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Differences in volcanic risk perception among Goma's population before the Nyiragongo eruption of May 2021, Virunga volcanic province (DR Congo)

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Abstract. Risk perception is an essential element to consider for effective risk management at the time of eruption, especially in densely populated cities close to volcanoes like Goma in the east of the Democratic Republic of the Congo, which is highly exposed to volcanic hazards from Nyiragongo. The perception of volcanic risk involves the processes of collecting, selecting and interpreting signals about uncertain impacts of volcanic hazards. Using a questionnaire survey, this study describes the spatial differences and factors influencing the individual volcanic risk perception of 2224 adults from eight representative neighbourhoods of Goma before the May 2021 Nyiragongo eruption. A composite risk perception indicator was built from the perceived severity and perceived vulnerability. Statistical analysis of the survey's results shows that the risk perception was high (mean = 3.7 on a five-point Likert scale) and varies less with demographic and contextual factors than with cognitive and psychological factors. Volcanic hazards were perceived to be more threatening the city and its functioning than the individuals themselves. The spatial analysis shows that respondents from the eastern neighbourhoods, affected by the 2002 eruption, demonstrated a significantly higher level of risk perception than participants living in the western neighbourhoods. This study will help to improve volcanic risk awareness raising in Goma.

1 Introduction

Risk perception studies aim to answer why individuals differ in their perception of the same hazard (Slovic, 2000; Chauvin, 2018). For an individual, risk perception involves the processes of collecting, selecting and interpreting signals about uncertain impacts of natural events, activities or technologies (Slovic et al., 2013). These signals may refer to direct observations (e.g. witnessing a hazard) or information from other sources (e.g. reading about a hazard in newspapers) (Paton et al., 2008). Therefore, risk perception is related to one's personal understanding of natural hazard processes and prior experience (Gaillard and Mercer, 2013; Barclay et al., 2015), which in turn are filtered by sociodemographic factors, world view and affective judgments (Dieckmann et al., 2021; Haynes et al., 2008; Wachinger et al., 2010; Slovic and Weber, 2013).

Bubeck et al. (2012) state that a proper approach to risk requires both good science and good judgment. Thereby, Favereau et al. (2018) point out that actions and reactions, specifically to volcanic hazards, are shaped by people's perception, previous experience, risk acceptability and tolerance, especially during rapid onset eruptions, like the recent May 2021 Nyiragongo eruption in the east of the Democratic Republic of the Congo (DR Congo). Therefore, risk perception has to be regarded as an essential component of disaster risk reduction (DRR) by examining people's attitudes, judgments and feelings about risk and the role it plays in formulating preferences and making decisions under conditions of uncertainty (Donovan and Oppenheimer, 2014; Brown et al., 2015; Donovan, 2019; Merlhiot et al., 2018). Indeed, risk perception has been a matter of research for several years and has led to the development of several theories such as the protection motivation theory (PMT) (Rogers, 1975; Maddux and Rogers, 1983), the community engagement theory (CET) (Paton, 2013), the protective action decision model (Lindell and Perry, 2012) and the theory of planned behaviour (TPB) (Vinnell et al., 2021). Among these theories, the PMT is a pioneer and widely used (Rainear and Christensen, 2017). In addition, meta-analyses have shown its efficiency in its uses (Milne et al., 2000; Sommestad et al., 2015; Bamberg et al., 2017). This model has however barely been used to study volcanic risk so far (Kothe et al., 2019). It states that the individual motivation to implement risk reduction measures is based on two components: the threat appraisal and the coping appraisal (Sommestad et al., 2015). Threat appraisal examines one's perception of the extent and likelihood of a threat to generate harm, while the coping appraisal evaluate one's perception of risk mitigation measures. In accordance with Floyd et al. (2000) and Mertens et al. (2018), the present study relies on a conceptualisation of risk perception based on the PMT threat appraisal.

For DRR stakeholders, it is essential to know which factors influence a population's acceptance and choices regarding risks and whether risk perception is contrasted in specific neighbourhoods or subgroups of the population. Such research can contribute to a better contextualisation of the vulnerability of people living near active volcanoes around the world, as in the case of the Virunga volcanic province, located across the border between the Democratic Republic of the Congo (DRC) and Rwanda (Michellier et al., 2016). The Virunga volcanic province hosts two active volcanoes, Nyiragongo and Nyamuragira, generating multiple lava flow eruptions over the last century (Pouclet and Bram, 2021; Smets et al., 2015b). The city of Goma, which has more than 1 million inhabitants, is at high risk of lava flows from the southern flank of Nyiragongo.

