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## ► To cite this version:

Jean-Claude Thouret, M. Taillandier, E. Arapa, E. Wavelet. Vulnerable settlements to debris flows in Arequipa, Peru: population characteristics, hazard knowledge, risk perception, and disaster risk management. *Natural Hazards*, 2023, 10.1007/s11069-023-06167-8. hal-04261478

**HAL Id: hal-04261478**

**<https://uca.hal.science/hal-04261478v1>**

Submitted on 10 Nov 2023

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## Natural Hazards

# VULNERABLE SETTLEMENTS TO DEBRIS FLOWS IN AREQUIPA, PERU: POPULATION CHARACTERISTICS, HAZARD KNOWLEDGE, RISK PERCEPTION, AND DISASTER RISK MANAGEMENT

--Manuscript Draft--

<b>Manuscript Number:</b>	NHAZ-D-23-00511R2
<b>Full Title:</b>	VULNERABLE SETTLEMENTS TO DEBRIS FLOWS IN AREQUIPA, PERU: POPULATION CHARACTERISTICS, HAZARD KNOWLEDGE, RISK PERCEPTION, AND DISASTER RISK MANAGEMENT
<b>Article Type:</b>	Manuscript
<b>Keywords:</b>	Hazard; Flood; Risk perception; Disaster Risk Management; statistics; Arequipa.
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<b>Abstract:</b>	<p>Approximately 75,000 people live in areas prone to volcanic hazards and floods in the large city of Arequipa, Peru. We have conducted three different surveys involving c. 280 respondents to appraise the socio-economic characteristics of urban dwellers living in informal settlements along two ravines, the extent to which they know hazards, perceive risk, and how they behave in case of disaster. This study also assesses how local communities consider, and civil authorities implement mitigation procedures in the city. The statistical analysis of the survey datasets included univariate, bivariate and multivariate techniques together with hierarchical agglomerative clustering. Low-income urban dwellers, with a minimum or without education, represent almost 32% of the vulnerable population living in four districts. Almost 45% of the respondents have a regular to minimum knowledge of hazards, and half of the population is worried or uncertain about volcano and debris flow threats. A large proportion of dwellers trust early warning messages, but almost half of them check them out before evacuating. Overall, between a third and half of people living in the four most exposed districts of Arequipa seem to be quite vulnerable in case of an imminent debris flow.</p> <p>Interviews and focus groups with risk managers aimed to understand why planning emergency operations and risk mitigation are not as efficient as the municipality and the communities would expect in Arequipa. Several issues hinder an adequate disaster risk management, as the underlying vulnerability factors of the exposed population are not accounted for. Under-investment in disaster risk management has led to diminish accountability among the risk managers and involvement of dwellers.</p>
<b>Response to Reviewers:</b>	In response to the comment of reviewer 6: "The only issue I have with the manuscript is that there were too many descriptions of the hypothesis and too many different hypothesis presented in different parts of the manuscript. Please just stick to one

hypothesis and present that at the earliest part of the manuscript where relevant. », we revised two sections of the manuscript as follows:

Line 119 and the following lines: these are the four “working hypotheses”, to which we come back while presenting the main results in the conclusion. We alluded to these working hypotheses in Lines 781-782.

Line 530 and Lines 532-545: we formulate and discuss the role of three parameters that would explain how respondents behave when they are facing flows and floods. These three parameters derive from data obtained through Factorial Correspondent analysis (FCA), and shown in biplots (Fig. 7). As we deal with FCA, the data shown in biplots represents mathematical hypotheses on links between pairs of parameters: 1) role of residence time in Arequipa on empowerment, i.e., enhancement of capabilities of people when they face hazardous flows, 2) role of interest in flows on enhancing people capabilities in similar situations, and 3) origin of knowledge and experience about flows.

Thus, FCA (one of the bivariate analyses) enables us to find out statistical links between pairs of parameters of interest. For example, we may link “time of residence in Arequipa” and “enhancement of capabilities of people”, based on the assumption that people living longer on the flanks of the volcano and in this hazard-prone environment would get more experience and would learn how to overcome the impacts of flows.

Please see how we have described the FCA objective in Lines 271, 280 and 281.

Simultaneously, multivariate analytical techniques (MCA, HAC) help us identify groups of people according to multiple parameters, including social characteristics, hazard knowledge, risk perception. We expected that the multivariate analysis of multiple parameters would enable us to appraise the behaviour of people in case of crisis.

Bivariate and multivariate techniques are complementary analyses, and together with univariate analysis, they enabled us to deal with different issues related to the “working hypotheses” that we presented at the beginning of the article, section 1.1 (Lines 120-133).

1           **VULNERABLE SETTLEMENTS TO DEBRIS FLOWS IN AREQUIPA, PERU:**  
2                   **POPULATION CHARACTERISTICS, HAZARD KNOWLEDGE, RISK**  
3                   **PERCEPTION, AND DISASTER RISK MANAGEMENT**

4  
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19                   Revised and re-submitted to *Natural Hazards*

20                                   24 August 2023

34 **ABSTRACT**

35 Approximately 75,000 people live in areas prone to volcanic hazards and floods in the large  
36 city of Arequipa, Peru. We have conducted three different surveys involving c. 280 respondents  
37 to appraise the socio-economic characteristics of urban dwellers living in informal settlements  
38 along two ravines, the extent to which they know hazards, perceive risk, and how they behave  
39 in case of disaster. This study also assesses how local communities consider, and civil  
40 authorities implement mitigation procedures in the city. The statistical analysis of the survey  
41 datasets included univariate, bivariate and multivariate techniques together with hierarchical  
42 agglomerative clustering.

43 Low-income urban dwellers, with a minimum or without education, represent almost 32% of  
44 the vulnerable population living in four districts. Almost 45% of the respondents have a  
45 regular to minimum knowledge of hazards, and half of the population is worried or uncertain  
46 about volcano and debris flow threats. A large proportion of dwellers trust early warning  
47 messages, but almost half of them check them out before evacuating. Overall, between a third  
48 and half of people living in the four most exposed districts of Arequipa seem to be quite  
49 vulnerable in case of an imminent debris flow.

50 Interviews and focus groups with risk managers aimed to understand why planning  
51 emergency operations and risk mitigation are not as efficient as the municipality and the  
52 communities would expect in Arequipa. Several issues hinder an adequate disaster risk  
53 management, as the underlying vulnerability factors of the exposed population are not  
54 accounted for. Under-investment in disaster risk management has led to diminish  
55 accountability among the risk managers and involvement of dwellers.

56 **Keywords:** hazard; flood; risk perception; disaster risk management; statistics; Arequipa.

57

58 **1.INTRODUCTION**

59

60 Disaster impacts in Latin America are felt in the cities, affecting the poorest  
61 populations hardest: at least 111 million urban dwellers live in informal settlements that are  
62 highly vulnerable to disasters (Charveriat, 2000, UN, 2018). Large cities (above 500,000  
63 inhabitants) are vulnerable to either cyclones, floods, droughts, earthquakes, landslides, and  
64 volcanic eruptions – or a combination of those. Recent earthquakes and/or tsunamis exacted a  
65 heavy toll and caused damage estimated to several billion US\$ in Peru, Chile and Ecuador

66 (Alves, 2021; Statista, 2022). River floods, mudflows and flash floods claimed at least 317  
67 lives, affected over 300,000 people, and caused heavy damage over the past ten years in South  
68 America (Statista, 2022). Peru ranked in the highest risk index due to the number of people  
69 exposed to seismic events per year (e.g., Tavera, 2020; Alves, 2021). Volcanic eruptions are  
70 less frequent than earthquakes, but the single VEI 6 eruption of Huaynaputina in 1600 CE  
71 wreaked havoc in Southern Peru and neighbouring countries, and had a global climate  
72 impact (Stoffel et al. 2015). Volcanic eruptions displaced 3,000 people and livestock around  
73 Ubinas, Peru in 2009 and 2014 (Statista, 2022). Currently, 14 active volcanoes are hazardous  
74 for the two million people living within a distance radius of 30 km around the active vents,  
75 while the most active Nevado Sabancaya and Ubinas near Arequipa are closely monitored by  
76 IGP and INGEMMET (Aguilar et al., 2021; Del Carpio, 2022).

77 Crucial to reduce the disaster risk of life and economic loss in cities are people's  
78 preparedness, good governance and resilient infrastructure. This work has the double purpose  
79 to assess the characteristics of vulnerable dwellers in one of the most exposed cities to natural  
80 hazards, in particular flows and floods, and to unravel some socio-economic and political  
81 factors that may hamper disaster risk management.

## 82 1.1. Scope and objectives

83 The Index for Risk Management measures the risk of disaster and humanitarian crises  
84 in Latin American countries (INFORM, 2018). It ranks Peru third with one of the largest  
85 populations exposed to natural disasters with an average of 2.6 major disasters per year, only  
86 exceeded by Colombia and Brazil (Charvériat, 2000). In the past 20 years, around 73,300  
87 natural disasters occurred in Peru according to the National Civil Defense Institute (INDECI).  
88 The most catastrophic natural disaster in the Peru's history was an earthquake combined with  
89 a subsequent landslide that caused ca. 67,000 fatalities in Ancash, northern Peru on 31 May  
90 1970 (Casaverde, 1995). Two earthquakes near Arequipa in 2001 and Ica in 2007 caused 679  
91 fatalities and affected ca. 655,000 people (Tavera, 2002, 2020; Tavera et al., 2008). Floods,  
92 debris flows, and landslides affected almost 4.50 million inhabitants in Peru over the last  
93 twenty years (Alves, 2021). Along the Peruvian Coast and the western flank of the Peruvian  
94 Andes, extreme floods have been associated with El Niño events (e.g., 1982-83, 1997, 2015).  
95 Extreme rainfall and floods in Peru have also been reported during La Niña episodes in 2009,  
96 2012 and 2014 (Póveda et al., 2020).

97 This article presents results obtained from a research programme on hazards and impacts in  
98 the city of Arequipa funded by the French I-Site Cap 2020-2025, devoted to the effects of

99 natural disasters and socio-economic vulnerability of large, developing cities exposed to  
100 nearby volcanoes such as Arequipa. An earlier paper by [Thouret et al. \(2022a\)](#) described and  
101 modelled the impacts of potential tephra fallout and floods and debris flows on the vulnerable  
102 building stock of the city. Previous publications ([Vargas et al., 2010](#); [Martelli, 2011](#); [Thouret  
103 et al., 2013, 2014](#)) described the setting of the city as well as the [principal hazards, among](#)  
104 them flash floods, HCFs and DFs or lahars being the most frequent. Recent studies also dealt  
105 with assessment and modelling of torrential flood hazards in Arequipa (e.g., [Mazer et al.,  
106 2020](#)). [Charbonnier et al \(2020\)](#) modelled the extent and runout of pyroclastic density currents  
107 (PDCs) from El Misti.

108 This article focuses on socio-demographic characteristics of urban dwellers living along  
109 valleys that convey frequent floods and flows, and how they [understand](#) hazards and perceive  
110 risk [based on](#) recurrent hazards, which occur every 2.7 years on average since 1915 ([Thouret  
111 et al., 2022a](#)). [Figure 1](#) summarizes the objectives and methods used in this work:

- 112 1. To define the socio-demographic, economic characteristics and origin of district dwellers to  
113 assess the vulnerability of Arequipa's population living in exposed settlements.
- 114 2. To correlate the knowledge of hazards with levels of risk perception at the individual scale,  
115 with the aim to appraise their potential behaviour in case of an imminent flow event.
- 116 3. To identify how public institutions and neighbourhood boards manage disaster risk from  
117 floods and flows, with the aim to unravel potential sources of divergences between the district  
118 and city municipalities.

119 [Four working hypotheses have guided the research project:](#)

- 120 1. A majority of the low- to modest income population lives along the margins of the ravines  
121 where land is cheap or obtained through [informal occupation](#), and housing poorly equipped  
122 and ill-protected. There, [migrants from the Cordillera, who are not acquainted with El Misti  
123 volcano and the hazard-prone environment, have been mixed with people who originally lived  
124 in the city area.](#)
- 125 2. Although urban dwellers have experienced the adverse effects of relatively frequent flows,  
126 a majority of them are not confident about how to behave during emergencies due to their  
127 limited knowledge of the occurrence, timing and consequences of the flows.

128 3. Actions of neighbourhood boards against flow **impacts** may not be sustained due to limited  
129 resources and lack of civil protection works, hence the urban dwellers feel that they are left  
130 behind by the municipality.

131 4. Potential conflicts have emerged between officials from overlapping institutions and  
132 administrations (districts, city hall and region of Arequipa, and state) in disaster risk  
133 management policy.

## 134 **1.2. Terminology**

135 Risk can be measured as the product of “probability × losses”, where the probability is a  
136 function of hazard and the losses depend on both exposure and external and internal  
137 vulnerability (Aspinall and Blong, 2015), comprising “the capacity of a community to cope  
138 with the consequences of a disaster” (UN, 2016; UNDRR, 2017). Risk assessment includes  
139 other components such as hazard knowledge, risk perception and community resilience  
140 (Gaillard, 2007, 2008; Gaillard and Dibben, 2008; Paton et al., 2008; Lavigne et al. 2008;  
141 Donovan et al., 2018; Thouret et al., 2022b).

142 Risk perception is not restricted to its affective response (e.g., feelings about a volcano), but it  
143 has “the double dimension of perceived severity and probability of occurrence” (*in*: Thouret  
144 et al., 2022b). Here, we consider the double dimension of risk perception together with a  
145 number of associated variables from social sciences: “concern and hazard salience; hazard  
146 likelihood and severity; experience with the source of the risk; past behaviour and impact of  
147 memory on future behaviour; origin of experience and knowledge; flow attractiveness;  
148 empowerment and self-confidence, and; trust in authorities” (e.g., Davis et al., 2005).

149 According to the UNDRR definition (2017), “Disaster risk management is the application of  
150 disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing  
151 disaster risk and manage residual risk, contributing to the strengthening of resilience and  
152 reduction of disaster losses”. Disaster risk management can be broken down into three actions  
153 (UNDRR, 2017): 1) “*prospective* disaster risk management” to avoid new or increased risk;  
154 2) “*corrective* disaster risk management” to remove or reduce risk, and; 3) “*compensatory*  
155 disaster risk management”, which involves affected communities at the local level. The  
156 compensatory disaster risk management includes preparedness, response and recovery  
157 activities, but also different financing instruments. By examining the disaster risk  
158 management policy in the city of Arequipa, we will consider to which extent existing plans of  
159 urban development (2016-2021) and disaster risk reduction (2019-2021) of the region of



160 Arequipa set out the goals together with relevant actions from officials and communities to  
161 accomplish these objectives.

162 Lahars (volcanic debris flows) and rain-triggered debris flows are potentially destructive  
163 water-saturated mass-flows in mountainous regions and in areas where steep slopes cut down  
164 into loose sediment. Lahars can be divided into two categories using sediment concentration,  
165 grain-size distribution and bulk density (Thouret et al., 2020, and references therein): 1.  
166 Debris flows (DFs) comprise a solid phase of at least 60 vol%, thoroughly mixed with water.  
167 2. Hyperconcentrated flows (HCFs) are two-phase flows transporting between 20 and 60  
168 vol% of sediment.

### 169 **1.3. Hazard and risk setting and population of Arequipa**

170 Arequipa, Peru's second largest city (1,137,087 inhabitants, INEI, 2018), is located in  
171 one of the fastest growing regions in the country, at the contact between the Andean highlands  
172 and the coast. Arequipa is situated at c. 2300 masl. in a tectonic basin between the west flank  
173 of the Western Cordillera and the Coastal batholith to the south (Thouret et al., 2022a). This  
174 basin was filled by ignimbrite deposits, partly covered by volcanoclastic deposits that make  
175 up the foothills of the Nevado Chachani (6080 masl.), El Misti (5822 masl.) and Pichu Pichu  
176 (5600 masl.) volcanoes. Chachani and Pichu Pichu are extinct volcanoes, but El Misti active  
177 stratocone currently exhibits seismic and fumarolic activity (Aguilar et al., 2021).

178 Arequipa was founded in 1540 AD, but the early urbanized area remained close to the Río  
179 Chili, mainly on its eastern side, currently known as the historic Centre (*Cercado*), about 17  
180 km from El Misti volcano. From 1960 onwards, the historic Centre did no longer restrain the  
181 demographic and construction growth. The rapid sprawl of the city towards the volcano was  
182 influenced by migrations due to the drought in the Cordillera and the economic growth of the  
183 Arequipa region (Gutiérrez et al., 1992). The urban area grew mainly to the north and east of  
184 the historic Centre, forming poorly designed suburbs and informal settlements, to cover about  
185 68 km<sup>2</sup> in the 1970's (Thouret et al 2014; Arela, 2021). In recent years, accelerated growth led  
186 to the expansion of peripheral areas towards the lower flanks of the Misti volcano and  
187 Chachani to the west, quadrupling its original area and reaching around 276 km<sup>2</sup> (Fig. 2;  
188 Arela, 2021). Over the 2007-2017 intercensal period, the annual economic rate accelerated to  
189 6.4% in the province of Arequipa, with a population increase of 2.8% due in part to migration  
190 from the regions of Arequipa, Puno, and the Altiplano in general.

191 Between 50,000 to 75,000 inhabitants live < 1 km from the ravine network and Río Chili  
192 likely to be affected by flash floods or lahars, and many more if El Misti volcano, located 17  
193 km NE of the city centre, produced tephra-fall and PDCs (Thouret et al., 2001; Charbonnier et  
194 al., 2020; Thouret et al., 2022a). Hydrometeorological events are the most recurrent hazards,  
195 inducing c.70% of all disasters that have occurred in the city (INDECI, 2020). Debris flows  
196 (DF) and hyperconcentrated flows (HCF) induced fatalities (at least 34 since 1915) and  
197 injuries, affected approximately 113,040 people and damaged 27,910 buildings, street  
198 network and infrastructure every 2.7 years on average in the city (Thouret et al., 2022a). One  
199 of the most destructive flows occurred on 8 February 2013 along the ravine Venezuela (Fig.  
200 1). Triggered by heavy rainfall (124.5 mm in 3 hours), the hyperconcentrated flows caused 5  
201 fatalities and impacted approximately 23,000 inhabitants (Ettinger et al., 2015).

202 The environment of Arequipa is propitious to flash floods (FF) and mass flows (HCF and  
203 DF), as the result of semi-arid climate ( $\leq 150$  mm a year), with concentrated thunderstorms  
204 often delivering more rainfall than the average monthly amount (Thouret, 2018; Thouret et  
205 al., 2022a; see also Mazer et al., 2020). A series of factors favour torrential floods across  
206 Arequipa: (i) Short-lasting (3–4 h) and intense rainstorms (26–42 mm/hour) typical of a  
207 semiarid climate, (ii) rapid runoff (30–60 minutes) in small mountainous catchments (18–40  
208 km<sup>2</sup>); (iii) the impervious network of roads and waterproofing of the built-up area that  
209 increase runoff, and; (iv) the steep, bare slopes of El Misti's foothills carved by ravine  
210 channels, which are filled by loose volcanic debris mixed with household and industrial waste  
211 (Thouret et al., 2022a).

212 A network of *quebradas* or *torreteras* (local name of ravines, usually dry but conveying  
213 flows under Austral summer rainfall) drain the SW flank of Misti, cross the city in a NE-SW  
214 direction, and eventually converge at the permanent artery Río Chili (Fig. 2; Thouret et al.,  
215 2013, 2014). The main ravines are San Lázaro, Venezuela-Miraflores, Huarangal-Mariano  
216 Melgar and Paucarpata: both San Lázaro and Huarangal cross the studied area (Fig. 2; ESD  
217 Fig. 1). Ravine channel and terraces narrowed due to urban sprawl, causing overflows during  
218 the rainy season (January-March) when the maximum flow of the riverbed is exceeded from  
219 an average discharge c. 19.50 m<sup>3</sup>/s to a maximum of 124–425 m<sup>3</sup>/s, respectively (Thouret et  
220 al., 2022a), affecting adjacent houses and urban dwellers.

## 221 2. METHODS AND DATA ACQUISITION

### 222 2.1. Field surveys and data acquisition

223 We conducted three surveys including semi-directed interviews in September 2018  
224 and 2019 to appraise the socio-economic characteristics of the population and to evaluate  
225 hazard knowledge and risk perception of the population in four districts adjacent to two  
226 ravines. Six researchers from the University of San Agustín of Arequipa (UNSA), the  
227 Instituto Geofísico del Perú, the University of Nariño (Pasto, Colombia) and the Université  
228 Clermont-Auvergne (France) collected a dataset from 220 households in 14 neighbourhoods  
229 of four districts along both margins of the two valleys: Alto Selva Alegre and Miraflores on  
230 the W and E margins of Qda San Lázaro to the North, and Mariano Melgar and Paucarpata on  
231 the W and E margins of Qda Huarangal-Mariano Melgar to the NE of the city (ESD Fig. 1).  
232 According to the INEI 2017 national census, the total population of the four districts is  
233 350,773, i.e., c. 31% of Arequipa's inhabitants on a surface area of 151.26 km<sup>2</sup>. A district has  
234 an average area of 37.8 km<sup>2</sup> and an average density of 2319 inhabitants/km<sup>2</sup>, the Alto Selva  
235 Alegre district with 68 km<sup>2</sup> being the largest, and Paucarpata the most populated one with  
236 135,923 inhabitants. These densely populated suburbs have been constructed north and east of  
237 the historic centre over the period 1930 and 1970 (INEI, 2018).

238 The surveys focused on the most exposed, ill-equipped neighbourhoods extending on low  
239 terraces near ravine channels, which are characterized by a combination of shanty homes,  
240 small and modest to regular houses, and a few 2 to 3-storey edifices on river banks (Thouret  
241 et al., 2013). Economic activity in the suburbs is dominated by informal jobs, handicraft,  
242 followed by employees or unskilled workers in small businesses, and civil servants (see  
243 section 3.1 below). After the 2018 national census at the district scale, we have collected data  
244 in 2019 and 2020 on population, economic activity, and emergency facilities from the district  
245 municipalities. A Trimble TC 1000 GIS mapper device, Google Earth maps and topographic  
246 maps have been used in QGIS to locate and collate structural observations on homes, offices,  
247 schools, health centres, churches, sport facilities, and markets.

248 Few limitations encumbered the field surveys on characteristics of people and their dwellings,  
249 which we collected in Spanish. We interviewed respondents available in the household, either  
250 male or female, through a random door-to-door approach with the help of local students. One  
251 limitation may be representativeness. Among 950,000 people around Misti, 50,000 to 75,000  
252 live along the ravines and the Río Chili. Surveys involving 279 respondents from 220  
253 households, which host at least 900 people, represent approximately 0.2% of people and 0.4%  
254 of homes in four districts. However, mapping the homes involved 14 neighbourhoods (c.

255 9,800 people) most exposed to flows and floods, hence a little less than 3% of the population  
256 and 5% of homes in the four districts.

## 257 2.2. Statistical analyses

258 Statistical analyses explored a set of as many as 51 variables collected through three surveys  
259 (Fig. 1; ESD Text). The first group of 17 variables helped define the demographics and socio-  
260 economic status of the dwellers living in the most vulnerable suburbs along the ravines. The  
261 second group of 11 variables determined the hazard knowledge among these people. The third  
262 group of 23 variables helped assess their risk perception. Table 1 summarizes the statistical  
263 methods and techniques together with their purposes for coding, quantifying and validating  
264 three groups of variables. Statistical investigation conducted with the R software has involved  
265 four operations: univariate, bivariate and multivariate analyses together with clustering  
266 techniques (e.g., Chambers et al., 2018; Taillandier, 2019).

267 1. Univariate analysis (UA, Table 1) is the first step for exploring and preparing a dataset for  
268 further analysis. UA summarizes descriptive statistics and provides graphical representations  
269 for their univariate distribution.

