes and associated value. Clean-up and initial recovery efforts were undertaken very quickly with 99% of over 25,000 residential properties reportedly repaired and new critical infrastructure services such as bridges and water tanks installed within about a month of the eruption. However, some clean-up processes such as the cleaning of electrical transformers appears to have been reactive, waiting to see if problems arose before taking any action. Some recovery processes were temporary such as the replacement of bridges with river crossings or military-built structures until funds permit more permanent structures.
11.0 LESSONS FOR FUTURE ERUPTIONS

Several lessons have been learnt from the 2014 eruption of Kelud volcano and associated impacts and response. Many can be applied to future eruptions in Indonesia and worldwide.

11.1 EMERGENCY PLANNING

- Awareness of the volcanic warning system and evacuation procedures was generally high in proximal areas. This highlighted the importance of strong pre-existing relationships between the various organisations involved including emergency management groups, the volcano observatory and community representatives. Recent training involving all parties likely aided the response.
- The strong relationships between groups and a variety of communication methods, both traditional and modern, allowed the quick dissemination of accurate information in most areas.
- The official CVGHM hazard map (Mulyana et al. 2004) was widely referred to by interviewees for its visual use in determining hazardous areas, particularly from lahars. However, such maps should be reviewed and updated if hazardous areas change, particularly following new eruptions and human activities such as sand mining. Various groups may base decisions on the information displayed within the CVGHM map and some expressed concerns that the lahar hazard depicted by the map may be out-dated. A lack of trust for official information may begin to arise if maps are not kept up-to-date.
- Compared to other volcanic hazards, there has been little focus on the threat posed by volcanic tephra fall in the area. The proximal and far-reaching impacts of volcanic tephra in February 2014 suggest that the hazard should receive more attention in future, perhaps through media such as the CVGHM hazard map.

11.2 EVACUATION AND RETURN

- Residents reacted quickly to the evacuation zoning associated with alert statuses and many outside of the official zones (some up to twice the distance) also evacuated. Such ‘shadow evacuations’ and the potential increased demand on transportation infrastructure in other urban areas should not be underestimated.
- Inhabitants of the local area were eager to return to check on properties, businesses, livestock and crops. Some did so within 24 hours of the eruption. Although this likely created challenging conditions for authorities, many seemed to heed additional advice such as to stay away from rivers due to the threat of lahars. The return of evacuees and reliable information provision upon return should be considered carefully in other locations worldwide.
- It should also be noted that the quick return of some evacuees likely minimised further impacts and economic loss following the eruption, particularly as roofs and streets were cleaned before heavy rain arrived. However, this increased life risk to some degree and many expressed concerns about residents returning so early, particularly due to the threat of lahars.
11.3 **Impacts on Tourism, Public Health, Infrastructure, Utilities and Agriculture**

- Despite numerous distal impacts from other eruptions in Indonesia, some in the recent past such as those from Sinabung volcano in the months preceding the Kelud event, there was a huge element of surprise that an eruption ~200 km away could cause so much disruption, including in Yogyakarta. This demonstrates the importance of contingency planning, and educational and media awareness for distal volcanic eruptions and associated impacts of ash fall in other cities with similar spatial settings worldwide.
- Lessons can be learnt from the various mitigative and proactive strategies that were taken to avoid loss both before and during the eruption, such as harvesting crops before an eruption starts and avoiding travel during ash fall if safe to do so. Protective measures to prevent ash infiltration into components, engines and buildings were also deemed successful.
- Similarly, the provision of timely advice to the public on mitigation strategies for reducing health impacts (e.g. staying indoors as much as possible, and the use of protective clothing and masks) may have played a role in the overall low incidence of health impacts reported to authorities.
- It was not evident whether some crops more resilient to tephra were purposefully selected but this could be considered in future, particularly in volcanically active agricultural regions.
- Tourism was negatively impacted through various attraction and infrastructure closures, particularly airports and temples, although aided by new opportunities near the vent in the following months. The net economic impact on tourism has often not been considered in detail as part of similar impact assessments associated with individual eruptions and further work could explore this.
- The report identifies a need for rapid and reliable tests to establish ash characteristics relevant to agriculture. The use of ash by the agricultural sector may reduce disposal challenges during future events.

11.4 **Clean-up**

- A collaborative and proactive approach to clean-up likely reduced continued impacts associated with the remobilisation of ash. Most clean-up processes were well planned and conducted effectively. However, the disposal of ash may present challenges where nearby land is unavailable or unsuitable for such uses following future events.
- Clean-up was helped by the use of ash for construction and agricultural purposes in some areas, adding a degree of value to the material. Other opportunities arose in the form of mining lahar deposits in river beds, which may reduce the threat from further lahars.
- Water use during clean-up was extensive and, amongst others, was used for cleaning vehicles, airport runways, substation transformers, buildings and trees. This may present challenges in other localities where water systems struggle to meet demand on a day-to day basis or in drier periods.
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Jakarta Globe (2014) Mount Kelud ash expected to fall on Jakarta. The Jakarta Globe


Kali Gendol (2014a) Interview with workers at the ticket office and café, Kali Gendol, Merapi, Yogyakarta, Indonesia. Conducted on 11 September 2014


Konto (2014) Interview with warung owners next to Konto River bridge, near Kandangan, East Java Province, Indonesia. Conducted on 20 September 2014

KVO (2014) Interview with staff at the Kelud Volcano Observatory, Sugihwaras Village, Ngancar District, Kediri Regency, East Java Province, Indonesia. Conducted on 20 September 2014


LSM Rumah Impian (2014) Interview with staff at LSM Rumah Impian (The Dream House), Yogyakarta, Indonesia. Conducted on 15 September 2014


Mahjum (personal communication, September 2014). Tour Manager, Kakadu Tour and Travel, Yogyakarta, Indonesia


Munjang (2014a) Interview with residents at a house being renovated in Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014

Munjang (2014b) Interview with farmer / Munjang resident in fields to south of Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014

Munjang (2014c) Interview with Munjang residents in centre of Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014

Munjang (2014d) Interview with Munjang residents at house which was rebuilt following fire resulting from hot ballistic impact, Munjang Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014


PLN (2014) Interview with staff at PLN Perusahaan Listrik Negara (the state owned electricity company), Yogyakarta, Indonesia. Conducted on 14 September 2014

PMI (2014) Interview with staff at PMI Palang Merah Indonesia (Indonesian Red Cross Society), Yogyakarta, Indonesia. Conducted on 17 September 2014


Purwana (personal communication, September 2014). Translator and Guide, Kakadu Tour and Travel, Yogyakarta, Indonesia


Selorejo (2014a) Interview with warung owners at Selorejo Hamlet, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014

Selorejo (2014b) Interview with sand miner in Sambong River, below Selorejo dam, Pandansari Village, Ngantang District, Malang Regency, East Java Province, Indonesia. Conducted on 21 September 2014


Health Hazards Network protocol ratified by IAVCEI, USGS, GNS Science, Cities and Volcanoes Commission, available online at www.ivhhn.org