As a pioneering study on population vulnerability in Goma, Michellier et al. (2020) evaluated the social vulnerability to volcanic hazards from Nyiragongo in the context of data scarcity. In Michellier et al. (2020), risk perception was assessed in a general way (based on the question: do you feel your household is in danger?), as well as in relation to the experience of a past geological disaster. It highlighted that risk perception and prior experience are strongly correlated, i.e. prior experience is associated with a high level of risk perception. However, while deepening that first approach, it was found that this question alone could not fully describe or assess the perception of volcanic risk in Goma. In our study, we aim at characterising the risk perception of people from different neighbourhoods across the city; looking at multiple volcanic hazards; and analysing the potential relationship to demographic, contextual, cognitive, and psychological factors. Our data were collected at the end of 2020 and therefore represent the risk perception directly prior to the May 2021 Nyiragongo eruption, which affected a significant part of the city's suburbs (Smittarello et al., 2022). In addition, this study helps to contrast most existing risk perception studies in which participants come from western countries (Henrich et al., 2010; Barrett, 2020). After defining the concepts of risk perception and its individual indicators, the collection and analysis of the survey data are explained before presenting the key results and discussing their implication for understanding volcanic risk perception. This study aims at contributing to broader research on the implementation of DRR measures for populations living near volcanoes like those in Goma.

2 Theoretical background of the study

While it began to be studied in the 1960s, particularly in the context of nuclear risk (Martin, 1989), the risk perception related to natural hazards has received increasing attention over the last 2 decades (Donovan, 2019). Bubeck et al. (2012) noticed that the definition of risk perception remained ambiguous for a long period and was used with different meanings. However, recent literature has defined risk perception as processes of collecting, selecting and interpreting signals about uncertain impacts of hazards (Donovan et al., 2017; Chauvin, 2018; Dieckmann et al., 2021). These mental processes involve quantitative or qualitative appraisals of two dimensions: likelihood and severity. Thereby, a risk perception indicator can be built from the individual appraisal of the likelihood of being personally impacted by a hazard (perceived vulnerability) and the individual appraisal of the likelihood of a hazard, as well as of the severity of its impacts on the inhabited area (perceived severity) (Barclay et al., 2015; Botterill and Mazur, 2004; Khan et al., 2019). These two components are in line with the PMT threat appraisal concepts of perceived severity and perceived vulnerability. Indeed, in the PMT framework, "perceived severity" is conceptualised as the extent to which people perceive that a hazard could have serious negative consequences and "perceived vulnerability" as the likelihood that people believe they could be personally exposed to the negative effects of the hazard (Floyd et al., 2000; Sommestad et al., 2015; Mertens et al., 2018).

2.1 Risk perception and the psychometric paradigm

The most common approach used to understand why there are individual differences in risk perception is the psychometric paradigm developed by Fischhoff et al. (1978) and modified by Slovic et al. (1986) and Sjöberg (2003). In contrast to the cultural approach, which is a qualitative understanding of risk perception (Douglas and Wildavsky, 1982), the psychometric approach seeks to quantify people's subjective assessment of risk and risk-related impacts. It argues that people make a quantitative appraisal about the current and likely risk of various hazards and the desired level of regulation of each risk (Lechowska, 2022). Therefore, the psychometric approach, used in this study, is an appropriate way to characterise factors to which risk perception is related.

2.2 Individual factors of risk perception

Wachinger et al. (2013) reviewed the main factors of risk perception, particularly in connection with natural hazards. They highlighted the influence of personal factors related to the demographic, cognitive and psychological characteristics of the individual, as well as contextual factors related to the family, community and society in which they live.

Personal factors are demographic, such as age (Knoll et al., 2017; Useche et al., 2019), gender (Bee, 2016), educational level (Carlino et al., 2008), disaster experience (Bronfman et al., 2020; Paton et al., 2000) or ownership of transport (Chauvin, 2018). In addition, personal factors can be cognitive, such as understanding of the risk processes (Sim et al., 2018) or interest in seeking risk information (Donovan et al., 2018). The perceived availability and predictive power of environmental cues (sights and sounds that are considered to indicate a hazard onset) are also cognitive factors influencing risk perception (Lindell and Perry, 2012; Perry and Lindell, 2008). In addition, personal factors are psychological, including anxiety (Lemée et al., 2019) or trust in authorities (Bronfman et al., 2016; Siegrist et al., 2005).

Contextual factors are economic, such as household income (Barclay et al., 2019, 2015), or family related, like family status or household size (Donovan, 2010; Barclay et al., 2015). Religion or other cultural dimensions are also key contextual factors shaping risk perception (Gaillard and Texier, 2010; Chester et al., 2008).

3 Materials and methods

3.1 Study area

Goma, the capital city of the North Kivu province, is built in the lava field of the Nyiragongo volcano along the northern shore of Lake Kivu in eastern DRC (Fig. 1). It shares a border with the town of Gisenvi in Rwanda. It is an important humanitarian hub (Büscher et al., 2010) and an economic centre for regional trade (Vlassenroot and Büscher, 2013, 2011). Small business is one of the main sources of income, forcing the population to spread out along the roads by doing odd jobs for day-to-day survival (Syavulisembo et al., 2021; Oldenburg, 2020). Over the past 3 decades, Goma and its surroundings have been affected by several armed conflicts (Pech et al., 2018; Vlassenroot and Büscher, 2011). People from the nearby villages and towns have sought refuge in Goma for safety and comfort, resulting in the growth of the population (Van Praag et al., 2021). Therefore, the city is constantly expanding, but it is bounded (Fig. 1a) to the south by Lake Kivu, to the northwest by the Virunga National Park and to the east by the Rwandan border, forcing the expansion of the urbanised area northwards, up to the foot of the Nyiragongo volcano (Büscher et al., 2010; Pech et al., 2018; Michellier et al., 2020). From 2002 to 2020, the population of the city had doubled from half a million to more than 1 million inhabitants (INS, 2021). Urban growth is associated with an increase in a population's exposure to volcanic hazards, especially to lava flows emitted on the southern flank of the volcano.