270 2. Bivariate analysis (BA, Table 1) involves the analysis of two variables with the aim of  
271 testing simple association or relationship between two variables and attributes. The Chi-  
272 square test (with Monte Carlo simulations) aims to compare observed results with the  
273 expected results and to determine whether the variables are independent or dependent (ESD  
274 Table 1); in other words, to find out whether the difference between observed and expected  
275 data is random or due to a relationship between the variables under study. The Chi-square  
276 tests two hypotheses: either, the null hypothesis  $H_0$  (i.e., the categorical variables are  
277 independent, without any relationship), or the alternative hypothesis  $H_1$  (i.e., the categorical  
278 variables are dependent, with a relationship). The hypothesis  $H_0$  can be rejected when the p-  
279 value is below the risk alpha threshold of 0.5%.

280 In BA, Factorial Correspondence Analysis (FCA) was used to study links (e.g., cause to effect  
281 relationship) between the pairs of variables of interest, which resulted from the  $\chi^2$  test, and  
282 further explore correlations and oppositions of categorical variables. One of the BA  
283 information derives from the Burt table (ESD Table 2, see below, 3b).

284 3. Multiple Correspondence Analysis (MCA) is run to examine the links between several  
285 qualitative variables. MCA is a data analysis technique used to detect and represent

286 underlying structures in a large categorical dataset (Abdi and Valentin, 2007). MCA  
287 represents data as points, in biplot graphs, and consists of the following steps (Table 1):

288 a) Eigenvalues provide the variance while the sum of eigenvalues is the total inertia. We  
289 retained dimensions containing the most pertinent or relevant information from a dataset  
290 totalling 38 variables (5 from Survey A, 10 from Survey B and 23 from Survey C). Benzécri  
291 correction (Benzécri, 1979) applied to the number of dimensions (inertia) helps estimate how  
292 much information is included in each dimension. To carry out the MCA, we selected the  
293 smallest number of dimensions i.e., the first five dimensions which hold over 91% of the  
294 information available from the whole dataset (ESD Fig. 2).

295 b) MCA biplots show the relationships between attributes of all variables, quantified by  
296 contribution to the dimensions and coordinates of each attribute on the dimensions. ESD  
297 Table 2 shows the coordinates, square cosines and contributions, which help identify the most  
298 contributory variables along the five principal MCA dimensions. The coordinates indicate the  
299 position of attributes, the most distant from the barycentre of each biplot contributing most.

300 4. Hierarchical Agglomerative Clustering (HAC; Table 1) constructs groups of people on the  
301 basis of the MCA results (MCA was run before HAC to transform qualitative variables into  
302 continuous variables). The HAC goal is to build up clusters of people who share similar  
303 characteristics, i.e., showing intra-class homogeneity. These clusters should be dissimilar  
304 from one another, i.e., showing inter-class heterogeneity. Each clustering is performed using a  
305 distance matrix that expresses the distance between each individual, two at a time. These  
306 individuals will be grouped according to the similarity criterion defined by the distance matrix  
307 and will thus form clusters.

308 HAC consists in four steps: 1) A factor map helps identify clusters and their number on the  
309 basis of distance between attributes of the individuals forming a cluster; 2) Another Chi-  
310 square test allows to identify the most discriminant variables; 3) We detect the most frequent  
311 attributes of variables in each of the clusters; 4) A study of paragons, i.e., the five most  
312 representative people in each of the four clusters, helps identify the attributes of the most  
313 discriminant variables, and we compare them with the results of the three previous steps. For  
314 example, cluster 1 is characterized by individuals « who like to observe lahars », as verified  
315 by that the majority of the paragons of cluster 1 who answered that « they like to watch these  
316 flows ».

317 **2.3. Survey on disaster risk management policy with civil authorities and communities**

318 Meetings, semi-structured interviews and focus groups were conducted with identified  
319 key actors, i.e., leaders of communities, officials of agencies in charge of disaster risk  
320 management, mayors of districts and the city governing body, to analyze how civil authorities  
321 and communities were organized and carried out relief, prevention and mitigation.

322 Interviews were conducted using the “snowball sampling method” (Van Meter, 1990; Baltar  
323 and Brunet, 2012), which was based on a limited sample of population, i.e., a small subgroup  
324 of people from the city hall and district municipalities in charge of urban management in  
325 general. Seven semi-structured interviews included 5 to 10 persons each and used a guide of 27  
326 questions related to training, knowledge and skills among local civil authorities, regarding  
327 proactive, corrective and compensatory disaster risk management policies: (ESD Table 5).  
328 Meetings of focus groups were held in each of the four districts, led by the Mayor of each of  
329 the district municipality, accompanied by the officials in charge of the urban environment and  
330 risk disaster management, as well as leaders of neighbourhoods, who represented their  
331 communities.

332 Information collected from interviews and focus groups was analysed using the matrix analysis  
333 method (Bonilla and Rodríguez, 2000), whose purpose is to organize, structure and validate the  
334 qualitative dataset. With the objective of obtaining a valid perspective about the collected data,  
335 we grouped statements provided by key actors using a triangulation of qualitative data, which  
336 stem from semi-directed interviews, meetings, and focus groups. This method allows  
337 visualizing a problem from different angles, so that findings can be consistent and validated  
338 (Okuda & Gómez-Restrepo, 2005). The application of the matrix analysis method helps the  
339 researcher to evaluate the level of coherence and links between the hypotheses, proposed  
340 objectives and the answers to questions.

### 341 **3. RESULTS**

#### 342 **3. 1. Demographic and socio-economic characteristics of the district dwellers**

343 Survey A included seven groups of questions to appraise the socio-demographic and  
344 economic characteristics of the population living on both sides of the ravines (See questions  
345 in EDS text): (1) Gender, age group, and marital status; (2) Household composition and age  
346 groups; (3) Education level; (4) Socio-professional categories; (5) Number of contributory  
347 persons and monthly income; (6) Geographical origins of respondents, parents and  
348 grandparents, and (7) Time living in the area. The results of the survey A were analysed using

349 uni, bi- and multivariate analyses of the dataset from 279 respondents (Fig. 3A, B). Table 2  
350 summarizes the survey results, allowing us to distinguish six socio-demographic and  
351 economic groups from the least vulnerable (groups A, B and C) to the most vulnerable  
352 individuals (groups D, E and F) (Table 2). This is based on four principal characteristics: 1)  
353 age group, 2) education level, 3) monthly wage above or below the national minimum wage  
354 (fixed to 930 PEN by a Presidential decree in April 2018, i.e., 230 € or 240 US\$), and 4)  
355 origin with respect to the volcano and the city, which has a role on hazard knowledge.

356 As a result, vulnerable, low-income urban dwellers with a secondary education (Groups E and  
357 F) represent almost 20% of the cohort, to which we add 12% of urban dwellers (Groups D and  
358 F) without or a minimal education. In contrast, a majority of the respondents (Groups A and  
359 B, almost 55%) appear less vulnerable: young and mature adults, with at least a secondary  
360 education level, and a monthly income above the minimum wage. We provide more detail on  
361 each group below:

362 The largest group B (ca. 39%, Table 2) includes young and mature adults (19 to 30 and 31 to  
363 60 years) who attended primary and secondary school, and a few of them high school. Their  
364 wage exceeds the national minimum, while these people came from outside of Arequipa.  
365 Group A (ca. 16%) is identical to Group B regarding the age group and monthly wage  
366 characteristics, but the level of education is slightly better, and the origin is different, as  
367 Arequipa is their birthplace.

368 Group C (20.50%) includes elderly and young people (over 60 years and 12 to 18 years).  
369 Their education level corresponds to either primary and secondary school or high school for  
370 some of them. Their monthly salary is above the national minimum, and these people came  
371 from various origins near and outside Arequipa.

372 Both groups D and E (c. 12%) present vulnerable young and mature adults and elderly people  
373 (10 to 30, 31 to 60, and > 60 years), with primary or secondary education. Group D, the  
374 smallest (c. 3%), without education, and a low-income (monthly salary *below* the national  
375 minimum), is more vulnerable.

376 The small Group F (c. 9%) includes the most vulnerable people, either elderly, adolescents or  
377 children (>60 years, 12 to 18 and 0 to 11 years). They have reached low education levels or  
378 remained without education, and their income is low, as the monthly salary stays *below* the  
379 minimum national wage. They came from distinct regions near and outside Arequipa.

380 We compare this low- to middle-income population sample (Fig. 3A-B, Table 2) with the  
381 socio-demographic data at the scale of the city according to the 2017 National Census (INEI,  
382 2018; Fig. 4) to highlight a few social and economic characteristics that determine how  
383 vulnerable urban dwellers can be.

384 The population of the studied districts shows a similar young demographic structure, with a  
385 largest proportion of the population whose age is below 40 years old (c. 45% of the  
386 inhabitants), while an almost equal proportion of people over 40 years old (c. 28%) and under  
387 18 years (c. 27%) (Fig. 4). Approximately 58% of the district households consist of 3 to 6  
388 persons living under the same roof, but 41% of the households also include one or two  
389 children and 34% one or two grandparents.

390 The studied suburbs include more people with or without a minimal education than the  
391 average urban dwellers in Arequipa: ca. 75% of respondents attended primary or secondary  
392 school, while 20.50% earned a higher education diploma. The 2017 national census (Fig. 4)  
393 indicates that less than the majority of the city inhabitants (c. 43%) attended secondary  
394 school, followed by less than a third of them attending either elementary school (29.2%) or  
395 high school (28.1%).

396 A little less than 77% of the respondents declare a that they earn over the minimum wage 930  
397 PEN (229 €), but almost 34% are ‘informal’ workers (unregistered workers holding unskilled  
398 jobs), while almost 21% are housewives. However, an overwhelming 79.50% of the  
399 respondents own their house, as they inherit it from, or live with their family under the same  
400 roof.

401 Birthplace or migration origin plays a role on the knowledge of hazard and perception of the  
402 risk posed by a volcano and a ravine network, as three quarters (74%) of the respondents were  
403 not born in Arequipa, having a minimum knowledge about volcanoes. However, almost 72%  
404 of respondents have been living in Arequipa for a period of at least 16 years. About two thirds  
405 of dwellers immigrated in the city area from a distance > 100 km, mainly from the region of  
406 Puno (Altiplano without volcanoes), whereas 22% of the dwellers were born within a distance  
407 of 30 km of El Misti summit in the surrounding department of Arequipa (Fig. 3B).

### 408 **3.2. Hazard knowledge**

409 To estimate the knowledge of hazards among the population living along the two  
410 valleys, survey B contained 11 questions around the following five themes (EDS Text): (1)



411 name of neighbouring volcanoes and date of the most recent eruption of El Misti, (2) ability to  
412 read the Misti hazard-zone map and locate the neighbourhood, (3) three most frequent  
413 volcanic threats in the area, (4) lahar occurrence, timing and fatalities, and (5) eruption  
414 duration and lahar arrival time. Figure 5 presents the results of a univariate analysis of the  
415 survey B (Fig. 5), while Table 3 distinguishes four levels of knowledge among 118 dwellers,  
416 based on frequency analysis from the Survey B dataset.

417 We computed the scores of knowledge on the basis of indicators corresponding to the  
418 attributes of 11 variables. The resulting score ranges from the lowest 0 to the highest  
419 (expected) 24. The distribution of scores is almost symmetric and does not follow a normal  
420 law (the hypothesis  $H_0$  has been rejected based on the Shapiro-Wilkinson test); thus, the  
421 equidistant (= equal width) discretization method may be more appropriate. We computed the  
422 range of classes as follows:

$$423 \quad a = (max - min) / k,$$

424 where  $k$  indicates the number of expected classes, which yields:  $a = (23 - 0) / 4 = 5.75$ .

425 Thus, the class 1 extends between the score thresholds 0 and 5.75, class 2 between 5.75 and  
426 11.5, class 3 between 11.5 and 17.25, and class 4 between 17.25 and 23. We obtained a  
427 distribution of scores into four groups, with an interval of about six units.

428 Overall, the majority of respondents (c. 55%) demonstrate a good knowledge of hazards,  
429 including <6% having acquired a very good knowledge at school or from experiences with  
430 past flow events (Table 3). In contrast, we estimate that almost 45% of the respondents  
431 possess a regular to minimum knowledge of hazards. The adjective *regular* is assigned to  
432 hazard knowledge shared by ca. 35% of urban dwellers, because they know the occurrence of  
433 lahars and floods, but they cannot read a hazard-zone map and ignore the timing or the effects  
434 of past flow events.

435 A few key answers to survey B questions help us to better estimate the level of urban  
436 dwellers' knowledge, based on univariate analysis (Fig. 5):

437 An overwhelming proportion (c. 97.50%) of the respondents were able to name several  
438 volcanoes surrounding the city of Arequipa. However, as many as three quarters of the  
439 persons do not know or cannot recall the date of the most recent eruption of El Misti. Almost  
440 three thirds of the respondents (c. 74%) cannot read a hazard-zone map and are unable to

441 locate their district, let alone their own neighbourhood. Reading maps, however, is not taught  
442 at elementary and secondary school in Arequipa.

443 A reassuring result is that at least three quarters of the respondents (>76%) know, at least  
444 approximately, the existing natural hazards, while the majority can estimate the occurrence  
445 and arrival time of debris flows. Some hazard knowledge has spread across neighbourhoods  
446 near ravines thanks to TV programs, social network videos, and the dissemination of leaflets  
447 by research institutes, INDECI, and NGOs that depict hazards and hazard-prone areas across  
448 the city.

### 449 **3.3. Risk perception and associated variables**

450 The goal of Survey C (23 questions, [ESD Text](#)) was to evaluate how people perceive  
451 flood and volcanic risk from Misti, and compare the risk perception with hazard knowledge.  
452 Questions asked under seven themes and adapted from a few concepts of social science (e.g.,  
453 [Johnston et al., 1999](#); [Paton, 2003](#); [Paton et al., 2008](#); [Davis et al., 2005](#); [Haynes et al., 2008a,](#)  
454 [2008b](#)), aimed to define risk perception and associated variables, as shown in [Table 4](#) and  
455 illustrated in [Figure 6](#). These themes include: 1) concern and hazard salience; 2) experience,  
456 either direct, indirect or vicarious, and hazard likelihood and severity; 3) past behaviour and  
457 impact of memory on future behaviour; 4) origin of experience and knowledge; 5) flow  
458 attractiveness; 6) empowerment, *i.e.*, [enhancement of people capabilities](#) and self-confidence;  
459 and; 7) trust in authorities. The answers to questions from the survey C were analysed using  
460 univariate analysis ([Fig. 6A-C](#)), a bivariate Chi<sup>2</sup> test and AFC ([Fig. 7](#); [ESD Table 1](#)), MCA  
461 and frequency analysis on a dataset from 268 respondents ([Table 4](#)). We also identified the  
462 most contributory attributes using MCA biplots.

463 To evaluate risk perception and associated variables among urban dwellers, we examined  
464 answers to six key questions from the themes mentioned above. The answers to C.Q1  
465 (“Concern about volcano or debris flow”) and C.Q14 (“Flow attractiveness”) on the one hand,  
466 helped us to [weigh people’s](#) concerns about natural hazards or daily life issues. On the other  
467 hand, the answers to C.Q19 (“self-confidence in case of an eruption”), C.Q20 (“obedience to  
468 evacuation”), and C.Q23 (“Trust in messages or content needed to be checked”) allowed us to  
469 gauge people’s self-confidence and trust in authorities in order to appraise their potential  
470 behaviour in case of an imminent flow event. Several factors may play a role in how urban  
471 dwellers behave, but we suggest that the most relevant ones derive from: (1) how dwellers

472 **weight flood** and volcano risk against personal or daily risk, and; (2) how confident or  
473 untrustful they **are** about early warning messages and evacuation orders.

474 Despite the difficulties in interpreting complex answers, we distinguished four groups of  
475 population (termed Rp for risk perception) based on the analysis of the most frequent  
476 attributes using **HAC replies** to specific questions related to concern and hazard salience  
477 (theme no.1), **past behaviour**, and impact of memory on future behaviour (theme no.3).

478 **Rp1.** A majority of people (c. 51.50%, A *in Table 4*) are worried and uncertain about **the**  
479 volcano and lahars and do not seem to be **interested in** flows. Respondents of Rp1 feel self-  
480 confident, trust and obey the authorities' messages.

481 **Rp2.** Over a third of people (c. 35%, B *in Table 4*) **are** less worried about volcano **events** or  
482 debris flows than other issues. The group Rp2 recognizes the hazard likelihood or severity,  
483 and they are little **interested in** flows. These dwellers do not feel self-confident and did not  
484 entirely trust the authorities, as they check early warning messages.

485 **Rp3.** About 12% of respondents (C *in Table 4*) are concerned by potential volcano **events** and  
486 debris flow threats. These people feel self-confident, but do not obey the warning messages,  
487 as they always check the early warning messages. However, many of them did not trust early  
488 warning messages or did not answer the question.

489 **Rp4.** A very small group of respondents (c. 1.50%, D *in Table 4*) did not provide answers or  
490 they did not understand **the** questions. We hypothesize that these people may be new migrants  
491 in the city, therefore unconcerned and uninterested in flows, and they would not know what to  
492 do in case of flow event.

493 Second, the univariate analysis of the Survey C dataset helped us to evaluate how the urban  
494 dwellers perceive risk and associated variables (**Fig. 6**):

495 1. Hazard salience prevails among the communities living near the ravines: ca. 60% of the  
496 respondents report that they feel worried about the volcano and/or debris flows (Q1, **Fig. 6A**).  
497 Personal concern (Q2, **Fig. 6A**) seems to co-exist (Q2, **Fig. 6A**), but as many as 73% of  
498 respondents answered "no concern", while c. 15% still declared that debris flow was **a**  
499 personal concern.

500 2. More than three quarters (c. 76.50%) of respondents have witnessed a flow/flood event, and  
501 two thirds (c. 67%) remember a recent flow, but an equal number of people (73.50%) have  
502 not been injured or affected by floods and debris flows (**Fig. 6A**). Most people do not perceive

503 well the likelihood and severity of lahars, but half of the respondents (51.50%) reasonably  
504 believe that they could be injured by flows.

505 3. Half of the respondents have behaved during flow events according to experiences, but  
506 more than one third of them (c. 39%) remained on the spot during a flow event and searched  
507 for advice. More worrisome, almost 18% of dwellers did not know what to do (Fig. 6A).

508 4. Over half of the respondents (c. 57%) are able to describe flow hazards correctly. An  
509 overwhelming majority (c. 82%) state that their hazard knowledge stems from experiences  
510 with flows, school lessons and authorities' warnings, while a small proportion of respondents  
511 obtained advice from their family and/or neighbours (Fig. 6B).

512 5. Almost two thirds (c. 63.50%) of the respondents feel that the population are empowered to  
513 surmount the hazardous flows/floods or their consequences. However, empowerment or self-  
514 confidence remains relatively limited, as less than one third (c. 31%) of them admit that they  
515 would be unable to overcome the phenomenon (Fig. 6B).

516 6. Trust in official early warning messages and accurate information about imminent  
517 eruptions are two major issues for evacuation policy (Haynes et al., 2008b). Almost three  
518 quarters of the respondents (c. 74%) declare that they are ready to abide by the evacuation  
519 orders. An overwhelming majority of people ( $\geq 88\%$ ) trusts and abides by the early warning  
520 message, but almost 42% check them out before evacuating (Fig. 6C). A reasonable  
521 behaviour of respondents in case of imminent evacuation has been undermined due to either  
522 poor memories from previous evacuations or unwise decisions taken during past flow  
523 disasters. Despite early warning messages, respondents stated that they would keep searching  
524 for advice or remain inactive. Mistrust in government agencies is based on personal poor  
525 experiences during evacuations and lack of respect for the civil authorities. Thus, there is  
526 room for improving information about mitigation policy and risk communication, as non-  
527 negligible proportions of the dwellers do not trust anyone (8%), will not obey (9%), or do not  
528 answer the relevant questions (2 to 4%) (Fig. 6B, C).

### 529 **3.4. Dwellers' risk perception and behaviour, and contributory variables**

530 First, FCA biplots allowed us to discuss the role of three parameters that may explain how  
531 respondents behave when they are facing flows and floods (Fig. 7).

532 *Residence time in Arequipa*: Respondents who have lived in Arequipa for a short period (6-15  
533 years) believe that they are unable to overcome the effects of debris flows, in contrast to

534 dwellers who have lived in the city for longer (>16 years) and answer that they would be able  
535 to overcome them (A.Q14 and C.Q18: Fig. 7A).

536 *Interest in flows and role on empowerment:* Respondents who witnessed hazardous flows may  
537 be interested in watching them, in contrast to people who have not witnessed flows in the past  
538 (C.Q3 and C.Q14: Fig 7B). Respondents who witnessed debris flows coincide with those who  
539 believe to be able to overcome their consequences, in contrast to people who never witnessed  
540 lahars (C.Q3 and C.Q18: Fig. 7C). Those who know how to describe hazardous debris flows  
541 feel that they could overcome their consequences (C.Q11 and C.Q18: Fig. 7D).

542 *Origin of knowledge and experience about debris flows:* People who cannot remember recent  
543 flows coincide with those whose knowledge has been acquired thanks to their family and  
544 neighbours (C.Q12 and C.Q8: Fig. 7E). Other respondents may have acquired a knowledge of  
545 flows from their own experience, school and authorities.

546 Second, the correlation between all variables and the first two dimensions (Fig. 8) has enabled  
547 us to identify variables using the first MCA and select the 17 most contributory ones to be  
548 considered for the final MCA. In fact, these 17 variables that lie away from the barycentre of  
549 the biplot of Figure 8 are most correlated to the principal dimensions:

550 (1) Eight variables of Survey B: B.Q3 district location, B.Q4 and B.Q5 zone colour meaning,  
551 B.Q6 hazard type definition, B.Q7, flow arrival time estimate, B.Q8 time interval after flow  
552 onset, B.Q9 lahar fatalities, and B.Q10 eruption duration;

553 (2) Nine variables of risk perception: Survey C: C.Q9 past behaviour, C.Q10 memory on  
554 behaviour, C.Q8 memory of flow, C.Q3 flow witness, C.Q6 indirect experience, C.Q15 flow  
555 observation, C.Q16 flow attractiveness, C.Q19 empowerment, and C.Q5 flow capacity to hit  
556 people.

557 The five illustrative variables from Survey A (Age group, education level, socio-professional  
558 category, time living in the area, and family origin) will be considered as hypotheses for the  
559 final MCA, because they are the least contributory variables (Fig. 8).

#### 560 **4. Four groups of city dwellers using Hierarchical Agglomerative Clustering**

561 HAC has been carried out according to the results of the last MCA, i.e., on the 17 most  
562 contributory variables afore mentioned. This analysis was made on 92 respondents who  
563 answered all questions included in the three surveys A, B and C (Table 5, ESD Table 1).

564 **Table 6** shows the most frequent and the least frequent attributes found for each of the  
565 clusters.

566 Results from HAC, including the Factor map based on the principle of distance  
567 between individuals (**Fig. 9**), enabled us to define four clusters among the population living  
568 along the two ravines (**Table 6**). A Chi<sup>2</sup> test on HAC variables allows us to identify and rank  
569 variables from the most to the least discriminant (**ESD Table 3**). The study of paragons (**ESD**  
570 **Table 4**), i.e., the most representative individuals with their attributes of each of the clusters,  
571 helps confirm the frequency analysis of the most frequent attributes illustrated in **Table 6** and  
572 **Table 7**. The eight more discriminant variables are: B.Q4, B.Q5; C.Q3, C.Q8, C.Q9, C.Q10,  
573 C.Q14 and C.Q16 (**ESD Table 3**), which are shown with the relevant answers from paragons  
574 in **Table 8**. As a result, we distinguish four groups of urban dwellers based on the most  
575 discriminant variables (**Table 6**):

576 **Group 1** (ca. 47% of the cohort)

577 From **Table 6**, hazard knowledge of Group 1 (almost half of respondents) on lahars and floods  
578 is regular, but quite limited on volcanic phenomena. These people know about the occurrence  
579 and arrival time of lahars, but most of them do not have any idea about the location of their  
580 district and the meaning of the hazard-zone map.

581 Their risk perception is based on experience from past flow events, and the majority of  
582 respondents like to **watch them**. All respondents have witnessed a debris flow at least once  
583 and memory of past flows had an impact on behaviour for many of the respondents. A  
584 majority of the respondents trusts civil authorities, but more than two thirds of Group 1  
585 remained on the spot during the flow event instead of evacuating.