Nyiragongo is a stratovolcano in the Virunga volcanic province (Poppe et al., 2013). Its main crater is surrounded by two main adventive cones: Baruta and Shaheru on the northern and southern flanks respectively. The volcanic field of Nyamuragira surrounds that of Nyiragongo, and both undergo permanent CO₂ degassing (Smets et al., 2010, 2015a). Since the early 1900s, an active lava lake has characterised almost continuously the activity of Nyiragongo, interrupted by three effusive flank eruptions in 1977, 2002 and 2021 (Barrière et al., 2022). Some of these eruptions were preceded by seismic swarms (Oth et al., 2017; Barrière et al., 2022), and each caused long and fast lava flows (i.e. speed of the order of 6 to 10 to 20 km h^{-1} in 1977 and less than 10 km h^{-1} in 2002) (Muhindo Syavulisembo, 2019) that came out from eruptive fissures and headed south towards the city of Goma (Favalli et al., 2009) (Fig. 1).

Two historical eruptions impacted the city before our survey in 2020. On 10 January 1977, the first one poured 20 million m³ of lava flows over 15 km² (including 4.9 km² within the Virunga National Park) on the northern, southern and western flanks of Nyiragongo, destroying several villages and roads north of Goma. Tazieff (1977) reported less than 100 deaths. After a relative calm period, Nyiragongo erupted on 17 January 2002 while the city was under rebel occupation (Komorowski et al., 2002). This new flank eruption, which generated lava flows, was larger (25 million m³ over 14 km²) and more destructive than that of 1977 (Wisner, 2017; Wauthier et al., 2012; Smets et al., 2015a). In less than 24 h, Goma was crossed by two lava flows, one of which reached Lake Kivu (Schmid et al., 2002). Komorowski et al. (2002) estimate that 40 people died and that 120 000 people had their homes destroyed. In addition, they note that several infrastructures were lost and evaluate the devastated part of the city at 13 %.

3.2 Questionnaire

For this risk perception study, data were collected through a questionnaire survey developed on the KoBoToolbox application installed on tablets. All questions related to perception used a five-level Likert scale. The specific questions on risk perception were constructed according to PMT (Mertens et al., 2018), as mentioned in the theoretical background of this study. The following questionnaire sections were used:



Figure 1. (a) The city of Goma and the surveyed neighbourhoods with a hill shade of SRTM 1 DEM (© NASA/NGA) updated with the 2016 topography of the Nyiragongo crater (Delhaye and Smets, 2021) and (b) an example of sampling points automatically distributed by defining a shortest distance allowed between two randomly placed points plotted on a 2017 very high resolution orthomosaic picture of Goma (Smets et al., 2018). The distance was determined according to the surface of the neighbourhoods, 40 m for very wide neighbourhoods and 20 m for narrower neighbourhoods.

- 1. *Demographic profile of participants*. This includes gender, age, family status, religion, household size, household monthly income, education level, prior experience of a volcanic eruption and possession of a means of transport;
- 2. *Risk perception indicator*. The risk perception was assessed as an aggregated indicator of perceived severity and perceived vulnerability (Fig. 2). On the one hand, perceived severity is conceptualised as the degree to

which people perceive (1) the likelihood of hazards and (2) the severity of their impacts on the city. On the other hand, perceived vulnerability is conceptualised as the perceived likelihood of being personally impacted. To better capture the risk perception of a person living in an area potentially threatened by a range of volcanic hazards such as Goma, it is critical to have several questions depending on the hazard type, as well as the range of potential impacts. Therefore, in order to obtain one indi-

cator, an aggregation of responses obtained is required. Before aggregating the values, the internal consistency of answers was checked using Cronbach's alpha coefficient (Fig. 2). The aggregation was done according to the coefficient of variation (CV) of response values. It was done either by mean when the CV < 25% or by median when the $CV \ge 25\%$.

- 3. *Perceived source of risk.* A set of potential sources of risk related to the technological, socioeconomic, political and natural contexts of the city of Goma was proposed to the respondents. In this section, participants determined in general their perception of impacts if each of the threat proposed occurs.
- 4. Environmental cues and predictive power. Availability and predictive power of volcanic environmental cues are factors defined by Lindell and Perry (2012) in the protective action decision model (PDAM), and they potentially influence risk perception. Environmental cues correspond to sights and sounds from the environment that are considered to indicate a hazard onset. In the case of this study, the considered environmental cues included the ash plume from the Nyiragongo crater, the emission of volcanic gas and a loud detonation in the volcano. They express the connectedness to the volcanic environment, i.e. whether a participant is able to observe and interpret the precursors of an eruption (Han, 2021). On the one hand, the availability of environmental cues indicates the perceived degree of being potentially exposed to these environmental cues. On the other hand, the predictive power indicates the perceived degree to which these signs indicate the likely occurrence of a volcanic eruption.
- Status induced by the reception of risk information. This includes anxiety (to what extent information regarding volcanic risk induces a degree of nervousness) and comprehension (the perceived extent of understanding volcanic risk information).
- 6. *Trust*. Trust in authorities in charge of volcanic risk management and interest in seeking information.