586 From **Table 7**, we hypothesize that Group 1 **are** mostly mature, low- to modest income adults  
587 who attended at least secondary school, arrived from beyond the department of Arequipa, and  
588 have been living in the area for over 16 years.

589 **Group 2** (ca. 31.50% of the cohort)

590 From **Table 6**, **volcanic** hazard knowledge of Group 2 (almost one third of respondents) **is**  
591 **minimal**. These people cannot locate their neighbourhood and do not know the meaning of the  
592 hazard-zone map. They have a hard time to estimate the occurrence, arrival time and duration  
593 of the debris flows. and they do not like to watch them. However, many respondents acquired  
594 some experience with past debris flows and remember them.

595 Their behaviour in case of a flow event is critical as the majority remained on the spot and/or  
596 provided no answer to the related question to trust in warning messages. Their risk perception  
597 is regular, as they are worried about the volcano and floods, but they trust official warnings  
598 more than all other groups.

599 From Table 7, we hypothesize that Group 2 includes low- to middle-income, mature adults  
600 and elderly people, who are less educated, arrived from beyond the department of Arequipa,  
601 but have been living in the area for at least 30 years.

602 **Group 3** (ca. 18.50% of the cohort)

603 From Table 6, Group 3 hazard knowledge is regular on volcanic ash, pyroclastic flow and  
604 lahars or floods owing to education, and these people can estimate the arrival time and  
605 occurrence of debris flows. In contrast, they did not provide any answer to questions related to  
606 the hazard-zone map, coloured hazard zones, and the location of their neighbourhood.

607 They did not get any experience from past flows/floods and they do not like to watch them,  
608 although some flow aspects *may be of interest to* these people. Their risk perception is poor or  
609 regular, they try to check early warning messages, and they do not provide answer to the  
610 question “how did you behave that day?”.

611 From Table 7, we hypothesize that the small group 3 gathers relatively low-income, young  
612 people (several of them being students) and mature adults relatively *well* educated, while they  
613 have been living in the area for less than 6 or 15 years. They are less worried about volcano  
614 *events* or debris flows, but they show other concerns perhaps related to daily life issues.

615 **Group 4** (only 3.25% of the cohort)

616 From Table 6, hazard knowledge of the smallest Group 4 *has fair knowledge* about volcanic  
617 phenomena and lahar occurrence and arrival time. These people can locate their  
618 neighbourhood, and they know the meaning of the hazard-zone colours, and *most recall the*  
619 recent eruption of El Misti.

620 Their risk perception seems contradictory, as they perceive the risk of lahars and floods from  
621 education, internet and experience, but they declare that they try to check the early warning  
622 messages, they would self-evacuate, or would not know what to do in case of an evacuation.

623 From Table 7, we hypothesize that the smallest group of respondents includes low-income,  
624 elderly and educated young people, having arrived from far away, and having settled in the  
625 area for 6 to 30 years. The small number of people in Group 4 prevents us from drawing solid

626 inferences from these correlations. They may correspond to persons who used to live in other  
627 districts of Arequipa further away and moved recently near the ravines for personal reasons.

628 Overall, almost 22% of the urban dwellers (Groups 3 and 4) seem to be quite  
629 vulnerable in case of a flow event or an eruption, as a majority declares that they remain on  
630 the spot. Such a proportion of vulnerable dwellers may raise to 53% of the population if we  
631 include the less educated, low- to middle-income people of Group 2. Together, they form a  
632 large cohort that the civil authorities and risk managers should involve into the prevention and  
633 mitigation policy across the city of Arequipa.

## 634 **5. RISK MANAGEMENT POLICY IN AREQUIPA: AN OVERVIEW**

635 The analysis of surveys has revealed that the majority of urban dwellers living along  
636 the hazard-prone valleys were wondering how to behave, and searched for advice in case of  
637 emergency and evacuation; hence, they remained in hazard-prone low river terraces.

### 638 **5.1. Meetings with key actors aimed at unravelling sources of potential difficulties**

639 During our investigation of factors that may influence people's behaviour in case of  
640 flow, we observed three sources of difficulties: 1) limited hazard knowledge and risk  
641 perception, coupled with minimal education; 2) catastrophic effects of flows (every five years  
642 on average; [Thouret et al., 2022a](#)), partly due to the lack of civil protection works, and; 3)  
643 delayed response of the institutions in charge of disaster risk mitigation in the city.

644 Meetings, interviews and focus groups, led by K. Mora (Universidad de Nariño, Colombia),  
645 aimed to examine the extent to which disaster risk management procedures have been  
646 implemented by a range of key actors in four districts adjacent to the ravines. The  
647 investigation pursued three objectives: 1) to identify how public institutions manage disaster  
648 risk related to floods and lahars; 2) to describe the actions promoted by neighbourhood boards  
649 to manage flood risk in the districts, and; 3) to unravel potential sources of conflict between  
650 the district municipalities, disaster risk management agencies, and the local communities.

651 Disaster Risk Management in Peru is organized by Law No. 29664, voted in 2011, which  
652 created the National Disaster Risk Management System (*Sistema Nacional de Gestión del*  
653 *Riesgo de Desastres SINAGERD*). Two national institutions are in charge of disaster risk  
654 management: the National Center for Estimation, Prevention and Reduction of Disaster Risk  
655 (CENEPRED), responsible for disaster prevention and post-disaster reconstruction, and the  
656 National Civil Defense Institute (INDECI), responsible for emergency response activities.



657 The SINAGERD system generated a significant change with respect to technical, legal and  
658 administrative procedures in disaster risk management in Peru (Fig. 10). In this important  
659 legal procedure, proactive risk management is carried out to avoid future disasters and  
660 corrective risk management to reduce existing impacts. Such procedure should be applied at  
661 three levels of national, regional, and district governance, each with specific competences and  
662 responsibilities for prevention and reduction of disaster risk. Nevertheless, it is not possible to  
663 take suitable decisions to deal with disaster risk in the long term, because political changes in  
664 municipalities every five years require new training of officials and risk managers in legal  
665 procedures, in particular during emergencies.

## 666 **5.2. Complex issues may hamper disaster risk management in Arequipa**

667 The results of interviews, meetings and focus groups have highlighted a number of  
668 complex issues, as summarised below (Table 9):

669 1. Officials and local communities consider increased vulnerability to be rooted in the  
670 ‘unlawful’ occupation of land on El Misti’s slopes and hazard-prone banks of the ravines, as  
671 low-income people or new migrants cannot afford homes in the urban territory. Since they  
672 often minimize the likelihood or severity of flows, low-income people often build homes in  
673 high-risk ravine channels and terraces or further up on the volcano slopes now within 9 km of  
674 the vent. Communities state that hazardous phenomena associated with future El Misti  
675 activity are distinct from, and less pivotal than daily concerns related to personal safety,  
676 family’s health, lack of economic resources, and environmental issues. Although decision-  
677 makers and stakeholders respond to emergencies in the wake of flood and debris-flow  
678 disasters, urban dwellers claim that the factors of social and physical vulnerability are not  
679 adequately dealt with.

680 2. Civil servants and elected authorities acknowledge that hazards have impacts on their  
681 districts and, based on their own experience, have identified the most frequent hazards, such  
682 as heavy rainfall inducing catastrophic flows. However, decision makers face difficulties in  
683 incorporating the policies of disaster risk management within the structure, functions and  
684 competence of the public offices, as many lack knowledge in the fields of urban planning and  
685 environment management. The limited knowledge about institutional competences may be  
686 due to different electoral agendas and turnover of officials who need to be trained again every  
687 five years.

688 3. Overlapping responsibilities between institutions have hampered an adequate and  
689 comprehensive investment in risk management. Lack of co-ordination with ONGs like  
690 PREDES, which promoted tools for disaster risk management ten years ago, has not allowed a  
691 suitable investment in the disaster risk management. Overlapping jurisdictions is illustrated by  
692 the fact that ravines form natural boundaries between districts, so that prevention  
693 requirements such as cleaning river channels before the rainy season are not adequately  
694 coordinated between the district municipalities on both sides of the ravines.

695 4. A limited investment in disaster risk management policy and urban planning in general  
696 leads to diminish accountability among key actors. For example, district mayors are prime  
697 authorities in charge of disaster risk management policies at the district scale, which include  
698 disaster risk management in urban planning, management of environmental issues and public  
699 investments. Although existing policies have assigned functions to disaster risk managers,  
700 limited investment is preventing mitigation and emergency procedures from being  
701 implemented in district municipalities. Despite previous experiences acquired with about 40  
702 earthquake and flow disasters in Arequipa over the past 105 years (INDECI, 2020; Thouret et  
703 al., 2022a), civil protection works are insufficient owing to minimal resources available for  
704 district offices and CENEPRED in charge of proactive mitigation procedures.

705 5. The city hall and INDECI elaborate on prevention, mitigation and disaster risk reduction  
706 plans, but those plans are partially implemented in the most vulnerable hazard-prone areas.  
707 This is due to a series of factors such as mistrust on behalf of the urban dwellers, so that there  
708 is no mutual links and collaboration between the threatened communities and the authorities  
709 in terms of response to emergency procedures. Decision makers and stakeholders organize  
710 and coordinate a Civil Protection committee in each district with the clear objective that  
711 emergency and relief operations need to be applied to help victims and support affected and  
712 displaced people during and after each destructive event (Fig. 10). However, the apparent lack  
713 of co-ordination between institutions prevents a fast response to cope with emergencies.

## 714 6. DISCUSSION

### 715 6.1. Limitations and uncertainties

716 Field surveys have included almost 280 respondents, representing at least 900 people  
717 living along the ravine channels. The final step of the statistical analyses, i.e., clustering using  
718 HAC, has led to a smaller number of respondents (92) who answered all questions from three  
719 surveys. This induces a low representativeness, although previous investigations carried out in

720 the framework of our research Project, obtained comparable results from a more limited  
721 number of respondents (Heitz and Nagata-Shimabuku, 2017).

722 Uncertainty is bound to our results in two ways: first, biases may arise from quick surveys  
723 collated during about 15 days, with some people missing in houses, being shy, or with  
724 prohibited access to the researchers, as well as safety issues in some ‘informal’  
725 neighbourhoods. Second, uncertainty abounds in the challenging analysis of the answers  
726 provided by respondents about risk perception and associated variables. A few people did not  
727 understand some questions or could not formulate answers to questions from Survey C. Thus,  
728 evaluating risk perception and potential behaviour during flow events remains a challenge.

## 729 **6.2. Comparison with studies on risk representation and risk management practice**

730 A few studies focused on hazard knowledge and risk perception among the vulnerable  
731 population of Arequipa, compared to studies that dealt with hazards and risk from volcanic  
732 eruptions and torrential floods (e.g., Thouret et al., 2013, 2014, 2022a; Mazer et al., 2021).  
733 Sandoval and Sarmiento (2020) aptly pointed that poor urban development and planning has  
734 led to informal settlements, while contributions to improving living conditions are marginal in  
735 Arequipa. Recently, two studies have been conducted on risk representation as well as on  
736 vulnerability and resilience of the urban dwellers living in informal settlements.

737 Heitz and Nagata-Shimabuku (2017) studied ‘risk representation’ in 16 exposed and  
738 ‘unexposed’ small neighbourhoods scattered throughout Arequipa. The survey methodology  
739 was based on self-administrated questionnaires, organized around three main themes: a  
740 general approach to how people estimate social issues, then questions on natural hazards, and  
741 lahar risk. Socio-economic characteristics for each individual, living conditions, salary, and  
742 profession were also specified. This study dealt with a smaller number of persons (209) and  
743 presented statistical results based on nine questions only. However, our results coincide with  
744 some of their findings. Respondents endow legitimacy in risk reduction to the national Civil  
745 Protection authority in charge of the risk management in the city of Arequipa, but questions  
746 were not asked about other key actors in charge of the disaster risk management. Two thirds  
747 of respondents consider that they are not sufficiently informed on the behaviour to adopt in  
748 case of a disaster, but factors explaining their behaviour were not investigated. The Authors’  
749 findings point to a weak implication of the respondents in the adoption of individual  
750 initiatives to protect themselves and to important expectations towards authorities’ actions in  
751 decreasing their vulnerability.

752 More recently, Lièvre et al. (2022) studied the evolution of volcanic risk management practice  
753 in Arequipa from the 1990s to the present. They claimed that management practices in  
754 Arequipa have focused on the paradigm of vulnerability since the 1990s, instead of resilience.  
755 City dwellers seem to be aware that disaster prevention also depends on the resilience of  
756 society, a factor that the Authors think the “technology-based vulnerability paradigm  
757 minimize”. Lièvre et al. (2022) recognized that another theoretical framework appeared from  
758 2015 around “geoheritage and resilience”. The Authors claim that this framework “tends  
759 towards the resilience paradigm by taking the territory and the capacity to adapt as a basic  
760 principle, and by emphasizing the involvement of the human factor”. Geosites, “landscape  
761 units that bring together what was previously generally separated”, are thought by the Authors  
762 to be “a more grounded approach around risk knowledge”. The geosite brings an essential  
763 “ecological and corporal anchoring” on the risk that is “contextualized instead of being only  
764 perceived” by surveys on risk perception whose results “do not seem to show a particular  
765 evolution in Arequipa”.

766 We do not share several points raised by Lievre et al. (2021), in addition to methodological  
767 biases involved in a review largely based on literature. Resilience had not been discarded in  
768 studies over at least the past 11 years, as shown by ONGs and publications (e.g., PREDES,  
769 2012; Zeballos-Velarde et al., 2019). We argue that hazard knowledge and risk perception  
770 have increased among city dwellers over the past 20 years thanks to the institutions, ONGs  
771 and the reorganization of SINAGERD since 2011. We also wonder how a ‘landscape unit’  
772 provides a suitable solution to the difficulties met by local communities and institutions in  
773 disaster risk reduction.

774 Arequipa also faces major challenges related to water supply and consumption in conjunction  
775 with climate change (Salmoral et al., 2020). This situation in combination with poor  
776 governance and lack of planning has exposed the vulnerability of Arequipa water supply  
777 system to future shocks. Both their study and our results concur in the need for urgent actions  
778 to strengthen governance and enforcement, and agree on a collective vision for integrated land  
779 and water planning in the city.

## 780 **7. CONCLUDING REMARKS**

781 A number of issues can be gleaned from our study that we have compared with the “working  
782 hypotheses proposed in section 1.1:

- 783 1. About 22% of the urban dwellers are quite vulnerable in case of a flow event or an  
784 eruption, a proportion that would raise to 53% in case of an imminent evacuation, as they  
785 report that they remained on spot or they did not know what to do during past flow events.
- 786 2. Risk managers and local authorities state that the ‘unauthorized’ occupation of hazard-  
787 prone areas near the ravines is a pivotal challenge for disaster risk management. Such  
788 informal settlements have expanded over the past 25 years in Arequipa and Peruvian cities  
789 alike, in which urban informality and precariousness persist despite the national economic  
790 growth. The vulnerability roots of local communities remain to be dealt with, [although urban](#)  
791 development plans articulate risk governance and disaster resilience principles.
- 792 3. Both respondents and disaster risk managers [require knowledge](#) and training (flood  
793 evacuation procedures similar to the existing earthquake simulations) should be extended for  
794 people living in flood-prone areas. The information needs to be targeted at the individuals’  
795 representation of the risk they incur and the level of legitimacy received from the risk  
796 managers, to compel the population to follow the authorities’ recommendations and adopt a  
797 suitable behaviour in case of a catastrophic flow.
- 798 4. Actions of neighbourhood boards against flow effects are not sustained due to the lack of  
799 civil protection works and relief operations during emergencies, while the legitimate  
800 communities’ claims cannot be quelled only by NGOs or international relief on the long term.
- 801 5. Potential conflicts have emerged between institutions despite the reorganization of  
802 SINAGERD in 2011. This is due to conflicting competences of the districts, municipality and  
803 region of Arequipa in urban planning, and overlapping jurisdictions of CENEPRED and  
804 INDECI in charge of the disaster risk management policy.

805 Overall, risk management policy has proved to be undermined during recent  
806 destructive events, as recognized by all risk managers during meetings. Our study provides an  
807 example of current shortfalls in daily practice of risk reduction taken by city authorities and  
808 dwellers from a generally low-income society. The case study of Quito, Ecuador, similar with  
809 respect to torrential floods, may provide solutions rooted in shared governance between  
810 institutions in charge of risk management, involvement of local communities, and adaptative  
811 plans to a changing environment (e.g., [Grieving et al., 2021](#)). It may offer a framework for  
812 approaching adaptation and building resilience in vulnerable settlements, as it advocates for a  
813 distributed governance system to be shared between institutions and city dwellers.

814

## 815 **Acknowledgements**

816 Fieldwork and laboratory analyses have been funded by the French government IDEX-ISITE  
817 initiative 16-IDEX-0001 (CAP 20-25, IRC 4). The first authors thank the Institut de Recherche  
818 pour le Développement (IRD) for constant logistical support in Peru. We thank our Peruvian  
819 colleagues and students from INGEMMET, IGP and UNSA (in particular J. Mariño, M. Rivera,  
820 F. Garcia, J. Belizario, K. Moroccoire), and INDECI as well (Mrs A. Arguedas, Mr J. Vasquez,  
821 Mr H. Pareja), and from colleagues (K. Mora, A. Guerrero, D. Rodriguez) of the University of  
822 Nariño, Pasto, Colombia as well as O. Santoni (FERDI-UCA) for their support over the years  
823 about hazards and risk in the city of Arequipa.

824

## 825 **Statements and Declarations**

826 *Funding:* Fieldwork and laboratory analyses have been funded by the French government  
827 IDEX-ISITE initiative 16-IDEX-0001 (CAP 20-25, International Research Centre 4,  
828 Clermont). There is no grant number.

829 *Competing interests:* All authors declare they have no financial interests.

830 *Authors contribution:* All authors contributed to the study conception and design. The first draft  
831 of the manuscript was written by JC Thouret and M. Taillandier. Artwork was performed by E.  
832 Arapa and E. Wavelet, and all authors commented on previous versions of the manuscript. All  
833 authors read and approved the final manuscript.

834

## 835 **References**

836 [Abdi, H., Valentin, D., 2007.](#) Multiple Correspondence Analysis, *in:* Salkind, N. (Ed.)  
837 Encyclopedia of Measurement and Statistics. Thousand Oaks (CA), Sage.

838 [Aguilar, R., Taípe, E., Antayhua, Y., Ortega, M., Apaza, F., Luis Cruz, L., 2021.](#) Hazard  
839 assessment studies and multiparametric volcano monitoring developed by the Instituto  
840 Geológico, Minero y Metalúrgico in Peru. *Volcanica* 04, 74-81, [doi.org/  
841 1030909/vol.04.S1.7392](https://doi.org/10.30909/vol.04.S1.7392)

842 [Alves B., 2021.](#) Natural Disasters in Latin America. Statistics and facts. United Nations  
843 Statista.

844 [Arela, R., Riesco, G., Chávez, G., 2021.](#) Una mirada a la expansión de la ciudad de Arequipa  
845 en los últimos 40 años. Informe del Centro de Estudios en Economía y Empresa. 30 pp.  
846 Universidad Católica San Pablo.

847 [Aspinall, W., Blong, J., 2015](#). Volcanic risk assessment. Chapter 70, pp. 1215-1231, *in*:  
848 Sigurdsson, H. et al., Encyclopedia of Volcanoes, 2nd edition, Academic Press.

849 [Benzécri, J.-P., 1979](#). Sur le calcul des taux d'inertie dans l'analyse d'un questionnaire. Les  
850 cahiers de l'analyse des données 4, 3, 377-378.

851 [Baltar, Brunet, 2012](#). Social research 2.0: virtual snowball sampling method using  
852 Facebook. Internet Research 22, 1, 55-74. doi:10.1108/10662241211199960.

853 [Bonilla, E., Rodríguez, P., 2000](#). Manejo de datos cualitativos. In B. E & P. Rodríguez (Eds.),  
854 Más allá del dilema de los métodos. La investigación en ciencias sociales (pp. 243- 310).  
855 Bogotá, Universidad de los Andes: Grupo Editorial Norma.

856 [Casaverde, M., 1995](#). El terremoto de Ancash y el alud aluvión del nevado Huascarán.  
857 Biblioteca virtual en Prevención y Atención de Desastres, INDECI, Lima (Unpubl.).

858 [Chambers, J. M., Cleveland, W. S., Kleiner, B., Tukey, P.A., 2018](#). Graphical methods for  
859 data analysis. Chapman and Hall/CRC.

860 [Charbonnier S., Thouret JC., Gueugnon V., Constantinescu, R., 2020](#). New insights into the  
861 c.2070 cal yr BP pyroclastic currents at El Misti volcano (Peru) from field investigations,  
862 satellite imagery and probabilistic modeling. Frontiers in Earth Sciences, September 2020,  
863 doi.org/10.3389/feart.2020. 557788

864 [Charveriat, C., 2000](#). Natural Disasters in Latin America and the Caribbean: An Overview of  
865 Risk. Inter-American Development Bank, Research department IDB, Working Paper #434,  
866 104 pp. <http://dx.doi.org/10.2139/ssrn.1817233>.

867 [Davis, M., Ricci, T., Mitchell, L. M., 2005](#). Perceptions of risk for volcanic hazards at  
868 Vesuvio and Etna, Italy. The Austral. J. Disaster Trauma Studies 1, 21 p.

869 [Del Carpio, J., Rivera, M., Torres, J., Tavera, H., Puma, N., 2022](#). Evaluación del peligro  
870 volcánico en Perú: Una herramienta para la gestión del riesgo de desastres. Informe Técnico,  
871 85 pp, [Repositorio Geofísico Nacional](#), Instituto Geofísico del Perú, Lima. <http://hdl.handle.net/20.500.12816/5276>.

873 [Donovan, A, Ayala, I.A, Eiser, J, Sparks, R.S.J., 2018](#). Risk perception at a persistently active  
874 volcano: warnings and trust at Popocatepetl volcano in Mexico, 2012–2014. Bull. Volcanol.  
875 80, 5, 47.

876 Ettinger, S., Mounaud, L., Magill, C., Yao-Lafourcade, A.-F., Thouret, J.-C., Manville, V.,  
877 Negulescu, C., Zuccaro, G., De Gregorio, D., Nardone, S., Uchuchoque, J.A., Arguedas, A.,  
878 Macedo, L., Manrique, L.N., 2015. Building vulnerability to hydro-geomorphic hazards:  
879 estimating damage probability from qualitative vulnerability assessment using logistic  
880 regression. *J. Hydrol.*, doi:10.1016/j.jhydrol. 2015.04.017

881 Gaillard, J.-C., 2007. Resilience of traditional societies in facing natural hazards. *Disaster*  
882 *Prev. Manag.* 16, 4, 522–544.

883 Gaillard, J.-C., 2008. Alternative paradigms of volcanic risk perception: the case of Mt  
884 Pinatubo in the Philippines. *J. Volcanol. Geoth. Res.* 172, 315–328.

885 Gaillard, J.-C., Dibben, C.J.L., 2008. Volcanic risk perception and beyond. *J. Volcanol.*  
886 *Geoth. Res.* 172, 163–169.

887 Grieving, S., Schödl, L., Gaudry, K.-H., Quintana Miralles, I.K., Prado Larraín, B.,  
888 Fleischhauer, M., Margoth, M., Guerra, J., Tobar, J., 2021. Multi-Risk Assessment and  
889 Management—A Comparative Study of the Current State of Affairs in Chile and Ecuador.  
890 *Sustainability* 13, 1366. <https://doi.org/10.3390/su13031366>

891 Gutiérrez, R., Belaunde, P., Mujica, E., 1992. Evolución histórica a urbana de Arequipa 1540-  
892 1990 (1ra edición). Facultad de Arquitectura Urbanismo y Artes, Universidad Nacional de  
893 Ingeniería, 249 pp. Epígrafe Editores, Lima.

894 Haynes, K., Barclay, J., Pidgeon, N.F., 2008a. Whose reality counts? Factors affecting the  
895 perception of volcanic risk. *J. Volcanol. Geoth. Res.* 172, 3-4, 259-272.