3.3 Participants

The survey was conducted in 7 out of 18 neighbourhoods of the city of Goma and in a part of the urbanised area of the Nyiragongo territory as an eighth neighbourhood (Fig. 1a). These eight representative neighbourhoods were selected based on the contrasted social vulnerability assessed in 2017 by Michellier et al. (2020a) and other criteria such as their existence in 2002 (year of last eruption at the time of survey); their spatial distribution relative to potential hazards and evacuation routes; and the existing contrasts in population density, average income, and level of education. One neighbourhood was selected to represent two or more neighbourhoods having similar characteristics.

A total of 2224 adults from the general population were surveyed (Mafuko Nyandwi, 2023a). The size of sampling was calculated from the following statistical formula (Krejcie and Morgan, 1970):

$$n = \frac{t_p^2 \times P(1-P) \times N}{t_p^2 \times P(1-P) + (N-1) \times y^2},$$
(1)

where *n* is the sample size, *N* is the population of the entire city, *P* is the population proportion (assumed to be 0.50 since this would provide the maximum sample size), t_p^2 is the table value of chi square for 1° of freedom at a confidence level (3.841) and *y* is the degree of accuracy expressed as a proportion (0.05).

According to the 2020 report of the National Institute for Statistics (INS) of the North Kivu province, the population of Goma exceeded 1 million inhabitants in 2020 (INS, 2021). With a 50% variance of population, 3% margin of error and 99% confidence level, our survey's sample size should be 1831 individuals. The 2224 inhabitants surveyed is a larger sample than the minimum sample size required to be representative of the population of Goma, even considering the Nyiragongo neighbourhood. We worked with an almost equal number of participants per neighbourhood (almost 280 people per neighbourhood). This sample is also representative for each neighbourhood within a confidence interval ranging between 0.01 to 0.05.

3.4 Procedure

The data were collected between September and October 2020. In every surveyed neighbourhood, around 280 points were randomly distributed and plotted with a defined minimum distance between points using a geographical information system (Fig. 1b) on a 2017 very high resolution orthomosaic picture of Goma (Smets et al., 2018). Data were collected in one of the four households located closest to the point. We undertook the survey with a team of 16 trained enumerators. The interviews were conducted face-to-face, with a questionnaire in French. Each enumerator had a notebook with the translation of the questions into Swahili, the common local language. The interviews were conducted with people aged 18 years or above, living in the selected household. Verbal informed consent was obtained from the survey participants before the survey. A survey day started early in the morning (07:00 local time) and was also conducted during weekends, to meet parents and working adults. Each interview lasted about 35 min.

3.5 Data analyses

Descriptive statistics were used for categorical variables, such as demographic and risk perception (Harpe, 2015). A non-parametrical test of Wilcoxon–Mann–Whitney (for two-



Figure 2. Overview of the variables used in this research to derive an aggregated risk perception indicator from indicators of perceived severity and perceived vulnerability and the potential controlling factors for highlighting differences in risk perception. Demographic factors are highlighted in orange, contextual in green, cognitive in blue, psychological in red and spatial in purple. α represents Cronbach's alpha index measuring the internal consistency of a set of answers.

group variables) or Kruskal–Wallis (for multi-group variables) was used to determine the variation in risk perception according to demographic, contextual, cognitive and psychological variables. Statistically significant variations were represented on boxplots. Pearson (for binomial variables) or Spearman's (for Likert-scale variables or ordinal demographic variables) correlations were used to measure the correlations between potential risk perception factors and the risk perception indicator. To analyse the spatial contrast of the risk perception, a geographic information system was used.

4 Results

4.1 Demographic profile of participants

Table 1 describes the demographic profile of the survey participants. There are fewer men than women among the participants, and most of them are parents. The majority lives in large households: half of the households surveyed counts 4 to 7 persons, and 30% have 8 to 11 persons. Despite the large household size, the average monthly income is very low. More than half of the households live on less than USD 250 per month, and another significant proportion (29%) live on a monthly income of USD 250–500, thereby limiting access to certain services such as transport. Nevertheless, 34.2% of the participants have a university degree, and 47.3% achieved their secondary school completion. The

high rate of participants who did not experience the 2002 eruption is an indication of the high migration reported in Goma. Table A1 in the Appendix shows the differences in demographic characteristics of participants between neighbourhoods. In general, households with a very low income live mainly in the Karisimbi municipality and the territory of Nyiragongo. In the Mugunga neighbourhood, one-third of participants are not educated, and this proportion falls to 1.7 % in Katindo or 4 % in the Les Volcans neighbourhood. To summarise, there are strong economic contrasts, but sampled respondents in the different neighbourhoods are homogenous in terms of demographic characteristic (age, gender, household size).