896 Haynes, K., Barclay, J., Pidgeon, N., 2008b. The issue of trust and its influence on risk  
897 communication during a volcanic crisis. *Bull. Volcanol.* 70, 605–621.

898 Heitz, C., Nagata Shimabuku, N., 2017. The role of individuals' risk representations  
899 in risk management - case-study on lahars in Arequipa (Peru). *Geoenvironmental Disasters* 4,  
900 28, doi:10.1186/s40677-017-0093-x

901  
902 INDECI Instituto Nacional de Defensa Civil, 2020. Compendio estadístico de desastres 2003-  
903 2020 (Unpubl.). Oficina Arequipa.

904 INEI, 2018. Resultados definitivos de los Censos Nacionales 2017 - Arequipa (XII de  
905 población, VII de vivienda y III de comunidades indígenas), Instituto Nacional de Estadística e  
906 Informática, Lima, 641 pp.



907 [Johnston, D.M., Bebbington, M.S., Lai, C.-D., Houghton, B.F., Paton, D., 1999.](#) Volcanic  
908 hazard perceptions: comparative shifts in knowledge and risk. *Dis. Prev. Man.* 8, 2, 118-126.

909 [INFORM, 2018.](#) Index for risk management for Latin America and the Caribbean. 18 pp. United  
910 Nations Children's Fund (UNICEF). New York. [https://www.unicef.org/lac/informes/índice-](https://www.unicef.org/lac/informes/índice-de-gestión-de-riesgo-para-américa-latina-y-el-caribe)  
911 [de-gestión-de-riesgo-para-américa-latina-y-el-caribe.](https://www.unicef.org/lac/informes/índice-de-gestión-de-riesgo-para-américa-latina-y-el-caribe)

912 [Lavigne, F., De Coster, B., Juvin, N., Flohic, F., Gaillard, J.-C., Texier, P., Morin, J.,](#)  
913 [Sartohadi, J., 2008.](#) People's behavior in face of volcanic hazards: Perspectives from Javanese  
914 communities, Indonesia. *J. Volc. Geoth. Res.* 172, 273-282.

915 [Lièvre, P., Mérour, E., Morin, J., Macedo Franco, L., Ramos Palomino, D., Rivera Porras, M.,](#)  
916 [Masías Alvarez, P., van Wyk de Vries, B., 2022.](#) Volcanic risk management practice  
917 evolution between vulnerability and resilience: The case of Arequipa in Peru. *Frontiers in*  
918 *Earth Science* 10:877161; doi: 10.3389/feart.2022.877161

919 [Martelli K.M., 2011.](#) The physical vulnerability of urban areas facing the threat of inundation  
920 from lahars and flash floods: application to the case study of Arequipa, Peru. (Unpublished)  
921 PhD dissertation, Université Blaise Pascal, Clermont-Ferrand, pp. 245

922 [Mazer, K.E., Abigail A. Tomasek, A.A., Daneshvar, F., Bowling, L.C., Frankenberger, J.R.,](#)  
923 [McMillan, S.K., Hector M. Novoa, H.M., Zeballos-Velarde, H., 2020.](#) Integrated Hydrologic  
924 and Hydraulic Analysis of Torrential Flood Hazard in Arequipa, Peru. *J. Contemp. Water*  
925 *Res. and Edu.* 171, 93-110, Universities Council on Water Resources.

926 [Okuda Benavides, M., Gómez-Restrepo, C., 2005.](#) Métodos en investigación cualitativa:  
927 triangulación. *Revista Colombiana de Psiquiatría XXXIV*, 1, 118-124. Asociación  
928 Colombiana de Psiquiatría. Bogotá, D.C., Colombia

929 [Paton, D., 2003.](#) Disaster preparedness: A social-cognitive perspective. *Dis. Prev. Manag.* 12,  
930 3, ABI/INFORM Global.

931 [Paton, D., Smith, L., Daly, M., Johnston, D., 2008.](#) Risk perception and volcanic hazard  
932 mitigation: individual and social perspectives. *J. Volcanol. Geoth. Res.* 172, 179–188.

933 [Póveda, G., Espinoza, J.C., Zuluaga, M.D., Solman, S.A., Garraud, R., van Oevelen, P.J.,](#)  
934 [2020.](#) High Impact Weather Events in the Andes. *Front. Earth Sci.* 8, 162. doi:10.3389/  
935 feart.2020.00162.

936 [PREDES, Centro de Estudios y Previsión de Desastres, 2012](#). Herramientas para la gestión  
937 del riesgo de desastres, DIPECHO Plan de acción 2022-2012 no.5 « Fortaleciendo  
938 capacidades de sistemas subnacionales de gestión del riesgo y desarrollando la resiliencia de  
939 comunidades vulnerables a desastres ». Biblioteca nacional del Perú, 104 p.

940 [Salmoral, G., Zegarra, E., Vázquez-Rowe, I., González, F., del Castillo, L., Rondón Saravia,  
941 G., Graves, A., Rey, D., Knox, J.W., 2020](#). Water-related challenges in nexus governance for  
942 sustainable development: Insights from the city of Arequipa, Peru. *Sci. Total Env.* 747,  
943 141114.

944 [Sandoval, V., Sarmiento, J.P., 2020](#). A neglected issue: informal settlements, urban  
945 development, and disaster risk reduction in Latin America and the Caribbean. *Disas. Prev. &  
946 Manag.: an Int. J.* 29, 5, 731-745. Doi: 10.1108/DPM-04-2020-0115

947 [Statista, 2022](#). Natural Hazards in Latin America. <https://www.statista.com>

948 [Stoffel, M., Khodri, M., Corona, C., Guillet, S., Poulain, V., Bekki, S., Guiot, J., Luckman,  
949 B.H., Oppenheimer, C., Lebas, N., Beniston, M., Masson-Delmotte, V. \(2015\)](#). Estimates of  
950 volcanic-induced cooling in the Northern Hemisphere over the past 1,500 years. *Nat. Geosci.*  
951 8, 784–788. <https://doi.org/10.1038/ngeo2526>

952 [Taillandier M. 2019](#). Analyse des questionnaires mesurant la connaissance de l'aléa et la  
953 perception du risque des écoulements de la population à l'aide d'un traitement statistique -  
954 l'exemple de la ville d'Arequipa, Pérou. (Unpubl.) MSc.1 report. Laboratoire de  
955 Mathématiques, Université Clermont-Auvergne, 47 pp.

956 [Tavera, H., 2002](#). El terremoto de la región sur de Peru del 23 de junio de 2001. Repositorio  
957 Geofísico Nacional, 444 pp. Instituto Geofísico del Perú, Lima. [http://hdl.handle.net/  
958 20.500.12816/695](http://hdl.handle.net/20.500.12816/695).

959 [Tavera, H., 2020](#). Análisis y evaluación de los patrones de sismicidad y escenarios sísmicos en  
960 el borde occidental del Perú. Repositorio Geofísico Nacional, 66 pp. Instituto Geofísico del  
961 Perú, Lima. <http://hdl.handle.net/20.500.12816/4893>.

962 [Tavera, H., Bernal, Y., Salas, H., 2008](#). El terremoto de Pisco (Peru) del 15 de agosto de 2007  
963 (7.9 Mw). Repositorio Geofísico Nacional, 483 pp. Instituto Geofísico del Perú, Lima.  
964 <http://hdl.handle.net/20.500.12816/1115>.

965 [Thouret, J.-C., Suni, J., Finizola, A., Fornari, M., Legeley-Padovani, Frechen, M., 2001.](#)  
966 [Geology of El Misti volcano near the city of Arequipa, Peru. Geol. Soc. Amer. Bull. 113 \(12\):](#)  
967 [1593-1610. doi:10.1130/0016-7606\(2001\) 1132.0.co;2](#)

968 [Thouret, J.-C., Enjolras, G., Martelli K., Santoni, O., Luque, J.A., Nagata, M., Arguedas, A.,](#)  
969 [Macedo, L., 2013.](#) Combining criteria for delineating lahar- and flash flood-prone hazard and  
970 risk zones in the city of Arequipa, Peru. *Nat Haz Earth Sys Sci* 13: 339-360.  
971 [Doi:10.5194/nhess-13-1-2013](#)

972 [Thouret, J.-C., Ettinger, S., Guitton, M., Santoni, O., Magill, C., Martelli, K., Zuccaro, G.,](#)  
973 [Revilla, V., Charca, J.A., Arguedas, A., 2014.](#) Assessing physical vulnerability in large cities  
974 exposed to flash floods and debris flows: the case of Arequipa (Peru). *Nat Haz* 73 (3): 1771-  
975 1815, doi: 10.1007/s11069-014-1172-x.

976 [Thouret, J.-C. \(Ed.\), 2018.](#) Hazard and risk mapping. The Arequipa El Misti case and other  
977 threatened cities. Presses Universitaires Blaise Pascal, Territoires H.S. 1, Clermont-Ferrand,  
978 154 pp.

979 [Thouret, J.-C., Antoine, S., Magill, C., Mead, S., 2020.](#) Lahars and debris flows:  
980 characteristics and impacts. *Earth-Sci Rev*, doi.org/10.1016/j.earscirev.2019.103003

981 [Thouret, J.-C., Arapa, E., Charbonnier, S., Guerrero, A., Kelfoun, K., Cordoba, G., Rodriguez, D,](#)  
982 [Santoni, O., 2022a.](#) Modeling tephra fall and sediment-water flows to assess their impacts on  
983 a vulnerable building stock in the city of Arequipa, Peru. *Front. Earth Sci.*10: 865989, doi:  
984 10.3389/feart.2022.865989

985 [Thouret J.-C., Wavelet E., Taillandier M., Tjahjono B., Jenkins S., Azzaoui N., Santoni O.,](#)  
986 [2022b.](#) Defining population socio-economic characteristics and adaptive capacity of  
987 communities to persistent volcanic threats from Semeru, Indonesia. *Int. J. Disas. Risk Red.*  
988 77, 103064 <https://doi.org/10.1016/j.ijdr.2022.103064>

989 [UN United Nations, 2016.](#) Report of the Open-Ended Intergovernmental Expert Working  
990 Group on Indicators and Terminology Relating to Disaster Risk Reduction. United Nations:  
991 Geneva, Switzerland, 41 pp.

992 [UN United Nations, 2018.](#) The World's cities in 2018: data booklet. UN Population Division,  
993 Population studies, New York, 29 pp.

994 [UNDRR United Nations Office for Disaster Risk Reduction, 2 February 2017](#). Terminology  
995 on Disaster Risk Reduction. Basic definitions on disaster risk reduction to promote a common  
996 understanding on the subject for use by the public, authorities and practitioners,  
997 <https://www.preventionweb.net/files/50683oiewgreportenglish.pdf>

998 [Van Meter, K., 1990](#). Methodological and design issues: techniques for assessing the  
999 representatives of snowball samples. NIDA research monograph, 98, 31–43.

1000 [Vargas Franco R., Thouret J.-C., Delaite G., van Westen C., Sheridan M.F., Siebe C., Marino](#)  
1001 [J., Souriot T., Stinton A., 2010](#). Mapping and Assessing Volcanic Hazards and Risks in the city  
1002 of Arequipa, Peru, based on GIS techniques. *In: G Groppelli & L. Viereck-Goette, eds.,*  
1003 *'Stratigraphy and Geology of volcanic areas'*, Geological Society of America Special Paper  
1004 464, 265-280, doi: 10.1130/2010.2464(13).

1005 [Zeballos-Velarde, C., M.Á. Huamaní, J.Q. Valdivia, S.C. Alejo, Espinoza, C.M., 2019](#). An  
1006 environmental atlas as a tool for improving local environmental education and awareness in  
1007 Arequipa. *In: Proceedings of the International Congress on Educational and Technology in*  
1008 *Sciences, Arequipa, Peru, December 10-12, 2019, pp. 191-200. Available at:*  
1009 <http://ceurws.org/Vol-2555/paper17.pdf>. Accessed April 13, 2020.

1010

## 1011 **Table captions**

1012 **Table 1.** Statistical observations, methods, techniques, and their purposes.

1013 **Table 2.** Results of cross-tabulation analysis from Survey A on socio-demographics  
1014 characteristics.

1015 **Table 3.** Results of cross-tabulation analysis from Survey B on hazard knowledge.

1016 **Table 4.** Results of cross-tabulation analysis from Survey C on risk perception. The most  
1017 discriminant questions appear in bold.

1018 **Table 5.** Chi<sup>2</sup> test on all variables from Surveys A, B, and C.

1019 **Table 6.** Attributes with high and low frequencies used to distinguish clusters among  
1020 respondents (see [Table 7](#)).

1021 **Table 7.** HAC showing four clusters based on the total frequency analysis of all survey datasets  
1022 (see [Table 6](#)).

1023 **Table 8.** Answers to questions representing the eight most discriminant variables that define  
1024 the paragons (i.e., the five most representative individuals) for each of the four clusters of  
1025 respondents.

1026 **Table 9.** Risk management policy: principal results from interviews, meetings and focus groups  
1027 including key actors on Disaster Risk Management in the city of Arequipa.

## 1028 **Figure captions**

1029 **Figure 1.** Flow chart: research steps, methods and parameters, objectives, and expected  
1030 results.

1031 **Figure 2.** Districts Alto Selva Alegre and Miraflores on the east and west margins of Qda. San  
1032 Lazaro, Mariano Melgar and Paucarpata along the west and east margins of Qda. Mariano  
1033 Melgar (called Huarangal upstream) and neighbourhoods under study north and NE of the city  
1034 of Arequipa (insert Figure showing the location of studied districts with regard to the city and  
1035 El Misti volcano). Population number and gender proportion for the districts and the city of  
1036 Arequipa.

1037 **Figure 3.** Diagrams showing the distribution of population living in the four studied districts  
1038 per age groups, education level, and socio-professional categories, compared with the  
1039 demographics in the city of Arequipa.

1040 **Figure 4.** Results of univariate analysis of the Survey A dataset. **A.** Graphs A.Q1-Q9. **B.**  
1041 Graphs A.11-15 and 17. Graphs A.Q10 and Q16 are located at the end of the Figure.

1042 **Figure 5.** Results of univariate analysis of Hazard knowledge acquisition among the  
1043 respondents from the Survey B dataset. Graphs B.Q1 to B.Q11.

1044 **Figure 6.** Results of univariate analysis of the Level of risk perception and associated  
1045 variables among the respondents from the Survey C dataset. **A.** Graphs C.Q1 to Q8. **B.**  
1046 Graphs C.Q9 to Q16. **C.** Graphs C.Q17 to Q23.

1047 **Figure 7.** AFC biplots showing attributes of five pairs of variables: A. B. C. D. E.

1048 **Figure 8.** Biplot showing correlations between five illustrative variables from Survey A (in  
1049 blue), active variables from Surveys B and C (in red), and principal dimensions 1 and 2.

1050 **Figure 9.** Factor map from HAC showing four clusters.

1051 **Figure 10.** Flow chart of the Governance of Disaster Risk Management at the national scale  
1052 in Peru and locally in the city of Arequipa.

### 1053 **Electronic Supplementary Data**

1054 **ESD Text.** List of questions of the surveys A, B, and C.

1055 **ESD Table 1.** Chi<sup>2</sup> test conducted separately on variables from each of the three surveys A,  
1056 B, and C.

1057 **ESD Table 2.** Coordinates, squared cosinus, and contributions. We only consider attributes  
1058 that exceed or are equal to the average of contributions and squared cosinus.

1059 **ESD Table 3.** Chi<sup>2</sup> test on HAC variables with p-value and degree of freedom.

1060 **ESD Table 4.** Paragons, i.e., the five most representative individuals for each of the four  
1061 clusters of respondents. The first number identifies each of the individuals and the second  
1062 number is the distance between individuals and the cluster centre (see [Fig. 9](#)).

1063 **ESD Table 5.** List of questions raised and topics covered in interviews, meetings and focus  
1064 groups held with the local authorities and community boards about disaster risk management.

1065 **ESD Figure 1.** Neighbourhoods under study showing flood-prone areas along the ravine  
1066 channels and buildings where three surveys A, B and C were collected. **A.** Quebrada San  
1067 Lazaro. **B.** Quebrada Huarangal Mariano Melgar and its tributary, Qda. Dahlia.

1068 **ESD Figure 2.** Scree plot showing percentages of variance distributed in 14 dimensions and  
1069 following Benzécri's correction.

1070 **ESD Figure 3.** Scores of hazard knowledge (based on questions/variables from survey B)  
1071 obtained by using the 'equal width' discretization method.

1072

**STATISTICAL APPROACH APPLIED TO THE SURVEY DATASET**

Uni-, Bivariate analyses, Factorial and Multiple Correspondence Analyses, Hierarchical Agglomerative Clustering, Polytomic Logistic Regression

<b>RESEARCH STEPS, OBJECTIVES &amp; METHODS</b>	<b>OBSERVATIONS</b> (51 variables, 14 neighbourhoods, c. 280 respondents)	<b>EXPECTED RESULTS</b>
<p>Field surveys Data acquisition Mapping</p> <p><b>STEP 1</b></p> <p>Investigate the parameters of urban dwellers living along the hazar-prone ravines and exposed to floods and flows</p>	<p><b>Socio-demographic, economic characteristics (Survey A)</b></p> <ol style="list-style-type: none"> <li>1. Gender, age group</li> <li>2. Household composition</li> <li>3. Education level</li> <li>4. Socio-professional categories</li> <li>5. Number of resource person and monthly income</li> <li>6. Place of birth or migration origin</li> <li>7. Time living in the city</li> </ol>	<p>Characteristics of population sample living in suburbs along the hazard-prone ravines</p>
<p><b>STEP 2</b></p> <p>Estimate the level of knowledge of volcano and flow related and the sources of knowledge among the urban dwellers living near the ravines</p>	<p><b>Hazard knowledge (Survey B)</b></p> <ol style="list-style-type: none"> <li>1. Name of neighbouring volcanoes and most recent Misti's eruption date</li> <li>2. Ability to read Misti's hazard-zone map and locate neighbourhood</li> <li>3. Three most frequent volcanic threats in the area</li> <li>4. Lahar occurrence, timing and fatalities</li> <li>5. Eruption duration and lahar arrival time since onset</li> </ol>	<p>Awareness Sources of knowledge Kinds of experience acquired with flow and flood events</p>
<p><b>STEP 3</b></p> <p>To evaluate how people perceive flood and volcanic risk from Misti, and compare the risk perception with hazard knowledge</p>	<p><b>Risk perception and associated variables (Survey C)</b></p> <ol style="list-style-type: none"> <li>1. Hazard salience</li> <li>2. Sense of community and social capital</li> <li>3. Hazard likelihood and severity</li> <li>4. Past behaviour and memory</li> <li>5. Self confidence, empowerment</li> <li>6. Trust in authorities</li> <li>7. Personal feelings</li> </ol>	<p>Preparedness and past behaviour during flow events</p>
<p><b>STEP 4</b></p> <p>Correlation Hazard knowledge with Risk perception</p>		<p>Appraise how and why groups of urban dwellers living in hazard-prone areas behave in case of imminent evacuation</p>
<p><b>STEP 5</b></p> <p>Clustering, Hierarchical Ascending Classification, frequency analysis, study of parangons</p>		
<p><b>STEP 6</b></p> <p>Analysis of risk management policy. Interviews and focus groups with key actors</p>	<p><b>Disaster risk management policy in city districts</b></p> <ol style="list-style-type: none"> <li>1. Identification of key actors</li> <li>2. Characteristics of authorities and communities' organization</li> <li>3. Potential sources of conflict</li> </ol>	<p>Understanding factors which hinder disaster risk management in the city</p>

Figure 1

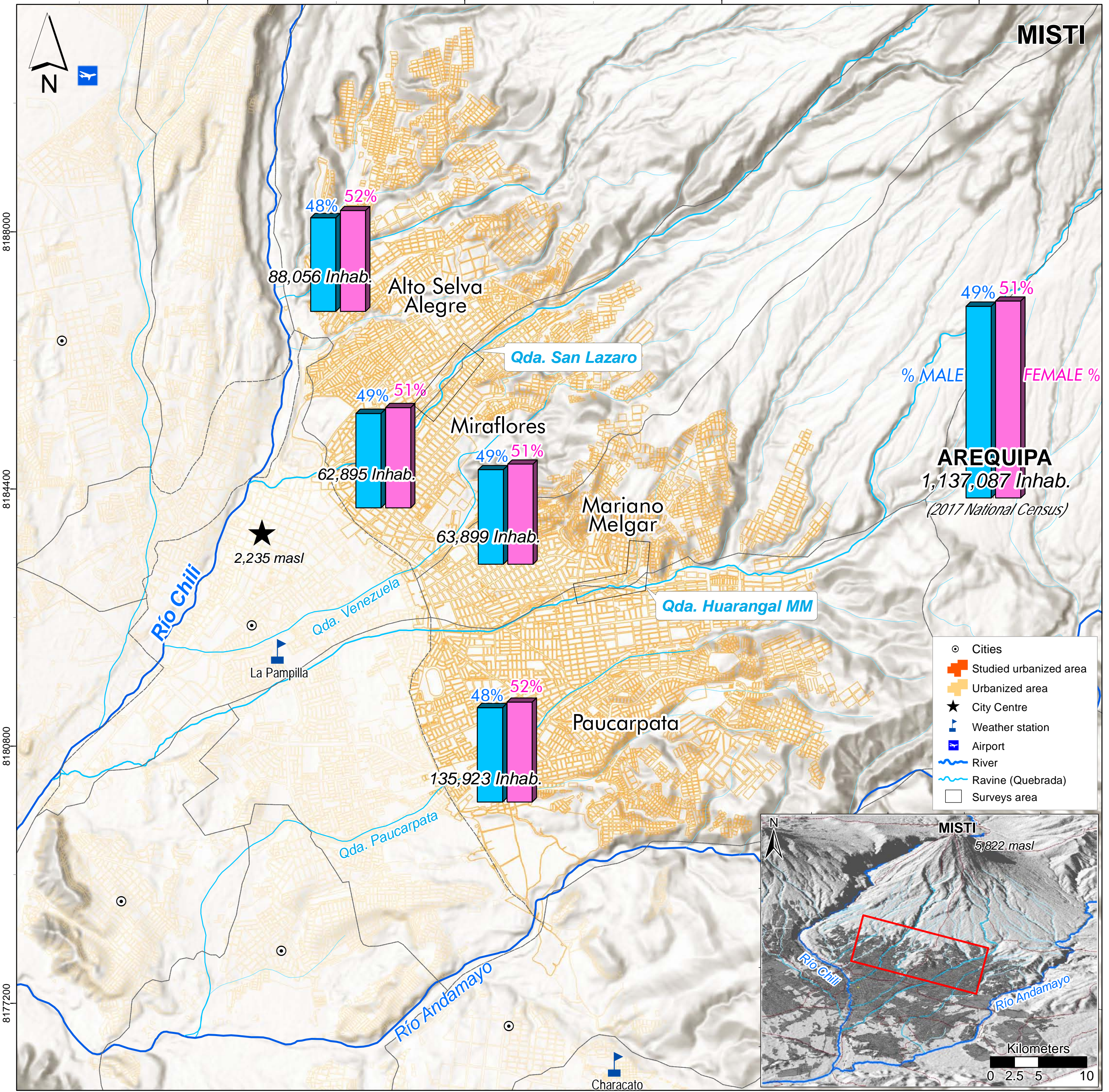
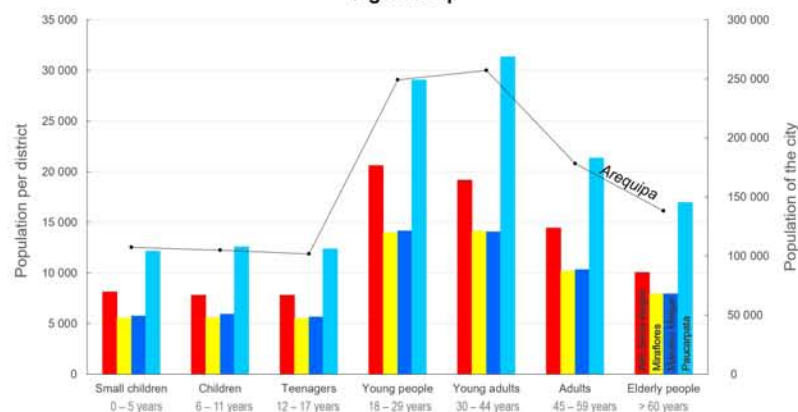




Figure 3

A

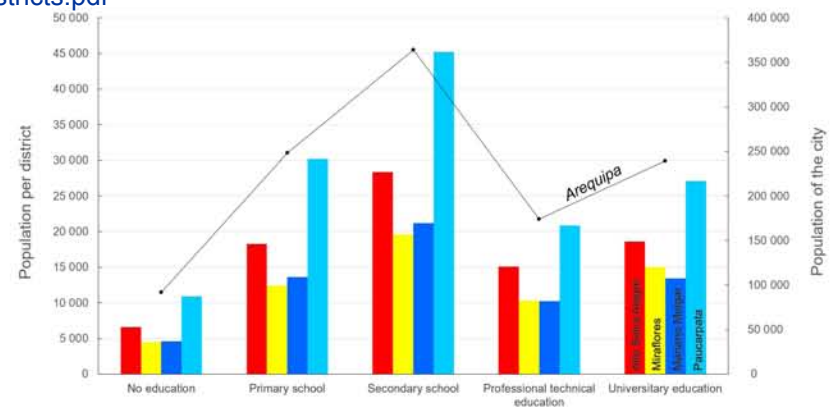
Age Group



Click here to access/download;Figure 3. Socio demo data city & Districts.pdf

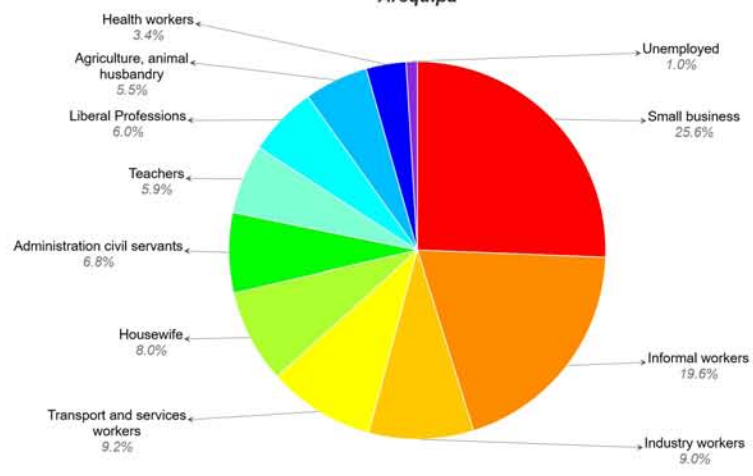
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Education level



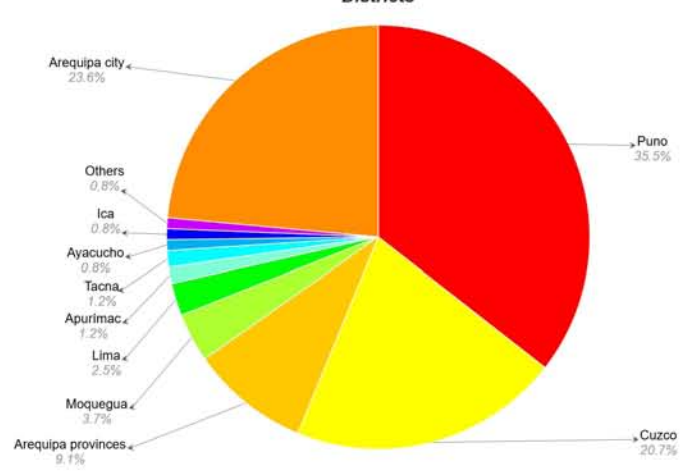
C

Social-professional categories Arequipa



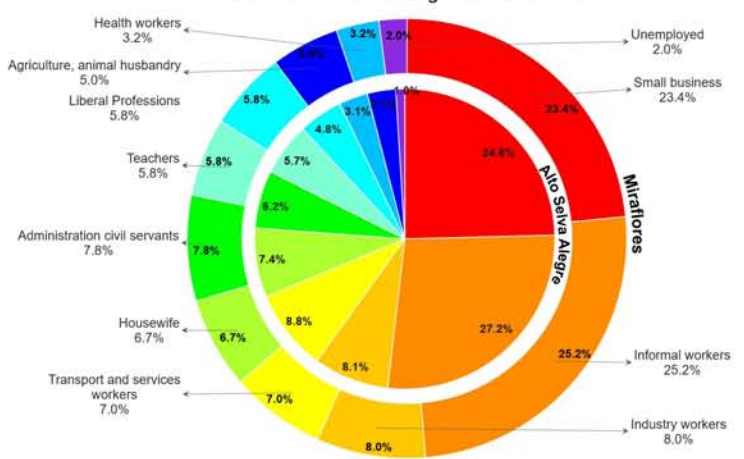
D

Regional origin of the respondents Districts



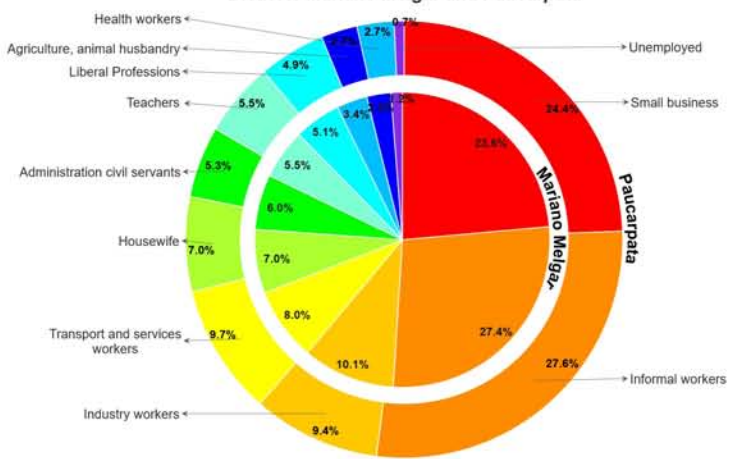
E1

Socio-professional categories Districts Alto Selva Alegre and Miraflores



E2

Socio-professional categories Districts Mariano Melgar and Paucarpata



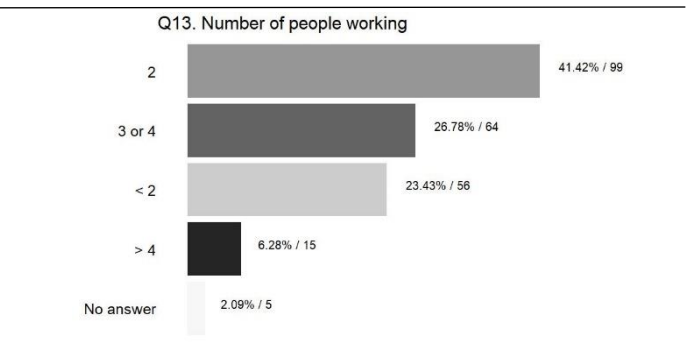
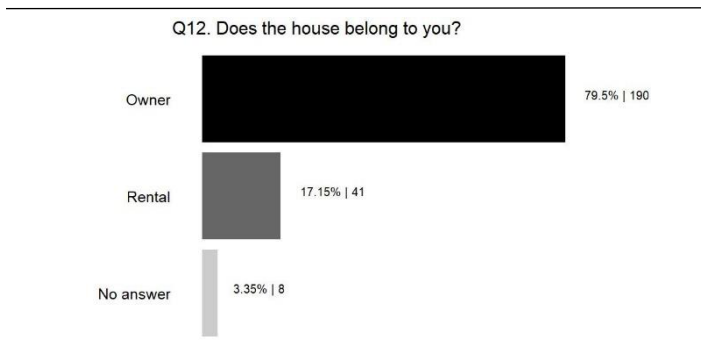
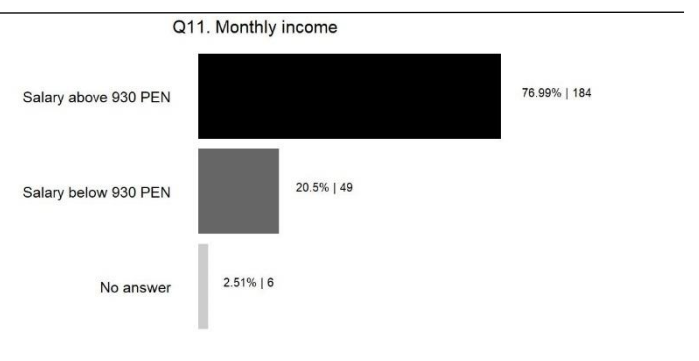
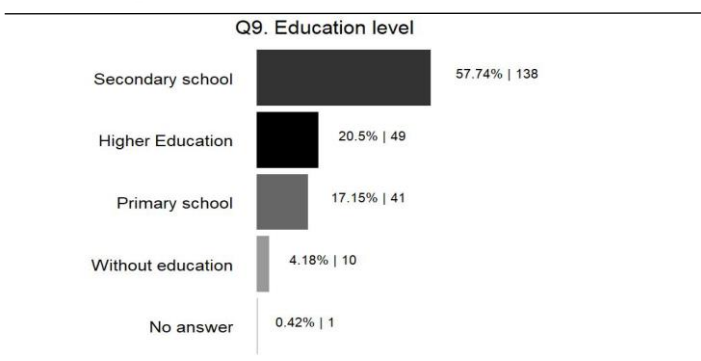
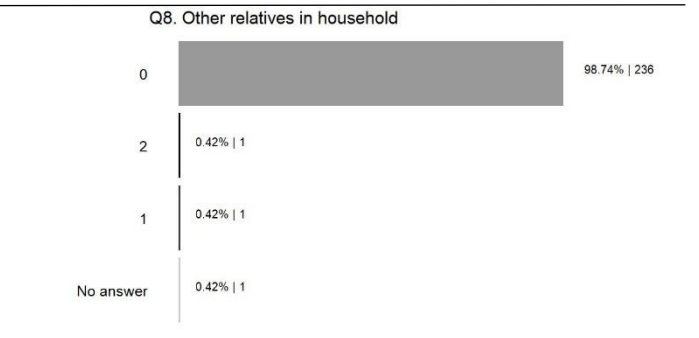
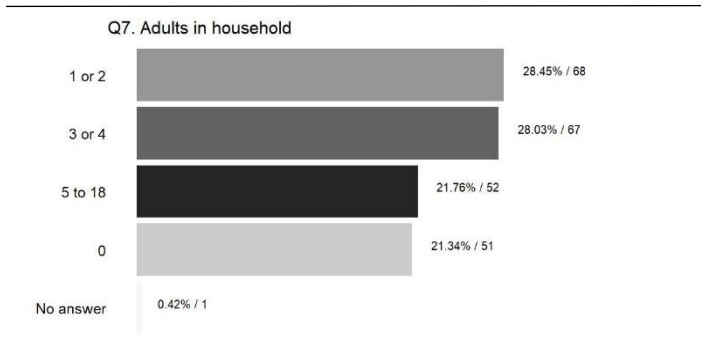
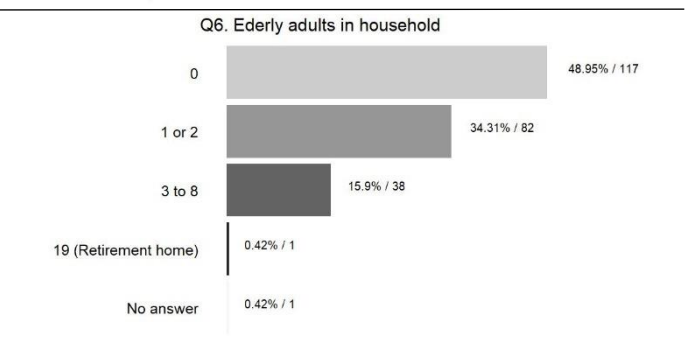
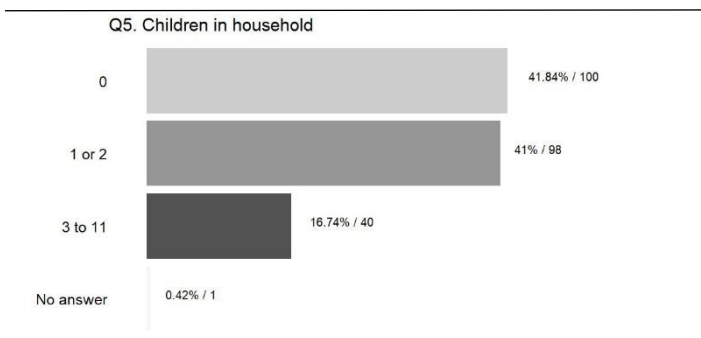
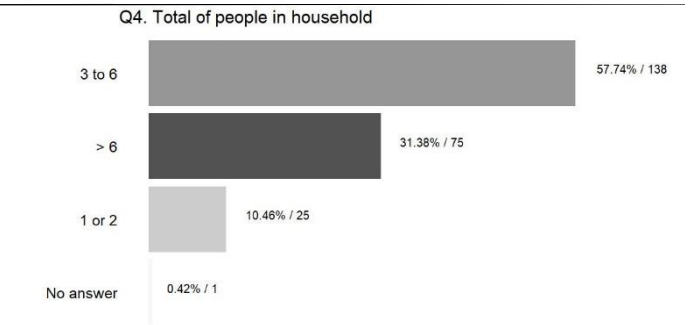
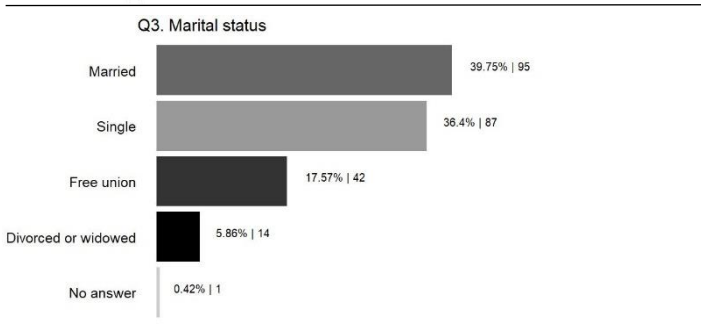
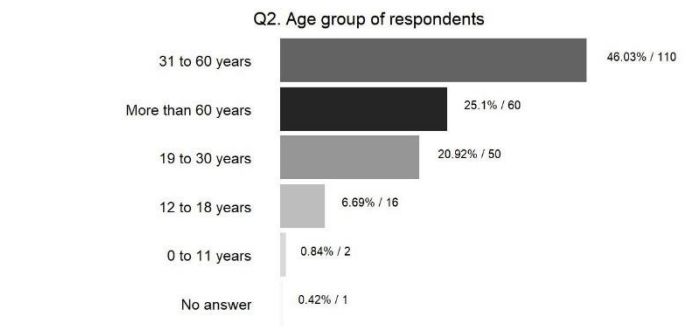
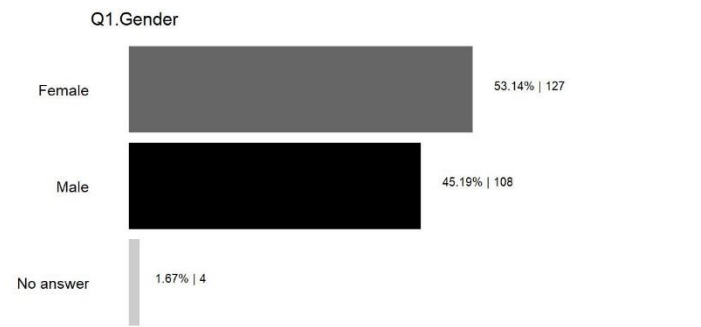