4.2 Risk perception

When asked to rate their perception of a range of threats, the population does not mention natural hazards as the main source of danger (Fig. 3) but rank it among its top five threats, after physical insecurity, at the same level as personal economic insecurity and above other environmental or health threats.

When evaluating perceived severity, there is no major variation in the levels of the perceived likelihood of different hazards (Fig. 4a), as well as in the perceived severity of their impacts on the city (Fig. 4b). This similar level of perception is surprising, as several of the hazards mentioned had not occurred (i.e. release of gas from Lake Kivu, explosive eruption at the shoreline of Lake Kivu, explosive ash from Nyiragongo) in recent history at the time of the survey and thus nor their potential impacts. Although all the listed hazards are possible scenarios at Nyiragongo, their homogeneous perception is interpreted to reflect a poor understanding of the contrast between these hazard processes, rather than a proper understanding of all eruption scenarios. Regarding perceived vulnerability, most respondents have a high to very high perception of the damaging impacts on infrastructure and functioning of the society. When considering the potential impact on their own life, participants have a lower perception of the risk of loss of life and family disruption than the perception of other impacts (Fig. 4c). When indicators of perceived likelihood of hazards and the perceived severity of impacts on the city are aggregated as the perceived severity, it is higher than the perceived vulnerability (Fig. 4d), suggesting that volcanic hazards are perceived to be more threatening to the city and its functioning than the individuals themselves. In general, the perception of volcanic risk by the population of Goma was high (mean = 3.7) before the May 2021 eruption of Nyiragongo.

4.3 Factors of risk perception

Table 2 shows the results of the tests of differences in the means of risk perception according to the different potential risk perception factors. Figure 5 presents the variation of the risk perception indicator according to factors for which the Wilcoxon and Mann-Whitney or Kruskal-Wallis's test highlighted a significant contrast between the factors' categories (Table 2). The level of risk perception varies less with demographic and contextual factors than with cognitive and psychological factors. Indeed, there is a limited variation in risk perception by age group i.e. the older age group having a slightly higher risk perception, family status and prior experience of a volcanic eruption (Fig. 5a, b, c). The results interestingly highlight that respondents from households with a lower income tend to have a higher risk perception than respondents from wealthier households. Moreover, the positive relationship between risk perception and anxiety suggests that the high risk perception among the population of Goma induces fear of the impacts from volcanic hazards. The risk perception is directly proportional to the perception of availability and the predictive power of environmental cues, as well as the comprehension and interest in seeking risk information (Fig. 5d, e, f, g, i). This means, as expected, that feeling exposed to the signs and sounds that indicate an onset eruption leads to a perception of a likely occurrence of a hazard and its impacts.

4.3.1 Demographic and contextual factors

Table 3 indicates the correlation of demographic variables with risk perception, as well as perceived vulnerability and severity. Risk perception has low to very low correlation with demographic and contextual factors (r < 0.1). Even though it is weak, the risk perception is negatively correlated with household income but positively with prior experience of a volcanic eruption. With age and education level, these are the only demographic and contextual factors that have a significant correlation.

In turn, household income is correlated with education and availability of a means of transport. Women are less educated than men (r = -0.22). Older respondents are less educated than young people (r = -0.17). As expected, older respondents more commonly reported a prior experience of a volcanic hazard. Even if it is a very low correlation, household income influences perceived vulnerability, not severity. Although risk perception is derived from the aggregation of perceived severity and vulnerability, it is more correlated with perceived vulnerability than perceived severity. Indeed, perceived vulnerability has a high standard deviation and therefore varies more between participants.

4.3.2 Cognitive and psychological factors

Correlation coefficients between cognitive and psychological factors with risk perception are indicated in Table 4. As expected, the correlation results suggest that Goma's population becomes anxious when they perceive the occurrence of hazards as likely, as well as when they perceive themselves as likely to be impacted by volcanic hazards. The trust in

Gender	n	%	Prior experience	n	%
Female	1231	55.4	No	1204	54.1
Male	993	44.6	Yes	1020	45.9
Age	п	%	Education	n	%
18-30 years old	888	39.9	Not educated	172	7.7
31–45 years old	914	41.1	Primary level	239	10.7
46–65 years old	365	16.4	Secondary level	1052	47.3
Over 66 years old	57	2.6	Graduated	761	34.2
Household size	n	%	Family status	n	%
1–3 persons	277	12.5	Grandparent	48	2.2
4–7 persons	1133	50.9	Parent	1472	66.2
8–11 persons	685	30.8	Child	591	26.6
Over 12 persons	129	5.8	Other relationship	113	5.1
Household monthly income	n	%	Transport	n	%
USD 0-250	1262	56.7	No	1570	70.6
USD 251-500	645	29.0	Yes	654	29.4
USD 501-750	213	9.6			
Over USD 750	104	4.7			

 Table 1. Demographic profile of participants.



Figure 3. Level of perceived likelihood of hazards as a potential source of harm to the respondent. After converting the Likert scale into a numerical scale (very low = 1 to very high = 5), the mean indicates the average perceived level of likelihood of occurrence of each hazard with a range of variation that the mean may have (standard deviation). The percentages on the right represent the proportion of those who perceived a high to very high likelihood of hazard occurrence and impact. The percentages on the left represent the proportion of those who perceive this likelihood to be low and very low. The middle percentages represent the proportion of the population with an intermediate perception level of the likelihood.

authorities is weakly and negatively correlated with risk perception, meaning that people with little trust in authorities have a high risk perception.

Both the reported extent of comprehension and interest in seeking information about volcanic risk are positively correlated with the risk perception indicator (r = 0.20). Specifically, the comprehension of volcanic processes rather leads to a higher perceived severity than to a higher perceived vulnerability. The perception of risk is positively and significantly correlated with the perception of the predictive power of environmental cues, in contrast to the perception of the availability of precursory signals of volcanic hazard occurrence.

4.4 Spatial differences in risk perception indicators

The spatial differences in risk perception indicators were assessed at two levels: between neighbourhoods and between the western and the eastern parts of the city (Fig. 6). We used a Kruskal–Wallis rank sum test for analysis between neighbourhoods and a Wilcoxon test for contrast between the western and the eastern parts of Goma. Results in Table 5 indicate that there are significant risk perception differences between neighbourhoods due to variations in perceived severity and in perceived vulnerability. In addition, a contrast was observed between the western and the eastern parts



Figure 4. (a) Perception of the likelihood of hazards, (b) perception of the severity of the impacts on the city, (c) perception of the likelihood of being personally impacted and (d) aggregated indicators.

of the city. Participants living in the eastern neighbourhoods, affected by the 2002 lava flows, demonstrate a higher level of perceived risk than respondents from the western neighbourhoods. In addition, there are significant differences in both perceived severity and perceived vulnerability between participants from these two areas.

The maps in Fig. 5 illustrate the differences in risk perception indicators per neighbourhood. The lowest levels of perceived vulnerability or severity are observed in the extreme west (Mugunga and Kyeshero), while the highest levels of these two risk perception indicators are observed in the neighbourhoods that were severely impacted in 2002 (Majengo and Virunga) and in Kahembe (the neighbourhood that hosted the Virunga and Majengo disaster victims in 2002). The risk perception as a derivative of the perceived severity and vulnerability follows the same pattern.

5 Discussion

5.1 Factors of volcanic risk perception

According to Chauvin (2018), Barclay et al. (2015) and Haynes et al. (2008), several sociodemographic factors (gender, age, level of education, level of income, etc.) have been shown to influence risk perception. However, in Goma, prior to the May 2021 eruption, only age (Fig. 5a), family status (Fig. 5b) and monthly household income (Fig. 5d) were associated, to a limited extent, with variation of risk perception. Younger people and those who do not belong directly to the close family have a lower perception than older people and close family members (Fig. 5b). The sense of responsibility for the well-being and security of the household seems to be one of the determinants of risk perception in Goma as doc-

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Figure 5. The level of risk perception according to significant determining factors. The level of risk perception is in a numerical scale from 1 (very low) to 5 (very high). In each boxplot, the horizontal bold line represents the median, the red dot indicates the mean and the small circles indicate the outliers. Apart from family status and experience of a volcanic eruption, the levels of each factor are in an ascending order.

umented in several other case studies (Gaillard and Dibben, 2007; Gaillard and Mercer, 2013). In addition, a high household income reduces the level of risk perception (Fig. 5d). Indeed, the perceived risk of asset loss or impact on livelihoods is higher compared to the perceived impact on lives (Figs. 3, 4b and c). This can be interpreted by the fact that, although poor households have little to lose, they would experience a relatively large impact of such loss, whereas rich people having many more assets would be relatively less affected by the loss. Blake et al. (2017) argue that people who are labelled as vulnerable, especially the poor, typically find it more challenging to reconstruct their lives after a disaster strikes.

Considering the demographic factors that control risk perception in other volcanic environments around the world, mostly assessed in western countries (Barrett, 2020), family



Figure 6. Spatial variation of (a) perceived severity, (b) perceived vulnerability and (c) risk perception. The perception levels were converted into a numerical scale (very low = 1 to very high = 5). The mean indicates the average level of perception by neighbourhoods with a range of variation within the neighbourhood (standard deviation). The spatial variation across all neighbourhoods was determined by the coefficient of variation of the perception indicator within all the neighbourhoods. It is 36.8% for the perceived severity, 27.0% for the perceived vulnerability and 18.0% for the perception of risk.

considerations do play a role in Goma. Reviewing sociodemographic factors of risk perception, Chauvin (2018) notes that gender is a determining demographic factor in controlling of risk perception in several cases, with women having a higher level of perception than men. However, in Goma, it is the economic context of the family, the position of the respondent in the household and their age that control the perception of risk. Considering these three parameters, it can be deduced that a parent or a responsible person in the household (usually the eldest of the household) with limited resources is more concerned by the household vulnerability to external hazards, and their risk perception level is higher than other family members'. Wu and Zhong (2022) highlight that people in collectivist cultures, as is the case to some extent in Goma, are better insured and supported by their nuclear and extended family members, as well as friends in their communities. Consequently, collectivist culture acts as a form of implicit mutual insurance to protect people from catastrophic losses, which leads to fewer perceived risks by family members who are not directly responsible for the household or community. Thereby, risk perception is influenced by the household's sense of responsibility and desire for wellbeing. Risk assessment and development of DRR strategies at the household level should be prioritised over those at the individual level.