Fig. 4A

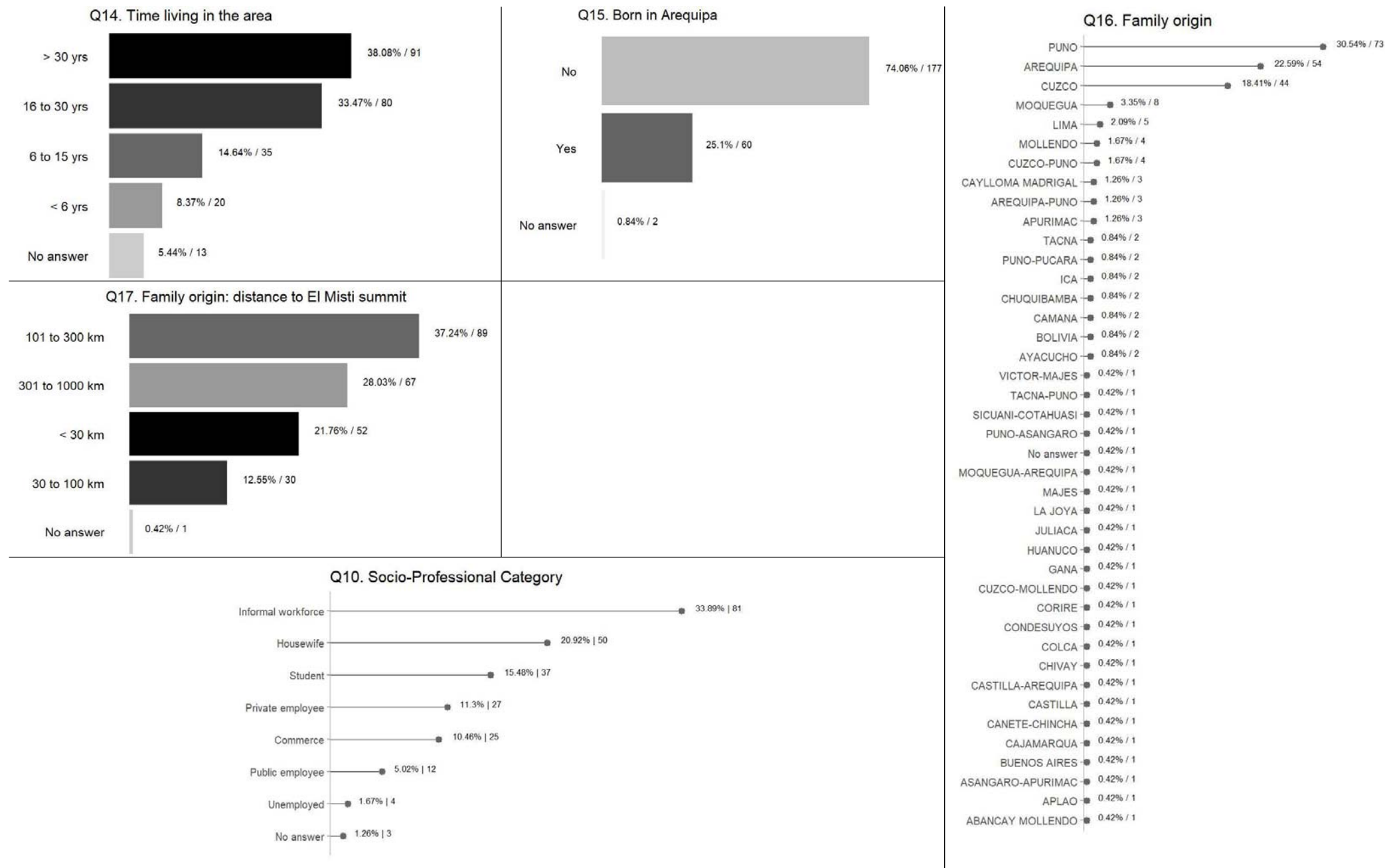


Fig. 4B

Figure 5

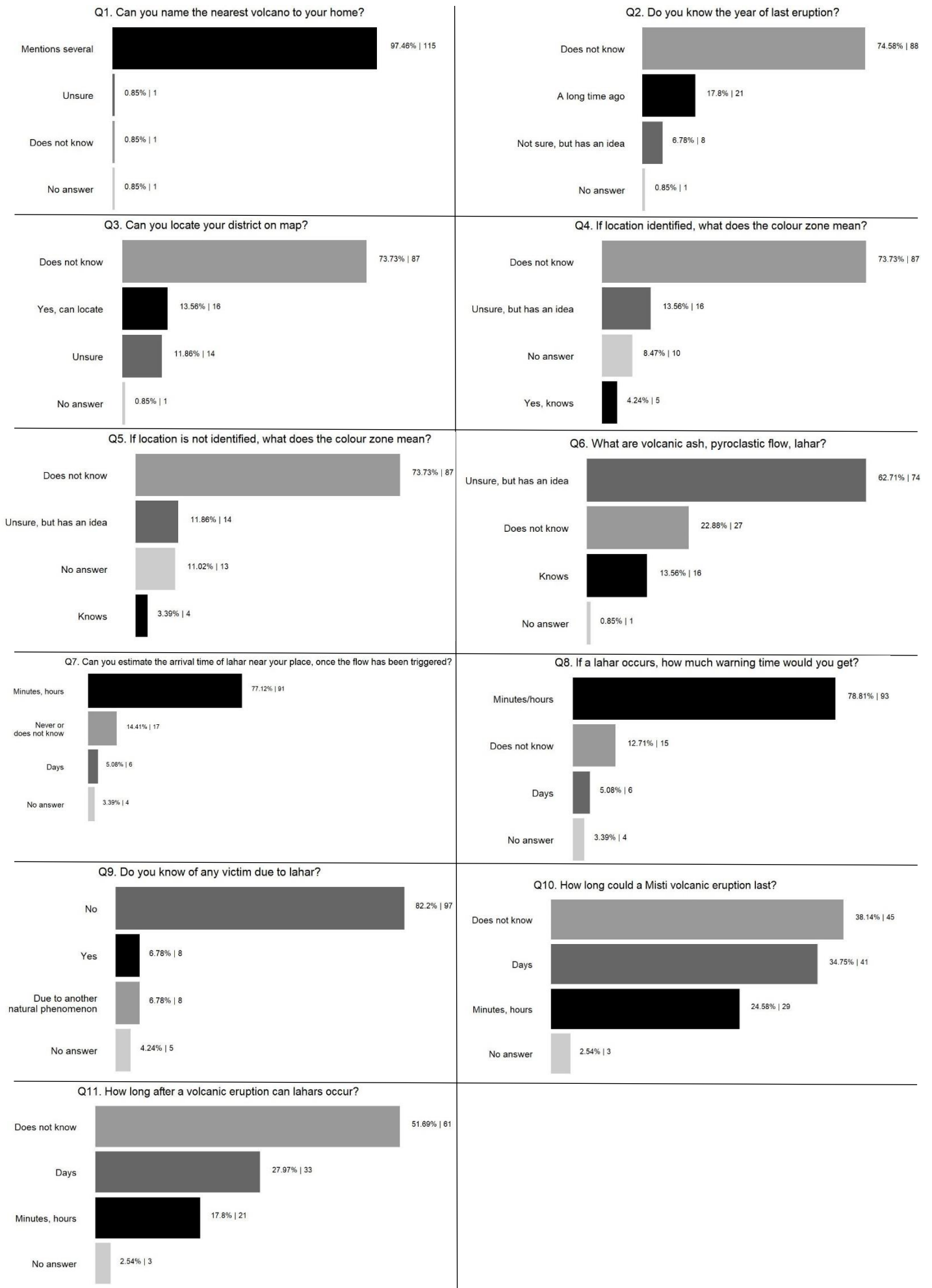


Fig. 5

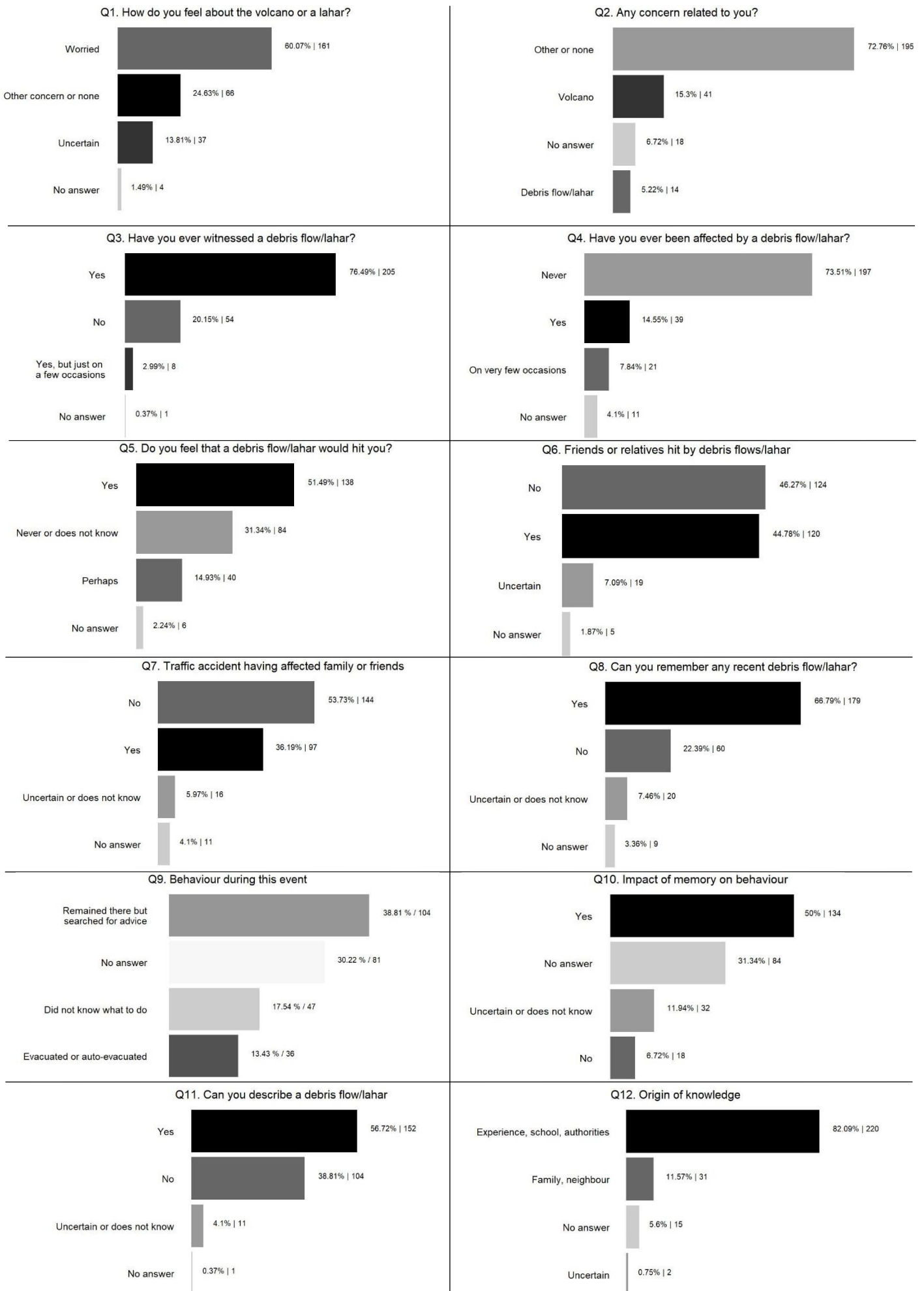


Fig. 6A

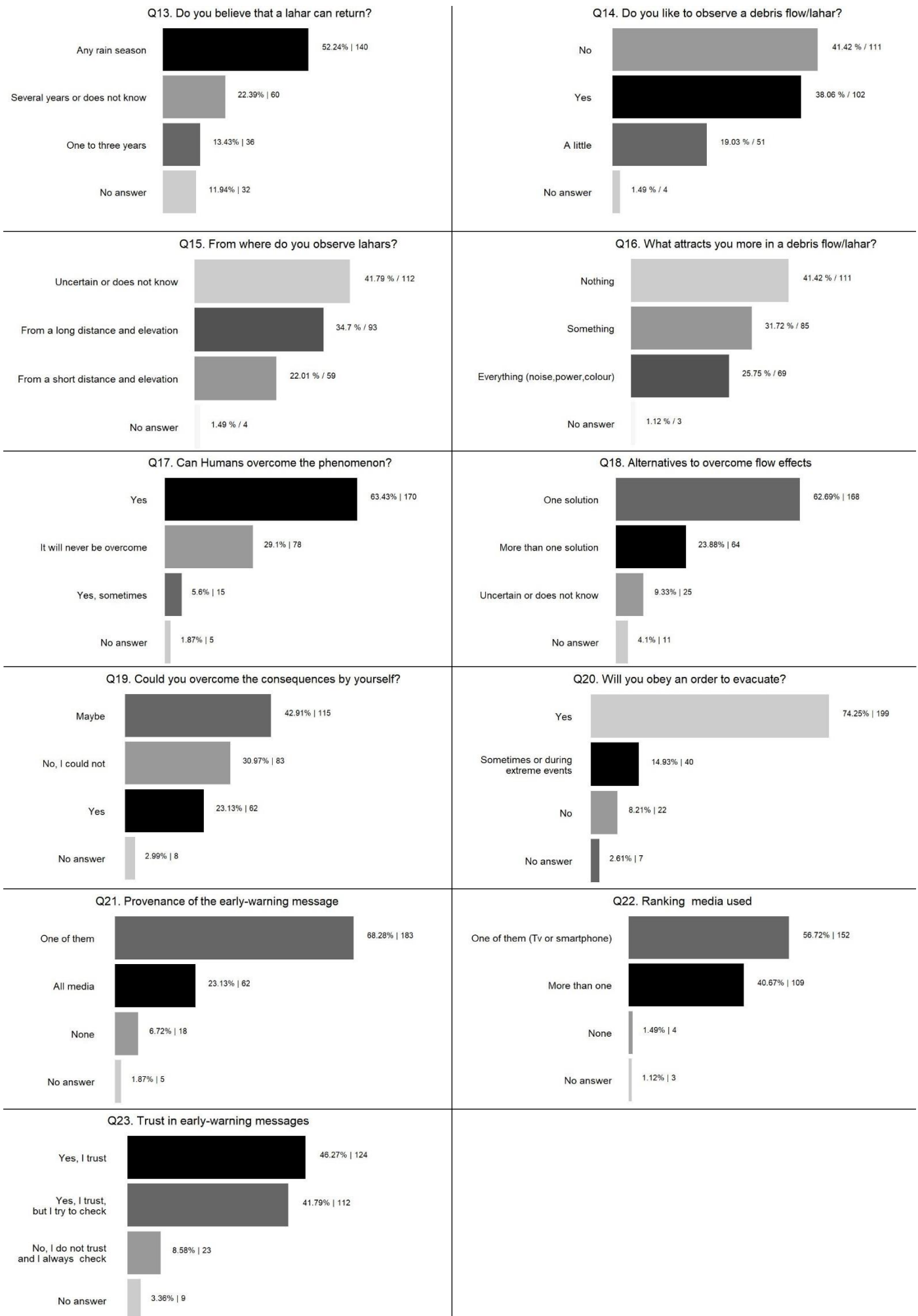


Fig. 6B



Fig. 7A

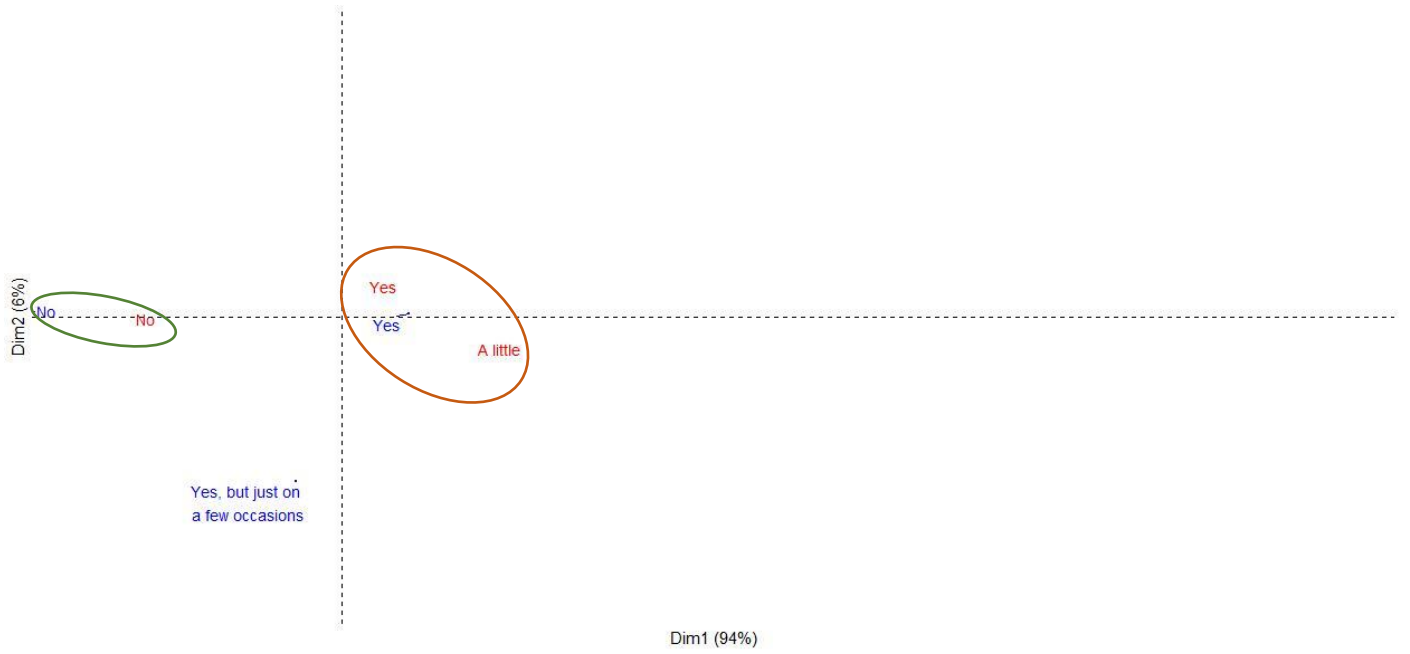


Fig. 7B



Fig. 7C



Fig. 7D



Fig. 7E



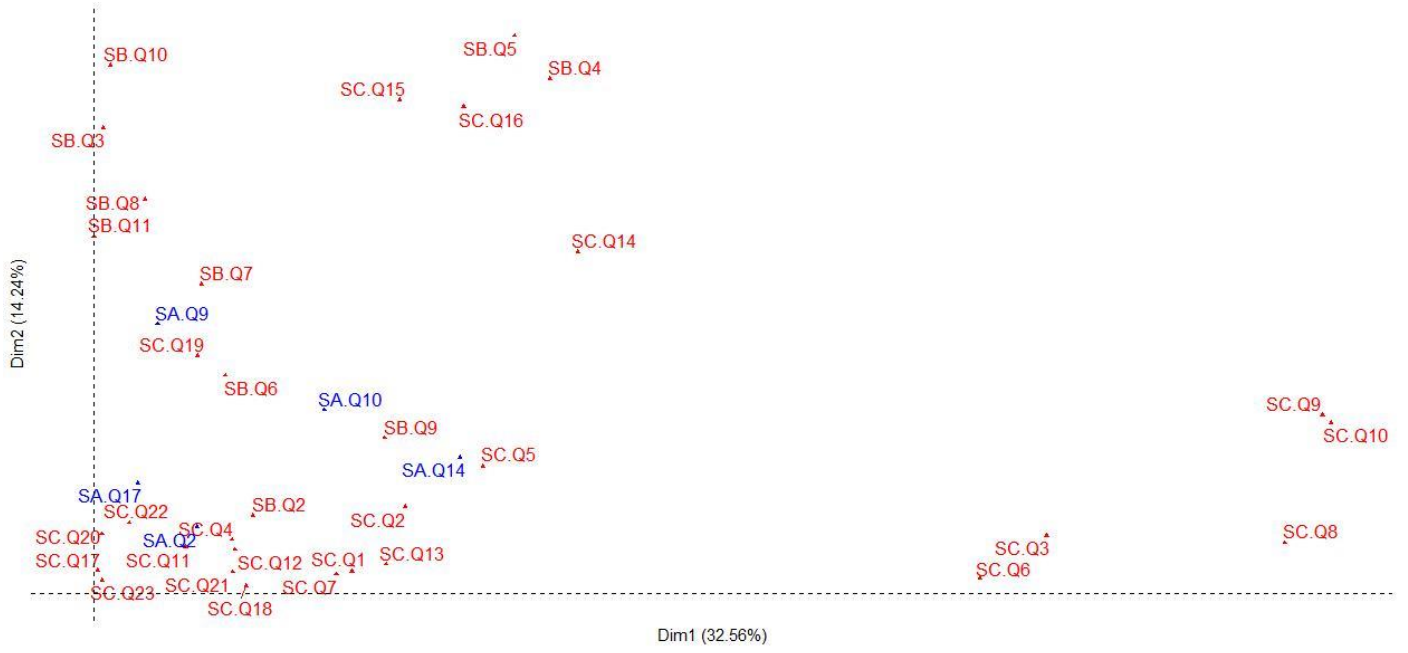


Figure 8

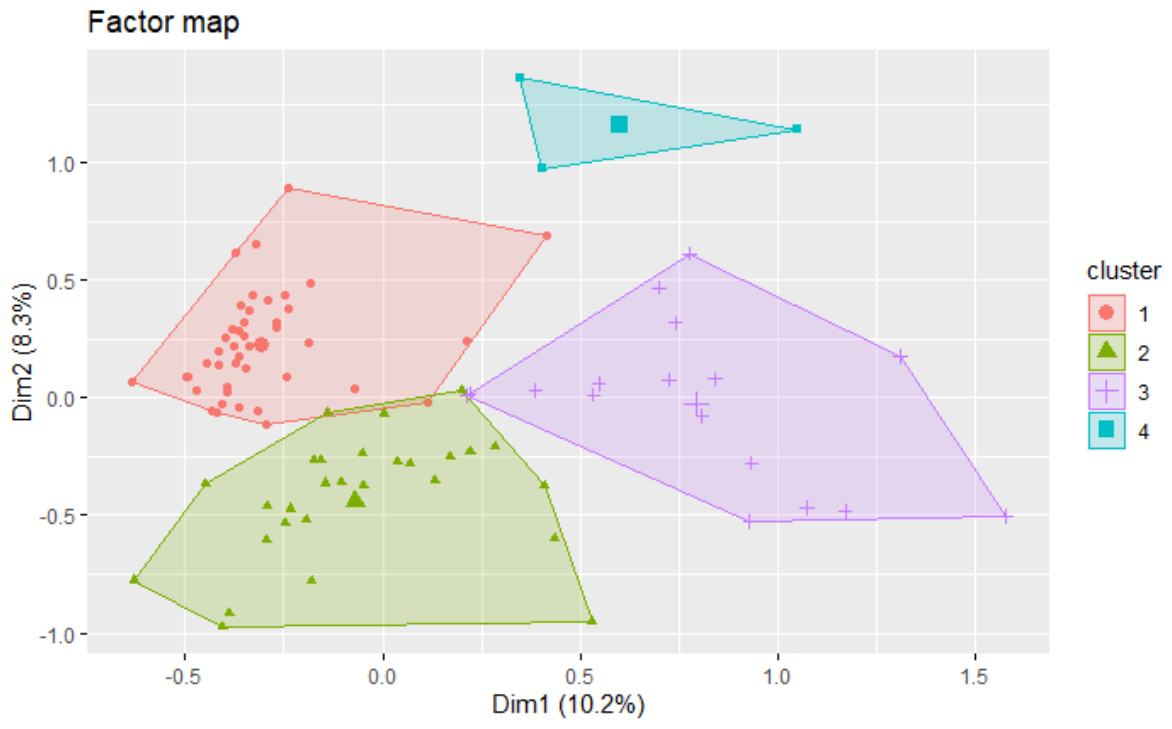


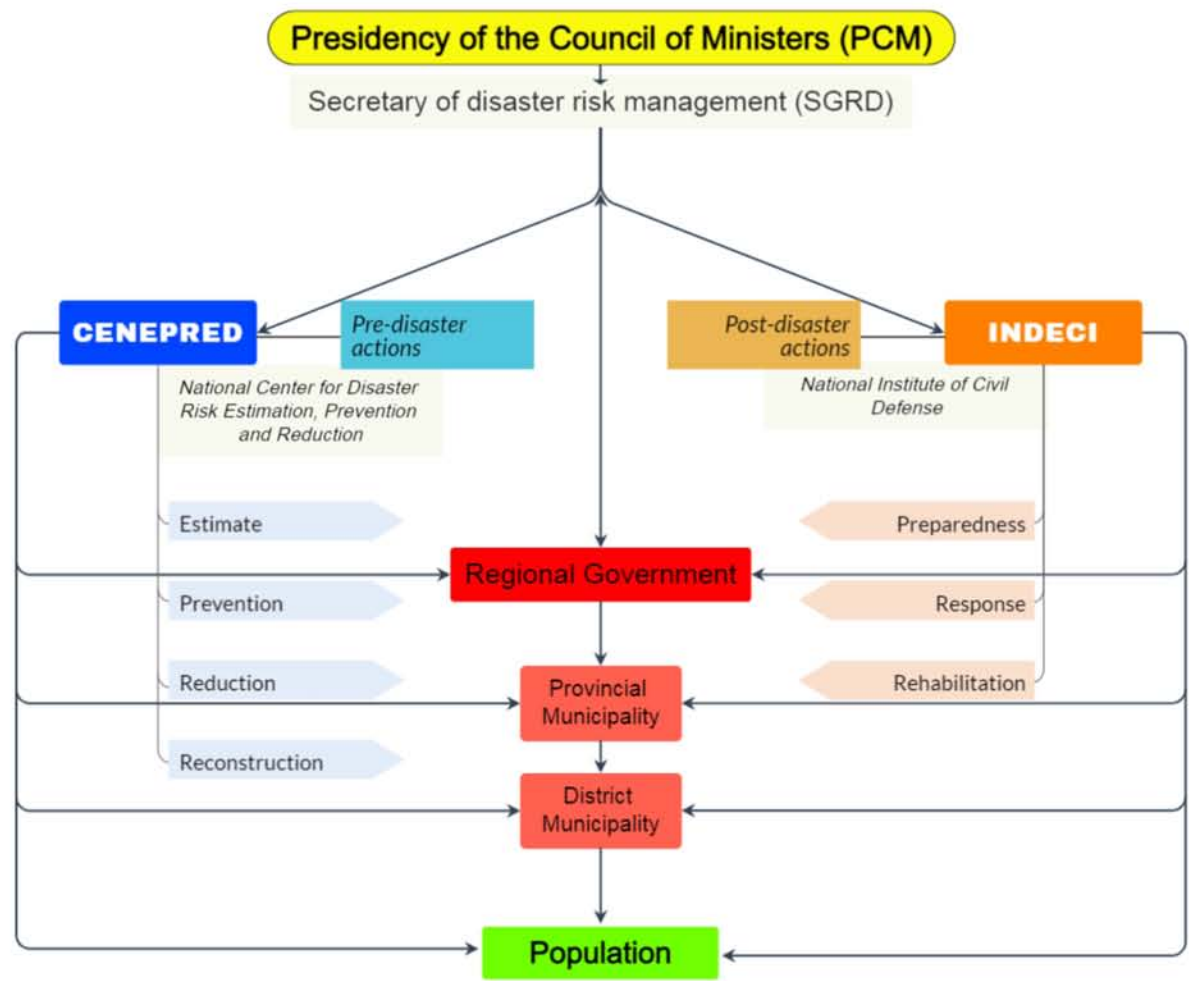
Fig. 9

SUPERIOR ENTITY

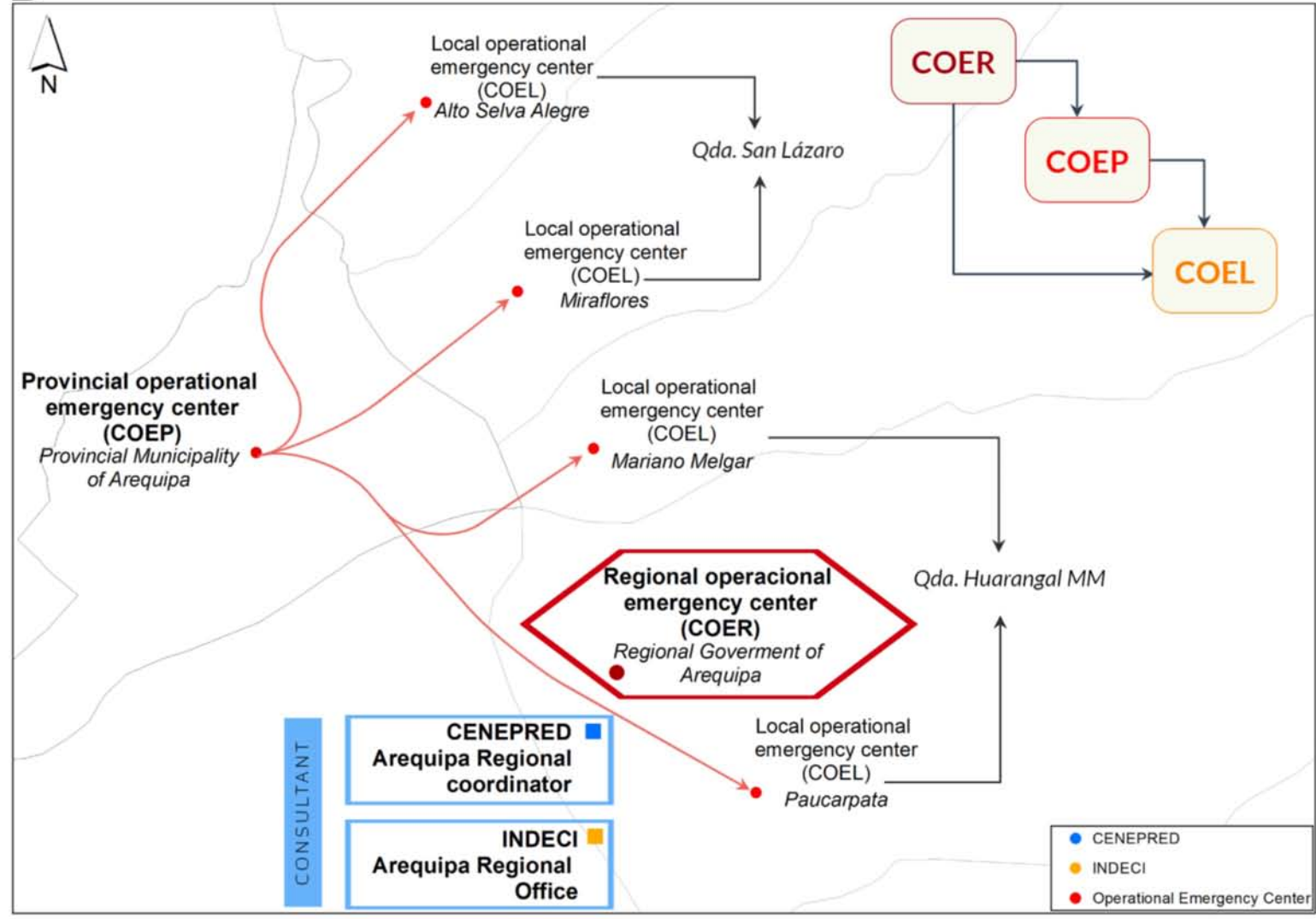
CONSULTANT

IMPLEMENTER

PARTICIPANT



**B**



<b>Observations</b>	<b>Methods</b>	<b>Techniques</b>	<b>Purposes</b>
Set of variables from all surveys	Univariate Analysis UA	Frequency: barplot	To obtain the frequency of all categories of every variable
All couples of variables	Bivariate Analysis BA	Chi-square test	To identify independence between two variables
		Contingence tables: Burt Table Factorial Correspondence Analysis (FCA) Biplot graphics	Allows to analyse the cross frequency between two variables To show links/correlation between categories of two variables
- Illustrative variables entail 5 questions from Survey A, 10 from Survey B, and 23 from Survey C - Active variables include all questions from four Surveys	Multiple Correspondence Analysis, MCA	Scree plot showing eigenvalues (with Benzécri's correction)	To define the number of dimensions (5) retaining most information
		Projection of observations (groups) in biplots Biplots Scatter plots	To show correlation between variables/categories and dimensions 1 and 2 To show contributory categories that better describe each dimension and have similar behaviour
Explore the MCA outputs to elaborate on population categories and distinguish clusters	Hierarchical Agglomerative Clustering HAC	Dendrogram and Factor map Chi-square test Frequency analysis of all survey datasets (replies to questions) for each cluster Study of parangons	To define the suitable number of clusters (4) To identify links between 38 variables, selecting 21 discriminant variables having a small p-value <0.05 To establish the socio-demographic, knowledge/perception and economic status for each cluster of individuals To characterize the five more representative individuals in each of the clusters