The sub-permanent lava lake hosted in the Nyiragongo crater emits a gas plume (Arellano et al., 2017; Michellier et al., 2020), and in some inhabited neighbourhoods, there is localised emission of dry volcanic gas through fractures, called mazuku (Smets et al., 2010). Moreover, in January 2002, before the eruption, strong detonations were heard from the volcano (Komorowski et al., 2002). These are environmental evidence that most of the respondents consider warning signs as a good predictor of an imminent or starting eruption.

Table 2. Results of Wilcoxon and Kruskal–Wallis tests testing the control of different variables on risk perception. *W* indicates Wilcoxon's rank sum test and χ^2 the value of Kruskal–Wallis's chi-squared test.

Factors	Test value	df	p value
1. Demographic			
Gender	W = 621255		0.50390
Prior experience	W = 555810		0.00010
Transport	W = 510589		0.83920
Age	$\chi^2 = 6.38$	3	0.09420
Education level	$\chi^2 = 2.57$	3	0.46260
Family status	$\chi^2 = 13.797$	3	0.0032
2. Contextual			
Religion	$\chi^2 = 3.8$	8	0.5626
Household size	$\chi^2 = 4.8$	3	0.1839
Income	$\chi^2 = 25.0$	3	0.00000
3. Cognitive			
Availability of environmental cues	$\chi^2 = 269.4$	4	0.00000
Predictive power of environmental cues	$\chi^2 = 244.7$	4	0.00000
Comprehension	$\chi^2 = 94.8$	4	0.00000
Interest in seeking information	$\chi^2 = 162.8$	4	0.00000
4. Psychological			
Anxiety	$\chi^2 = 314.7$	4	0.00000
Trust	$\chi^2 = 5.8$	4	0.21320

Indeed, the predictive power of these processes is considered very high for respondents that have a high risk perception. However, Lindell and Perry (2012) warn that the perception of these environmental cues can bias interpretations of a hazard prediction. For the individual, a good knowledge of the mechanisms related to the hazard is required, as well as an understanding of the uncertainty associated with predictions of the natural event.

Our study also highlights a logical link between the level of interest in seeking information related to volcanic phenomena and the level of their understanding. It is however unclear whether the understanding is higher because people actively look for information on the volcano or whether a good understanding of the threat encourages inhabitants to further inform themselves on the volcanic activity. Both elements are associated with a high level of risk perception. Moreover, confidence in the actors involved in DRR does not influence the perception of risk (r = -0.06), but it influences the interest in seeking information (r = 0.22). This means that the population considers that it is possible to find reliable information from those actors. Finally, as advocated by Gaillard and Mercer (2013), increasing knowledge about volcanic phenomena could have a real impact on the level of risk perception.

5.2 Influence of prior disaster experience on risk perception

5.2.1 Homogenisation of the volcanic risk perception

In 2017, Michellier et al. (2020) assessed Goma residents' judgment of whether their household was at risk of a natural hazard or not. Consistent with similar studies, they found that considering one's household to be at risk was positively correlated with past experience of a geological hazard (Plattner et al., 2006; Heitz et al., 2009; Chauvin, 2018; Miceli et al., 2008; Paton et al., 2008; Lindell and Perry, 2000). However, our results (Fig. 5c) show little variation in risk perception between those who experienced the 1977/2002 eruptions (n = 1204) and those who did not (n = 1020). The correlation between eruption experience and risk perception is very weak (0.09), although positive and significant. This limited influence of experience of past eruptions - before the May 2021 eruption – on risk perception can be explained by four reasons: (1) the long period (nearly 20 years) since the last eruption prior to our survey, in agreement with Perry and Lindell (2008) and Merlhiot et al. (2018); (2) the experience of the 1977/2002 eruptions but without having suffered considerable personal damages as also found by Hall and Slothower (2009); (3) for those who have not experienced the last eruption before the May 2021 eruption, the high risk awareness maintained by the Goma Volcano Observatory's communications combined with anxiety caused by false alarms spread by social media in accordance with Mileti and O'Brien (1992); and (4) the fact that Nyiragongo is an open system volcano, with regular gas plume and a red glow at night (i.e. the activity of the volcano is well known to everyone in the city, not only those who were there during the last lava flow eruption). A further study of risk perception after the recent May 2021 eruption would allow for a better interpretation of the effect of prior experience on risk perception after a short time period. Despite this homogenisation of risk perception, the spatial analysis of our data shows differences between neighbourhoods and between the eastern (prior impacted area) and the western parts of Goma.