Table 1

**SOCIO-DEMOGRAPHIC CHARACTERISTICS (Survey A, 239 respondents)**

Questions		Answers					
<b>1.SOCIO-DEMOGRAPHIC CATEGORIES</b>							
Q2. Age group	0 to 11 years/12 to 18 years	19 to 30 years	31 to 60 years	> 60 years			
Q3. Marital Status	Single	Single	Married/Free union	Single/ Divorced or widowed			
<b>Sub-total</b>	<b>Cohort 18 7.53%</b>	<b>33 13.81%</b>	<b>76 31.80%</b>	<b>16 6.69%</b>			
Q4. Household: Total of people	≥ 7	3 to 6	3 to 6	≤ 2			
Q6. 0-14y	1 to 11	1 to 5	0	0			
Q7. 15-60y	≥ 1	1 to 5	0 to 6	≤ 2			
Q8. >60y	0 to 8	0 to 6	0 to 6	≤ 2			
Q13. Number of people working	2 to 8	≤ 4	≤ 4	≤ 2/ No answer			
<b>Sub-total</b>	<b>Cohort 54 22.59%</b>	<b>56 23.43%</b>	<b>66 27.62%</b>	<b>24 10.04%</b>			
Q9. Education level	High education	Seconday school	Primary school	Primary school/without education			
Q10. Socio-professional category	Private and public employee/Informal/Commerce/Housewife/ Student	Private and public employee/Informal/Commerce/Housewife/ Student/Unemployed	Informal/Commerce/Housewife/ Student	Informal/Commerce/Housewife/ Student			
Q11. Minimum salary threshold (930 PEN, 2019)	Above	Above	Above	Below			
<b>Sub-total</b>	<b>Cohort 43 17.99%</b>	<b>108 45.19%</b>	<b>26 10.88%</b>	<b>16 6.69%</b>			
<b>2.GEOGRAPHICAL ORIGIN AND ARRIVAL TIME IN THE AREA</b>							
Q15. Geographical origin of the respondent (born in Arequipa)	Yes	No	No	No			
Q17.Family origin (Distance to El Misti summit)	< 30 km	30 to 100 km	300 to 1 000 km	100 to 300 km			
Q14. How long have you been living in the area?	≥ 16 years	≥ 6 years	≥ 6 years	≤ 6 years/ No answer			
<b>Sub-total</b>	<b>Cohort 38 18.00%</b>	<b>96 45.50%</b>	<b>58 27.49%</b>	<b>21 9.95%</b>			
<b>GROUPS (Frequency analysis)</b>							
A. Young and mature adults, independent and resource person, educated and born in Arequipa	B. Young and mature adults, independent and resource person, educated and born in Arequipa or elsewhere	C. Younger and older adults, independent, resource person and educated, born in the region?	D. Mature and older adults, independent resource person without education, born far away	E. Young and mature adults, without or low resources, and educated, born in	F. Younger and older adults, dependent on families, without or low resources, poorly or not educated, born far away		
<b>Cohort 35 15.90%</b>	<b>93 38.91%</b>	<b>49 20.5%</b>	<b>7 2.93%</b>	<b>28 11.72%</b>	<b>21 8.79%</b>		

**HAZARD KNOWLEDGE (Survey B, 118 respondents)**

<b>Question</b>	<b>Answer</b>			
	<b>1. VOLCANO AND ERUPTION</b>			
Q1. Can you name the nearest volcano to your home?	Mentions several (Should mention at least El Misti)	Mentions several	Mentions several	Unsure/No answer
Q2. Do you know what year this volcano last erupted?	A long time ago	Not sure, but has an idea	Does not know the date	Does not know the date/No answer
<b>Sub-total</b>	<b>Cohort 20 16.95%</b>	<b>8 6.78%</b>	<b>83 70.34%</b>	<b>2 1.69%</b>
	<b>2. HAZARD-ZONE MAP</b>			
Q3. Can you locate your district?	Yes, can locate	Yes, can locate/Unsure	Yes, can locate/Unsure	Does not know
Q4. Do you know the hazard-zone colour meaning?	Yes, knows/ Unsure, but has an idea	Yes, knows/ Unsure, but has an idea	Unsure, but has an approximate idea/ Does not know	Does not know/ No answer
Q5. Can you show your village location and what does represent colour shown?	Knows	Unsure, but has an idea/No answer	Does not know	Does not know/ No answer
<b>Sub-total</b>	<b>Cohort 4 3.39%</b>	<b>13 11.02%</b>	<b>7 5.93%</b>	<b>80 67.80%</b>
	<b>3. LAHAR OCCURRENCE AND IMPACT</b>			
Q7. Can you estimate the arrival time of a lahar to your village, once it has been triggered on the mountain?	Minutes, hours	Minutes, hours/Days	Minutes, hours/ Never/ Doesn't know	Never or doesn't know
Q8. Can you estimate how many times lahars can happen?	Minutes, hours	Minutes, hours/Days	Minutes, hours	Doesn't know
Q9. Do you know of any victim or/and injured people?	Yes	No	Another natural phenomenon	No/Another natural phenomenon/No answer
<b>Sub-total</b>	<b>Cohort 6 5.08%</b>	<b>85 72.03%</b>	<b>7 5.93%</b>	<b>14 11.86%</b>
	<b>4. ERUPTION AND LAHAR OCCURRENCE INTERVAL TIME</b>			
Q10. How long could the next El Misti volcanic eruption last?	Minutes, hours	Minutes, hours/Days	Days	Does not know/No answer
Q11. How long after a volcanic eruption can lahars occur?	Minutes, hours	Minutes, hours/Days	Does not know	Does not know/No answer
<b>Sub-total</b>	<b>Cohort 15 12.71%</b>	<b>32 27.12%</b>	<b>16 13.56%</b>	<b>41 34.75%</b>
	<b>LEVEL OF KNOWLEDGE</b>			
<b>A. Very good knowledge</b>	<b>B. Good knowledge</b>	<b>C. Regular knowledge</b>	<b>D. Poor knowledge or un-educated</b>	
<b>Cohort 7 5.93%</b>	<b>58 49.15%</b>	<b>41 34.75%</b>	<b>12 10.17%</b>	

Table 3

**RISK PERCEPTION AND ASSOCIATED VARIABLES (Survey C, 268 respondents)**

<b>Question</b>	<b>Answer</b>	<b>Answer</b>	<b>Answer</b>	<b>Answer</b>
Q1. How do you feel about volcano or lahar? Q2. Any concern related to you?	Other or none/No answer	Other or none/No answer	Worried/Uncertain	Worried/Uncertain
<b>Sub-total</b>	<b>Cohort 12 4.48%</b>	<b>58 21.64%</b>	<b>43 16.04%</b>	<b>155 57.84%</b>
Q3. Have you ever witnessed a debris flow? Q4. Have you ever been affected by a debris flow? Q5. Do you feel that a debris flow would hit you?	Yes Yes/A little Yes/Perhaps	Yes/Yes, but just a little Never Yes/Perhaps	Yes/Yes, but just a little Never Never or does not know	No Never/No answer Never or does not know/No answer
<b>Sub-total</b>	<b>Cohort 44 16.42%</b>	<b>115 42.91%</b>	<b>42 15.67%</b>	<b>35 13.06%</b>
Q6. Do you know of anyone among your family or friends who has been affected by a debris flow? Q7. Traffic accident, family or friends?	Yes Yes	Yes No/Undecided or doesn't know	No/Uncertain Yes	No/Uncertain No/Undecided or does not know
<b>Sub-total</b>	<b>Cohort 48 17.91%</b>	<b>67 25%</b>	<b>49 18.28%</b>	<b>91 33.96%</b>
Q8. Can you identify or discuss a particular lahar that you remember? Q9. How did you behave that day? Q10. Had this memory impacted the way you behaved that day?	Yes Evacuated or auto-evacuated/ Remained Yes	Yes Did not know what to do Yes	Yes Remained/Did not know what to do No/Uncertain or doesn't know	No/Uncertain or doesn't know No answer No answer
<b>Sub-total</b>	<b>Cohort 109 40.67%</b>	<b>19 7.09%</b>	<b>37 13.91%</b>	<b>65 24.25%</b>
Q11. Can you describe a debris flow? Q12. Where does your knowledge on debris flow come from? Q13. Do you believe that a lahar can return, and how long would it return?	Yes Experience, school or authorities Any rain season/ 1 to 3 years/ Several years or does not know	Yes Family or neighbour Any rain season/One to three years/ Several years or does not know	No Experience/ Family, neighbour Any rain season/One to three years/ Several years or does not know	No/Uncertain or does not know Family, neighbour/ No Answer Several years or does not know/ No Answer
<b>Sub-total</b>	<b>Cohort 115 42.91%</b>	<b>18 6.72%</b>	<b>95 35.45%</b>	<b>7 2.75%</b>
Q14. Do you like to observe a debris flow? Q15. From where do you observe lahars? Q16. What attracts he/she much in a debris flow?	Yes/a little At a long distance and elevation Everything	Yes/a little At a long distance and elevation Something	Yes/a little At a short distance and elevation Everything/Something	No Uncertain or doesn't know Nothing
<b>Sub-total</b>	<b>Cohort 37 13.91%</b>	<b>45 16.79%</b>	<b>59 22.01%</b>	<b>103 38.43%</b>
Q17+Q18+Q19. Do you feel that such a phenomenon is so powerful than Mankind cannot do anything about it? Do you think of any alternative to overcome flow effects? Do you feel self-confident in case of an eruption?	Yes More than one solution Yes/Maybe	No, too powerful One/More than one solution Yes/Maybe	Yes One/More than one solution No	No, too powerful One No
<b>Sub-total</b>	<b>Cohort 30 11.19%</b>	<b>48 17.91%</b>	<b>30 11.19%</b>	<b>18 5.60%</b>
Q20. Will you comply with the evacuation order in any type of situation? Q21+22. Whom do you receive warning from in case of lahar? Which type of device? Q23. Do you believe messages and/or do you try to check the content?	Yes All media More than one Yes, trusts	Yes All/one media One/More than one Try to check	Sometime or in extreme events All/one media One/More than one Yes, trusts/Try to check	No/ Sometime or in extreme events None/One/All media One of them No/Try to check
<b>Sub-total</b>	<b>Cohort 18 6.72%</b>	<b>84 31.34%</b>	<b>38 14.18%</b>	<b>19 7.09%</b>
<b>GROUPS (Survey C)</b>				
<b>A.</b>	<b>B.</b>	<b>C.</b>	<b>D.</b>	
<b>Cohort 138 51.49%</b>	<b>94 35.07%</b>	<b>32 11.94%</b>	<b>4 1.49%</b>	

		Survey A					Survey B											Survey C																					
		2	9	10	14	17	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Survey A	2	0.00	0.00	0.00	0.00	0.48	0.54	0.27	0.33	0.25	0.44	0.81	0.64	0.80	0.14	0.26	0.69	0.39	0.02	0.61	0.71	0.34	0.60	0.04	0.74	0.27	0.02	0.14	0.45	0.80	0.53	0.82	0.25	0.00	0.51	0.04	0.91	0.46	0.12
	9	0.00	0.00	0.15	0.26	0.03	0.91	0.22	0.07	0.14	0.24	0.31	0.13	0.64	0.39	0.74	0.27	0.25	0.27	0.06	0.15	0.08	0.54	0.64	0.82	0.62	0.75	0.39	0.53	0.16	0.16	0.30	0.74	0.40	0.08	0.55	0.39	0.44	0.04
	10	0.00	0.15	0.00	0.02	0.56	0.79	0.24	0.27	0.30	0.04	0.05	0.04	0.61	0.16	0.21	0.15	0.14	0.06	0.38	0.77	0.44	0.60	0.06	0.04	0.08	0.24	0.22	0.41	0.02	0.21	0.18	0.21	0.21	0.00	0.32	0.27	0.09	0.28
	14	0.00	0.27	0.02	0.00	0.10	0.63	0.24	0.00	0.02	0.51	0.86	0.84	0.25	0.17	0.05	0.74	0.05	0.00	0.26	0.57	0.08	0.96	0.02	0.41	0.04	0.08	0.53	0.31	0.38	0.10	0.15	0.74	0.03	0.34	0.71	0.93	0.87	0.13
	17	0.48	0.02	0.56	0.10	0.00	0.29	0.22	0.47	0.86	0.03	0.13	0.16	0.69	0.26	0.88	0.19	0.47	0.42	0.64	0.69	0.06	0.31	0.58	0.20	0.86	0.18	0.37	0.12	0.69	0.30	0.78	0.83	0.08	0.75	0.27	0.09	0.48	0.54
Survey B	2	0.55	0.92	0.79	0.63	0.28	0.00	0.38	0.25	0.21	0.19	0.93	1.00	0.02	0.33	0.31	0.03	0.34	0.09	0.25	0.67	0.01	0.78	0.18	0.28	0.21	0.81	0.50	0.90	0.47	0.31	0.53	0.82	0.13	0.71	0.31	0.39	0.31	0.10
	3	0.28	0.22	0.23	0.24	0.21	0.38	0.00	0.00	0.00	0.01	0.77	0.86	0.74	0.48	0.18	0.02	0.64	0.56	0.79	0.03	0.87	1.00	0.77	0.36	0.37	0.81	0.74	0.89	0.25	0.15	0.17	0.25	0.17	0.05	0.54	0.70	0.15	1.00
	4	0.34	0.07	0.27	0.00	0.45	0.25	0.00	0.00	0.00	0.00	0.98	0.79	0.13	0.62	0.13	0.02	0.08	0.03	0.56	0.33	0.25	0.53	0.16	0.17	0.07	0.73	1.00	0.38	0.13	0.13	0.47	0.91	0.61	0.10	0.97	1.00	0.41	0.05
	5	0.26	0.14	0.29	0.02	0.86	0.20	0.00	0.00	0.00	0.04	0.90	0.88	0.09	0.17	0.00	0.01	0.05	0.05	0.77	0.14	0.12	0.52	0.12	0.05	0.01	0.83	1.00	0.41	0.49	0.19	0.17	0.58	0.51	0.05	0.42	1.00	0.47	0.53
	6	0.43	0.23	0.04	0.53	0.03	0.18	0.01	0.00	0.04	0.00	0.17	0.17	0.76	0.05	0.17	0.53	0.08	0.44	0.63	0.07	0.24	0.46	0.45	0.31	0.81	0.46	0.80	0.48	0.84	0.74	0.22	0.48	0.45	0.41	0.69	0.04	0.31	0.68
	7	0.81	0.32	0.05	0.87	0.13	0.93	0.77	0.98	0.90	0.18	0.00	0.00	0.39	0.00	0.31	0.27	0.88	0.02	0.58	0.54	0.48	0.28	0.49	0.39	0.27	0.90	1.00	0.52	0.21	0.13	0.19	0.15	0.03	0.04	0.67	0.51	0.68	0.30
	8	0.64	0.13	0.04	0.84	0.15	1.00	0.87	0.80	0.87	0.17	0.00	0.00	0.18	0.01	0.16	0.55	0.72	0.29	0.66	0.10	0.90	0.22	0.61	0.63	0.20	1.00	1.00	1.00	0.46	0.31	0.24	0.30	0.08	0.00	0.73	0.18	0.27	0.77
	9	0.79	0.63	0.60	0.25	0.68	0.02	0.75	0.12	0.09	0.77	0.38	0.18	0.00	0.27	0.34	0.19	0.15	0.81	0.59	0.05	0.00	0.24	0.24	0.11	0.00	0.52	1.00	0.45	0.23	0.83	0.40	0.66	0.83	0.28	0.57	0.21	1.00	0.88
	10	0.14	0.38	0.17	0.17	0.29	0.33	0.48	0.61	0.17	0.05	0.01	0.01	0.25	0.00	0.00	0.25	0.41	0.46	0.85	0.11	0.93	0.42	0.80	0.33	0.56	0.68	0.24	0.75	0.39	0.10	0.15	0.72	0.67	0.13	0.45	0.05	0.89	1.00
	11	0.26	0.72	0.21	0.05	0.88	0.30	0.18	0.12	0.00	0.17	0.30	0.17	0.35	0.00	0.00	0.21	0.38	0.94	0.20	0.54	0.91	0.13	0.19	0.19	0.32	0.18	0.49	0.31	0.52	0.50	0.36	0.84	0.84	0.25	0.90	0.05	0.01	0.72

Table 5 (cont'd) Chi-square Surveys A and B



		Survey A					Survey B											Survey C																					
		2	9	10	14	17	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Survey C	1	0.69	0.26	0.16	0.74	0.20	0.04	0.01	0.02	0.01	0.54	0.26	0.54	0.20	0.25	0.20	0.00	0.60	0.80	0.22	0.01	0.03	0.06	0.36	0.31	0.03	0.51	0.47	0.21	0.80	0.75	0.67	0.86	0.28	0.16	0.80	0.74	0.20	0.90
	2	0.40	0.24	0.13	0.05	0.47	0.35	0.63	0.08	0.05	0.09	0.87	0.73	0.15	0.39	0.38	0.60	0.00	0.11	0.87	0.07	0.00	0.31	0.14	0.07	0.28	1.00	1.00	0.37	0.73	0.66	0.58	0.64	0.89	0.59	0.20	0.51	1.00	0.84
	3	0.02	0.26	0.07	0.00	0.41	0.08	0.55	0.03	0.05	0.46	0.02	0.28	0.82	0.45	0.95	0.79	0.10	0.00	0.56	0.05	0.00	0.23	0.02	0.00	0.02	0.03	0.15	0.05	0.01	0.14	0.08	0.24	0.00	0.37	0.23	0.12	0.37	0.48
	4	0.62	0.06	0.40	0.25	0.64	0.26	0.78	0.57	0.77	0.63	0.57	0.67	0.60	0.86	0.21	0.22	0.87	0.54	0.00	0.45	0.03	0.29	0.29	0.05	0.39	0.11	0.74	0.62	0.55	0.74	0.31	0.69	0.38	0.83	0.93	0.56	0.04	0.20
	5	0.71	0.15	0.78	0.58	0.68	0.68	0.03	0.33	0.14	0.06	0.55	0.10	0.05	0.12	0.55	0.01	0.08	0.05	0.44	0.00	0.00	0.16	0.01	0.03	0.01	1.00	0.51	0.27	0.08	0.42	1.00	0.09	0.75	0.24	0.51	0.25	0.07	0.69
	6	0.36	0.07	0.43	0.07	0.05	0.01	0.88	0.25	0.12	0.24	0.47	0.91	0.00	0.92	0.92	0.03	0.00	0.00	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.19	0.08	0.04	0.14	0.46	0.34	0.62	0.10	0.34	0.46	0.48	1.00	0.38
	7	0.59	0.52	0.61	0.95	0.30	0.79	1.00	0.54	0.52	0.45	0.29	0.22	0.25	0.43	0.13	0.07	0.32	0.22	0.30	0.17	0.04	0.00	0.06	0.26	0.01	0.64	0.73	0.08	0.76	1.00	0.86	0.87	0.85	0.10	0.62	0.86	1.00	0.67
	8	0.04	0.63	0.06	0.02	0.58	0.18	0.77	0.15	0.11	0.47	0.50	0.62	0.25	0.80	0.19	0.35	0.13	0.02	0.30	0.01	0.00	0.05	0.00	0.01	0.00	0.04	0.43	0.07	0.16	0.37	0.07	0.02	0.37	1.00	0.40	0.37	0.34	
	9	0.73	0.82	0.04	0.42	0.19	0.29	0.34	0.17	0.05	0.31	0.39	0.63	0.11	0.32	0.19	0.31	0.07	0.00	0.05	0.03	0.00	0.25	0.00	0.00	0.00	0.22	0.07	0.02	0.30	0.32	0.43	0.96	0.01	0.75	0.94	0.17	0.45	0.48
	10	0.26	0.63	0.08	0.04	0.85	0.21	0.37	0.07	0.01	0.81	0.27	0.21	0.00	0.56	0.32	0.03	0.29	0.02	0.40	0.01	0.00	0.01	0.01	0.00	0.00	0.33	0.17	0.59	0.41	0.46	0.45	1.00	0.20	0.46	0.07	0.51	0.60	0.11
	11	0.02	0.76	0.24	0.07	0.18	0.81	0.83	0.72	0.82	0.48	0.90	1.00	0.51	0.68	0.17	0.50	1.00	0.03	0.12	1.00	0.19	0.64	0.00	0.21	0.32	0.00	0.03	0.62	0.28	0.24	0.49	0.03	0.00	0.57	1.00	0.12	0.78	0.80
	12	0.13	0.40	0.23	0.51	0.39	0.48	0.74	1.00	1.00	0.81	1.00	1.00	1.00	0.24	0.49	0.48	1.00	0.15	0.74	0.51	0.09	0.74	0.04	0.08	0.17	0.03	0.00	0.22	0.30	0.92	0.84	0.06	0.23	0.12	0.74	1.00	1.00	1.00
	13	0.45	0.52	0.39	0.32	0.11	0.90	0.87	0.38	0.41	0.48	0.51	1.00	0.45	0.74	0.32	0.21	0.37	0.06	0.63	0.26	0.04	0.08	0.43	0.02	0.59	0.63	0.23	0.00	0.13	0.03	0.32	0.58	0.92	0.91	0.08	0.93	0.01	0.06
	14	0.79	0.16	0.02	0.37	0.70	0.45	0.26	0.13	0.46	0.84	0.21	0.46	0.24	0.38	0.51	0.81	0.72	0.01	0.55	0.08	0.15	0.75	0.09	0.31	0.40	0.26	0.29	0.13	0.00	0.00	0.00	0.90	0.63	0.90	0.69	0.07	0.07	0.11
	15	0.53	0.15	0.22	0.11	0.31	0.31	0.15	0.12	0.18	0.75	0.13	0.31	0.83	0.10	0.51	0.76	0.66	0.15	0.74	0.42	0.47	1.00	0.16	0.32	0.47	0.23	0.92	0.03	0.00	0.00	0.00	0.64	0.33	0.67	0.13	0.37	0.14	0.16
	16	0.82	0.30	0.19	0.13	0.80	0.52	0.16	0.46	0.16	0.22	0.20	0.24	0.40	0.15	0.35	0.67	0.57	0.08	0.30	0.99	0.34	0.86	0.36	0.44	0.46	0.47	0.85	0.33	0.00	0.00	0.00	0.54	0.31	0.54	0.28	0.05	0.19	0.37
	17	0.26	0.74	0.22	0.76	0.84	0.82	0.26	0.91	0.60	0.48	0.15	0.31	0.67	0.71	0.82	0.86	0.65	0.23	0.70	0.08	0.62	0.86	0.06	0.96	1.00	0.03	0.06	0.59	0.90	0.64	0.56	0.00	0.17	0.01	0.06	0.58	0.09	0.57
	18	0.00	0.41	0.21	0.03	0.08	0.14	0.16	0.60	0.52	0.45	0.03	0.07	0.82	0.66	0.84	0.28	0.89	0.00	0.39	0.76	0.09	0.86	0.02	0.01	0.19	0.00	0.23	0.92	0.64	0.34	0.30	0.16	0.00	0.22	0.66	0.18	0.52	0.48
	19	0.50	0.07	0.00	0.37	0.76	0.71	0.04	0.10	0.06	0.41	0.04	0.00	0.28	0.14	0.25	0.17	0.59	0.38	0.82	0.24	0.33	0.09	0.36	0.76	0.44	0.59	0.13	0.91	0.90	0.66	0.54	0.01	0.22	0.00	0.87	0.83	0.37	1.00
	20	0.04	0.55	0.31	0.69	0.27	0.31	0.55	0.97	0.43	0.70	0.67	0.73	0.58	0.45	0.91	0.79	0.19	0.23	0.93	0.51	0.48	0.62	1.00	0.94	0.06	1.00	0.75	0.09	0.69	0.14	0.28	0.06	0.66	0.87	0.00	0.63	0.03	0.91
	21	0.91	0.42	0.27	0.93	0.11	0.39	0.71	1.00	1.00	0.04	0.53	0.17	0.22	0.06	0.05	0.73	0.50	0.12	0.56	0.26	0.49	0.85	0.39	0.16	0.51	0.12	1.00	0.94	0.07	0.37	0.05	0.59	0.18	0.83	0.64	0.00	0.22	0.29
	22	0.47	0.44	0.10	0.87	0.48	0.30	0.15	0.41	0.47	0.31	0.66	0.27	1.00	0.89	0.01	0.19	1.00	0.38	0.04	0.06	1.00	1.00	0.36	0.46	0.60	0.79	1.00	0.01	0.07	0.13	0.21	0.09	0.52	0.36	0.04	0.22	0.00	1.00
	23	0.12	0.04	0.27	0.12	0.55	0.10	1.00	0.06	0.54	0.66	0.31	0.77	0.87	1.00	0.72	0.90	0.83	0.48	0.21	0.67	0.37	0.66	0.34	0.47	0.11	0.78	1.00	0.06	0.11	0.16	0.38	0.56	0.50	1.00	0.92	0.29	1.00	0.00

Table 5. Chi-square (Cont'd) Survey C

Cluster 1	Cluster 2	Cluster 3	Cluster 4
<b>Attributes with high frequency</b>			
<p>SC.Q16. What does attract you much in a debris flow?</p> <p>SC.Q6. Do you know of anyone among your family or friends who has been affected by a debris flow? Yes</p> <p>SC.Q3. Have you ever witnessed a debris flow? Yes</p> <p>SC.Q9. How did you behave that day? Remained there and searched for advice</p> <p>SC.Q14. Do you like to observe a debris flow? A little</p> <p>SC.Q15. From where do you observe lahars? From a long distance and elevation</p> <p>Something</p> <p>SC.Q8. Can you identify or discuss a particular lahar that you remember? Yes</p> <p>SB.Q4. Do you know the hazard-zone colour meaning? Unsure, but has an idea</p>	<p>SC.Q15. From where do you observe lahars? Uncertain or does not know</p> <p>SC.Q16. What does attract you much in a debris flow? Nothing</p> <p>SC.Q14. Do you like to observe a debris flow? No</p> <p>SB.Q10. How long could the next El Misti volcanic eruption last? Does not know</p> <p>SB.Q3. Can you locate his/her district? Does not know</p> <p>SA. Q9. Education level: Primary school</p> <p>SA. Q14. How long have you been living in the area? &gt; 30 yrs</p> <p>SB.Q5. Can you show village location and what does represent colour shown? Does not know</p> <p>SB.Q4. Do you know the hazard-zone colour meaning? Does not know</p> <p>SB.Q8. Lahar occurrence estimate: Does not know</p>	<p>SC.Q10. Impact of memory on behaviour? No answer</p> <p>SC.Q8. Can you identify or discuss a particular lahar that you remember? No</p> <p>SC.Q9. How did you behave that day? No answer</p> <p>SC.Q3. Have you ever witnessed a debris flow? No</p> <p>SC.Q6. Do you know of anyone among your family or friends who has been affected by a debris flow? No</p> <p>SA.Q10. Socio-Professional category: Student</p> <p>SA. Q14. How long have you been living in the area? &lt;6 yrs/6 to 15 yrs</p> <p>SA. Q9. Education level: Secondary school</p> <p>SB.Q5. Can you show village location and what does represent colour shown? No answer</p> <p>SC.Q5. Do you feel that a debris flow would hit you? Perhaps</p> <p>SB.Q6. What are volcanic ash, pyroclastic flow, lahar? Knows</p>	<p>SB.Q11. How long after a volcanic eruption can lahars occur? Minutes, hours</p> <p>SB.Q10. How long could the next Misti volcanic eruption last? Minutes, hours</p> <p>SC.Q10. Impact of memory on behaviour: No</p> <p>SB.Q6. What are volcanic ash, pyroclastic flow, lahar? Knows</p> <p>SB.Q4. Do you know the hazard -zone colour meaning? Yes, knows</p> <p>SB.Q3. Can you locate his/her district? Yes, can locate</p>
<b>Attributes with low frequency</b>			
<p>SC.Q10. Impact of memory on behaviour. No answer</p> <p>SC.Q6. Do you know of anyone among your family or friends who has been affected by a debris flow? No</p> <p>SC.Q8. Can you identify or discuss a particular lahar that you remember? No</p> <p>SC.Q9. How did you behave that day? No answer</p> <p>SC.Q15. From where do you observe lahars? Uncertain or does not know</p> <p>SC.Q16. What does attract you much in a debris flow? Nothing</p> <p>SC.Q14. Do you like to observe a debris flow? No</p>	<p>SB.Q5. Can you show village location and what does represent colour shown? Unsure, but has an idea</p> <p>SC.Q15. From where do you observe lahars? From a long distance and elevation</p> <p>SB.Q10. How long could the next El Misti volcanic eruption last? Minutes, hours</p> <p>SC.Q14. Do you like to observe a debris flow? Yes</p> <p>SC.Q15. From where do you observe lahars? From a short distance and elevation</p> <p>SC.Q16. What does attract you much in a debris flow? Something</p> <p>SA. Q9. Education level: Secondary school</p>	<p>SA. Q9. Education level: Primary school</p> <p>SC.Q14. Do you like to observe a debris flow? A little</p> <p>SA. Q14. How long have you been living in the area? &gt; 30 yrs</p> <p>SC.Q5. Do you feel that a debris flow would hit you? Yes</p> <p>SC.Q9. How did you behave that day? Remained there but searched for advice</p> <p>SC.Q6. Do you know of anyone among your family or friends who has been affected by a debris flow? Yes</p> <p>SC.Q10. Impact of memory on behaviour: Yes</p> <p>SC.Q3. Have you ever witnessed a debris flow? Yes</p>	<p>SB.Q3. Can you locate his/her district? Does not know</p> <p>SB.Q5. Can you show your village location and what does represent colour shown? Does not know</p> <p>SB.Q4. Do you know the hazard -zone colour meaning? Does not know</p>

CLUSTERS	1.	2.	3.	4.
SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE POPULATION (FROM SURVEY A)				
ISSUES QUESTIONS AND ANSWERS	1. SOCIO-DEMOGRAPHIC CATEGORIES			
	<b>A.Q2. Age group</b>	31 to 59 51.16%	31 to 59 48.28%	19 to 30 29.41%
	≥ 60 20.93%	≥ 60 41.38%	31 to 59 35.29%	19 to 30 66.67%
	19 to 30 23.26%	19 to 30 10.34%	≥ 60 17.65%	
<b>A.Q9. Education level</b>	High education 13.95%	Primary school 37.93%	Secondary school 94.12%	Secondary school 100%
	Secondary school 76.74%	Secondary school 37.93%		
<b>A.Q10. Socio-professional category</b>	Housewife, informal workforce, public employee, private employee, commerce and student	Housewife, informal workforce, public employee, private employee, commerce and student	Housewife, student, informal workforce and private employee	Private employee, informal workforce and commerce
2. ARRIVAL TIME IN THE AREA AND GEOGRAPHICAL ORIGIN				
<b>A.Q14. How long have you been living in the area?</b>	> 16 years 93.02%	> 30 years 82.76%	> 16 years 52.94%	6 to 30 years 100%
			< 16 years 47.06%	
<b>A.Q17. Family origin (Distance to El Misti summit)</b>	> 100 km 62.79%	> 100 km 68.97%	> 100 km 58.82%	> 300 km 66.67%
	< 30 km 18.60%	< 30 km 10.34%	< 100 km 41.17%	< 30 km 33.33%

Table 7 c'td

CLUSTERS	1	2	3	4
<b>HAZARD KNOWLEDGE (FROM SURVEY B)</b>				
<b>ISSUES QUESTIONS AND ANSWERS</b>	<b>1. VOLCANO AND ERUPTION</b>			
<b>B.Q2. Do you know what year this volcano last erupted?</b>	A long time ago Does not know	30.23% 62.79%	Does not know A long time ago	86.21% 10.34%
				Doesn't know Unsure
				82.35% 17.65%
				A long time ago
				66.67%
<b>2. HAZARD-ZONE MAP</b>				
<b>B.Q3. Can you locate your district?</b>	Unsure/ Does not know	86.05%	Does not know	96.55%
<b>B.Q4. Do you know the hazard-zone colour meaning?</b>	Does not know	72.09%	Does not know	96.55%
<b>B.Q5. Can you show your village location and what does represent colour shown?</b>	Does not know	74.42%	Does not know	96.55%
<b>B.Q6. What are volcanic ash, pyroclastic flow, and lahar?</b>	Unsure, but has an idea	74.42%	Unsure, but has an idea	68.97%
				Does not know\No answer
				82.35%
				Unsure, but has an idea
				52.94%
				Knows
				17.65%
				Knows/ Unsure, but has an idea
				100%
<b>3. LAHAR OCCURRENCE AND IMPACT</b>				
<b>B.Q7. Can you estimate the arrival time of a lahar to your village, once it has been triggered on the mountain?</b>	Minutes, hours	83.72%	Minutes, hours	72.41%
<b>B.Q8. Lahar occurrence estimate</b>	Minutes, hours	86.05%	Minutes, hours	75.86%
<b>B.Q9. Do you know of any victims or/and injured people?</b>	No	95.35%	No	89.66%
				Minutes, hours
				88.24%
				Minutes, hours
				94.12%
				Minutes, hours
				100%
				No
				76.47%
				No
				66.67%
<b>4. ERUPTION AND LAHAR OCCURRENCE INTERVAL TIME</b>				
<b>B.Q10. How long could the next El Misti volcanic eruption last?</b>	Minutes, hours Days	37.21% 37.21%	Does not know	65.52%
<b>B.Q11. How long after a volcanic eruption can lahars occur?</b>	Does not know Days	46.51% 37.21%	Does not know	72.41%
				Days
				41.18%
				Minutes, hours
				35.29%
				Does not know
				41.18%
				Minutes, hours
				100%
				Days
				41.18%
				Minutes, hours
				100%

GROUPS	1		2		3		4	
RISK PERCEPTION AND ASSOCIATE VARIABLES (from Survey C)								
<b>C.Q1. How do you feel about the volcano or a debris flow?</b>	Worried	62.79%	Worried	68.97%	Worried	58.82%	Worried	66.67%
	Uncertain	18.60%	Other concern or none	27.59%	Other concern or none	35.29%	Other concern or none	33.33%
<b>C.Q2. Any concern related to you?</b>	Other or none	81.40%	Other or none	75.86%	Other or none	47.06%	Other or none	100%
	Debris flow/lahar	9.30%	Debris flow/lahar	13.79%	Debris flow/lahar	17.65%		
<b>C.Q3. Have you ever witnessed a debris flow?</b>	Yes	100%	Yes	93.10%	No	64.71%	Yes	100%
<b>C.Q4. Have you ever been affected by a debris flow?</b>	Never	72.09%	Never	72.41%	Never	88.24%	Never	100%
	Few occasions	6.98%	Yes	24.14%				
<b>C.Q5. Do you feel that a debris flow would hit you?</b>	Yes	69.77%	Yes	72.41%	Perhaps	41.18%	Does not know	66.67%
	Perhaps	11.63%	Perhaps	13.79%	Does not know	35.29%		
<b>C.Q6. Do you know of anyone among your family or friends who has been affected by a debris flow?</b>	Yes	93.02%	Yes	68.97%	No	88.24%	No	66.67%
<b>C.Q7. Traffic accident, family or friends?</b>	Yes	44.19%	Yes	41.38%	No	82.35%	No	100%
	No	53.49%	No	58.62%				
<b>C.Q11. Can you describe a debris flow?</b>	No	76.74%	No	79.31%	No	88.24%	No	66.67%
	Yes	23.26%					Yes	33.33%
<b>C.Q12. Origin of knowledge</b>	Experience, school, authorities	100%	Experience, school, authorities	93.10%	Experience, school, authorities	88.24%	Experience, school, authorities	100%
<b>C.Q8. Can you identify or discuss a particular lahar that you remember?</b>	Yes	97.67%	Yes	79.31%	No	94.12%	Yes	100%
<b>C.Q9. How did you behave that day?</b>	Remained	69.77%	Remained	51.72%	No answer	100%	Did not know what to do / Evacuated or auto-evacuated	100%
			No answer	31.03%				
<b>C.Q10. Impact of memory on behaviour</b>	Yes	74.42%	Yes	65.52%	No answer	100%	Yes	66.67%
<b>C.Q14. Do you like to observe a debris flow?</b>	Yes	41.86%	No	75.86%	No/ A little	70.58%	No/ A little	100%
	A little	55.81%	A little	20.69%				

<b>C.Q15. From where do you observe lahars?</b>	From a long distance	60.47%	Does not know	82.76%	Does not know	47.06%	Does not know	66.67%
	From a short distance	34.88%			From a long distance	29.41%		
<b>C.Q16. What does attract you much in a debris flow?</b>	Something	81.04%	Nothing	79.31%	Nothing	47.06%	Nothing/Everything	100%
<b>C.Q17+18+19. Do you feel that such a phenomenon is so powerful than mankind cannot do anything about it?</b>	Yes	88.37%	Yes	89.66%	Yes	94.12%	Yes	100%
	One solution	90.70%	One solution	79.31%	One solution	76.47%	One/More than one solution	100%
<b>Alternatives to overcome flow effects?</b>	May be	55.81%	More than solution	13.79%	Does not know	17.65%		
<b>Do you feel self-confident in case of an eruption?</b>	No	32.56%	Yes	37.93%	May be	58.82%	May be	100%
<b>C.Q20. Will you comply with the evacuation order in any type of situation?</b>			May be	37.93%	No	35.29%		
	Yes	79.07%	Yes	65.52%	Yes	100%	Yes	66.67%
<b>C.Q21+22. Whom do you receive warning messages from in case of lahar?</b>	One of them	93.02%	Sometimes or during extreme events	31.03%	One of them	88.24%	Sometimes or during extreme events	33.33%
	One of them (TV or smartphone)	72.09%	One of them	89.66%	None	11.76%	One of them	100%
	More than one	27.91%	One of them (TV or smartphone)	89.66%	One of them (TV or smartphone)	88.24%	One of them (TV or smartphone)	100%
<b>C.Q23. Do you believe messages and/or do you try to check the content?</b>	Yes, I trust	46.51%	Yes, I trust	55.17%	Yes, I trust	52.94%	Yes, I trust	33.33%
	Yes, I trust but I try to check	53.49%	Yes, I trust but I try to check	44.83%	Yes, I trust but I try to check	47.06%	Yes, I trust but I try to check	66.67%
<b>GROUPS</b>	<b>Cluster 1</b>		<b>Cluster 2</b>		<b>Cluster 3</b>		<b>Cluster 4</b>	
<b>SUB-TOTAL</b>	<b>46.74% (43)</b>		<b>31.52% (29)</b>		<b>18.48% (17)</b>		<b>3.26% (3)</b>	
<b>TOTAL</b>	<b>100% (92)</b>							

Table 7

Clusters	Individuals	B.Q5	C.Q10	B.Q4	C.Q8	C.Q3	C.Q9	C.Q16	C.Q14
1	No.123	Does not know	Uncertain or does not know	Does not know	Yes	Yes	Remained there but searched for advice	Everything	Yes
	231	Does not know	Uncertain or does not know	Does not know	Yes	Yes	Did not know what to do	Something	Yes
	104	Does not know	Yes	Unsure, but has an idea	Yes	Yes	Did not know what to do	Something	Yes
	247	Does not know	Yes	Does not know	Yes	Yes	Remained there but searched for advice	Something	A little
	261	Does not know	Yes	Does not know	Yes	Yes	Remained there but searched for advice	Something	A little
2	No.220	Does not know	Yes	Does not know	Yes	Yes	Did not know what to do	Nothing	No
	236	Does not know	Yes	Does not know	Yes	Yes	Remained on the spot but searched for advice	Nothing	No
	239	Does not know	Yes	Does not know	Yes	Yes	Remained on the spot but searched for advice	Nothing	No
	266	Does not know	Yes	Does not know	Yes	Yes	Did not know what to do	Nothing	No
	148	Does not know	Yes	Does not know	Yes	Yes	Remained there but searched for advice	Nothing	No
3	No.125	Does not know	No answer	Does not know	No	No	No answer	Something	Yes
	101	Unsure, but have an idea	No answer	Does not know	No	Yes	No answer	Something	A little
	119	Does not know	No answer	Does not know	No	No	No answer	Nothing	No
	112	Does not know	No answer	Does not know	No	Yes	No answer	Something	Yes
	225	Does not know	No answer	Does not know	No	No	No answer	Nothing	No
4	No.102	Knows	Yes	Yes, knows	Yes	Yes	Evacuated or auto-evacuated	Nothing	No
	105	Knows	Yes	Yes, knows	Yes	Yes	Did not know what to do	Everything	A little
	116	Knows	No	Yes, knows	Yes	Yes	Did not know what to do	Nothing	No

**Survey B**

B.Q4. Do you know the hazard-zone colour meaning?

B.Q5. Can you locate your neighbourhood and what does represent colour shown in the hazard-zone map?

**Survey C**

C.Q3. Have you ever witnessed a debris flow/lahar?

C.Q8. Can you identify or discuss a particular debris flow that you remember?

C.Q9. How did you behave that day?

C.Q10. Did your memory have an impact on behaviour?

C.Q14. Do you like to observe a debris flow?

C.Q16. What does attract you much in a debris flow?

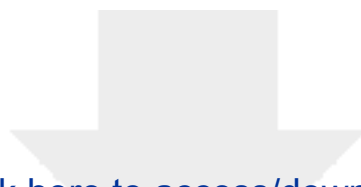
Table 9. Results from interviews, meetings and focus groups with key actors and officials in charge of disaster risk management.

<b>Disaster Risk Management DRM</b>	<b>Topic</b>	<b>KEY ACTORS</b>	<b>ANSWERS, OBSERVATIONS AND PROPOSED REGULATIONS</b>	<b>Domain inferred from answers and field of application</b>
<b>Training, knowledge, and skills</b>	Perception and knowledge	Heads of neighbourhoods	<p>Leaders recognize a number of issues:</p> <ul style="list-style-type: none"> <li>- Volcanic hazard is one of the characteristics of the city of Arequipa</li> <li>- Earthquakes are a constant Hazard, based on their own experience</li> <li>- Heavy rainfall is a constant hazard on an annual basis.</li> </ul> <p>They state that a large number of the urban dwellers do not know which areas are most prone to volcanic hazards</p>	Cultural beliefs on risk Hazard knowledge
		Civil servants	<p>Officials admit that earthquakes and heavy rainfall show some periodicity acknowledge that pyroclastic flows from El Misti volcano represent danger State that many 'unlawful' edifices are built in the vicinity of active ravines and many edifices near the Qda. San Lazaro exhibit physical vulnerability.</p>	Recurrent flow/flood hazards adopted as 'inevitable' in the city Unlawful or non-authorized land occupation in some areas of the districts
		District Mayors	<p>Mayors know which hazards are commonly acting in their district and national regulations related to disaster risk management Mayors admit their limited knowledge of the guidelines for the incorporation of disaster risk management into the organisation and functions of their districts.</p>	Knowledge about disaster risk management
<b>Proactive risk management</b>	Planning and mitigation	Heads of neighbourhoods	<p>Leaders suggest that contention walls be built in pilot reaches along ravines as well as street network be re-organized so that evacuation would be easier in case of an emergency They acknowledge to be in charge of the communication between the city hall and the urban dwellers They wish they had more training in themes related to hazards and risk posed to their neighbourhoods They admit that dwellers do not fully trust the actions of the State (Region and Peru's governance) in terms of risk mitigation</p>	<p>Mitigation actions on disaster risk on behalf of the community Self-management suggested to be applied to natural disasters Mistrust towards national governance</p>



		Civil servants in public offices in charge of DRM	<p>The officials suggest a number of required actions:</p> <ol style="list-style-type: none"> <li>1) further studies on hazards that affect the district</li> <li>2) activities together with neighbours, families and school children on knowledge of hazards (earthquakes and heavy rainfall in the first place) and risk prevention</li> <li>3) Planning to prevent and mitigate disaster risk</li> <li>4) Planning of actions to be carried out during rainy season</li> <li>5) Report edifice construction in hazard-prone and non-authorized areas close to quebradas</li> <li>6) To identify vulnerability of housing and street network in the vicinity of quebradas</li> </ol>	<p>City growth Vulnerable house building in hazard-prone areas Prevention plans to reduce vulnerability</p>
		District Mayors	<p>Meetings including leaders of neighbourhoods that aim to let them know regulations of the disaster risk management.. Information is given to dwellers about areas not to be constructed due to high risk, but these hazard-prone areas are unlawfully occupied. Relocation of population has been studied and proposed, but this operation is not within their competence and very difficult due to the lack of economic resources.</p>	<p>Policies to reduce disaster risk 'Informal' and non-authorized constructions</p>
Corrective management	Disaster risk reduction	Heads of neighbourhoods	<p>Dwellers communicate via smartphones on hazards related to the volcano Plans exist about construcción of temporary barricades along selected reaches to prevent or reduce flooding by intense rainfall. Students and pupils who receive information about hazards in high schools should share this information with their families. Mistrust is widespread with respect to plans and projects of reduction of risk on behalf of the State.</p>	<p>Mistrust towards the State Community auto-management</p>
		Civil servants in public offices	<p>To identify and delineate safe areas in case of emergency. Functions of the state create dissatisfaction with respect to the corrective actions on persistent risk in the district (e.g., contention walls and check dams). No action can be undertaken against unlawful occupation and construction in hazard-prone areas, due to the lack of laws regulating this issue.</p>	<p>Areas &amp; shelters designed for evacuation Habitat vulnerability</p>
		District Mayors	<p>They carry out operations before the rainy season, including cleaning of the ravine channel, repair of the streets near the ravine and cleaning of sewers. Consider that existing hazard-zone maps should be updated. There is no budget to adapt or retrofit the infrastructure near the ravines due to the fact that the majority of constructions are non-authorized and national regulations to solve the issue are lacking.</p>	<p>Mitigation of risk Budget State policy for disaster risk management</p>

<b>Compensatory management</b>	Institutional preparation and ability to cope with potential conflicts with the community	Heads of neighbourhoods	<p>The community is being organized following a common sense to cope with natural disasters.</p> <p>Dwellers require that ravine channels full of debris and garbage be cleaned.</p> <p>Houses with high physical vulnerability are constructed on un-authorized land, as the new dwellers are low-income and with limited resources.</p> <p>Due to mistrust, collaborative work on emergency policy between the community and civil authorities is often lacking.</p>	<p>Common sense in front of hazard and risk</p> <p>Lack of social capital and community awareness</p> <p>Unlawfully occupied land</p>
		Civil servants in offices in charge of DRM	<p>Existing planning of operations of emergencies in case of earthquakes and intense rainfall is not entirely undertaken.</p> <p>Co-ordinate with the Committee of Civil Protection of each District the required actions to help victims and support affected people from natural disasters.</p> <p>There is a lack of network between distinct public offices of the municipality and neighbourhood boards to provide an integrated response to emergency procedure.</p> <p>Promote training and workshops to disseminate prevention of disaster risk to the exposed people and city dwellers in general.</p> <p>Risk is increasing due to socio-economic vulnerability of the settlements in unlawfully occupied areas.</p>	<p>Integrated regulations towards disaster risk reduction</p> <p>Actions to cope with population affected by natural disasters</p> <p>Training and workshops</p>
		District Mayors	<p>Budget allotted to the district municipalities often is insufficient to operate emergency relief and to promote retrofitting or reconstruction.</p> <p>They should elaborate on and distribute the budget for disaster risk management according to their priorities and the amount allocated by the Government.</p> <p>They are in command of the District Civil Protection committee, organising the necessary actions for relieving the population affected by natural disasters.</p>	<p>Participative budgets</p> <p>Difficulties in elaborating on and tapping budgets towards disaster risk management</p>



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**Electronic Supplementary Material**  
ESD Text Figures Tables.pdf