5.2.2 Influence of living in a prior impacted area on risk perception

Previous studies have highlighted spatial variations in the perceived severity of volcanic hazards according to the distance between the location of an inhabitant and a volcano (Quinn et al., 2019; Chester et al., 2008; Haynes et al., 2008; De la Cruz-Reyna and Tilling, 2008; Njome et al., 2010; López-Fletes et al., 2022). Goma is located 18 km south of Nyiragongo, but this volcano is clearly visible from all parts of the city. Lava flow is the main volcanic hazard, as experienced in 2002, when it crossed the city centre from north to south, and reached lake Kivu (Favalli et al., 2009, 2006). The variation in risk perception between neighbourhoods does

	Gender	Age	Household size	Household income	Education	Prior experience	Transport	Perceived vulnerability	Perceived severity
Age	-0.10^{***}								
Household size	0.02	0.13***							
Household income	-0.08^{***}	0.07**	0.13***						
Education	-0.22^{***}	-0.17^{***}	-0.06^{**}	0.31***					
Prior experience	-0.06^{**}	0.18***	0.10***	0.05*	0.06**				
Transport	-0.12^{***}	0	0.03	0.47***	0.27***	0.07**			
Perceived vulnerability	0.02	0.03	0.02	-0.08^{***}	0.03	0.07***	0.01		
Perceived severity	-0.01	0.06**	0.05^{*}	-0.03	0.05^{*}	0.08^{***}	0.01	0.39***	
Risk perception	0.01	0.05*	0.03	-0.07***	0.05*	0.09***	0.01	0.91***	0.74***

Table 3. Correlation matrix of demographic and contextual factors with the risk perception indicators.

*** p value < 0.001, ** p value < 0.01 and * p value < 0.1.

Table 4. Correlation matrix of cognitive and psychological factors with the risk perception indicators.

	Availability	Predictive power	Comprehension	Interest	Anxiety	Trust	Perceived vulnerability	Perceived severity
Predictive power	0.29***							
Comprehension	0.01	0.07***						
Interest	-0.01	0.09***	0.29***					
Anxiety	0	0.13***	0.12***	0.29***				
Trust	-0.03	-0.03	0.13***	0.22***	0.08^{***}			
Perceived vulnerability	-0.04	0.31***	0.13***	0.13***	0.28***	-0.12^{***}		
Perceived severity	-0.03	0.16***	0.23***	0.23***	0.30***	0.06**	0.39***	
Risk perception	-0.04^{*}	0.30***	0.20***	0.20***	0.34***	-0.06^{**}	0.91***	0.74***

**** p value < 0.001, ** p value < 0.01 and * p value < 0.1.

not differ depending on whether the neighbourhood is far from the volcano or not (Fig. 5a). Brown et al. (2017) state that it is almost exclusively with the ballistic volcanic hazard that the perceived likelihood of hazards and the severity of their impacts vary with distance from the volcano. However, at the Nyiragongo volcano, the constant "visibility" of the threat and the knowledge that lava flows can extend to a large distance cause a homogeneous risk perception. Furthermore, impacts from an eruption like the one of 2002 are expected to be high and to affect the whole city (Fig. 4b).

In addition, Goma is not officially subdivided into risk zones, contrary to some volcanic areas around the world (Slovic, 1991; Capra et al., 2015; Brown et al., 2017; Tsang and Lindsay, 2020). Therefore, the perceived likelihood of volcanic hazards and the severity of their impacts on the city could not be influenced by official risk zonation, despite the fact that the hazard from lava flows is not homogenous across the city (Syavulisembo et al., 2015; Favalli et al., 2009; Michellier et al., 2020). Indeed, in Italy as a concrete example, the areas of Vesuvius and Campi Flegrei are subdivided into risk zones (red, yellow and blue zones), and a spatial variation of the perceived likelihood of hazards was observed in these different zones (Barberi et al., 2008; Ricci et al., 2013). In Goma, the existing map of lava flow probability (Favalli et al., 2009; Kervyn et al., 2022) is not sufficiently disseminated among the population, or in official documents, like the volcanic eruption contingency plan, to influence the risk perception. Therefore, it seems not to be a specific factor that pushes people living in different neighbourhoods of Goma to perceive the likelihood of the occurrence of volcanic hazards differently.

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The variation in risk perception between neighbourhoods does not differ depending on whether the neighbourhood is far from the volcano or not. The highest level of risk perception is observed in the east of the city (Fig. 5c), i.e. not only the area that has been historically impacted by lava flows but also the oldest inhabited area (Komorowski et al., 2002; Michellier et al., 2020). Although the difference in the average perception per neighbourhood is limited, living in an area historically impacted by eruption influences the level of risk perception. Indeed, in an editorial review, Gaillard and Dibben (2007) showed that the spatial dimension of risk perception is closely related to memory of past events or prior experience. This demonstrates that, in some cases, it is not the individual experience that matters but rather that of a community in a neighbourhood where the impacts of past eruptions are still visible (Gaillard and Dibben, 2007). In Goma, the signs of the impact of the 2002 lava flows are still visible in the eastern neighbourhoods, and these events are part of the oral tradition, suggesting indeed that it is not

	Test b neighbo	etwee ourho	en ods	Test between the east and west			
Indicators	Test value	df	p value	Test value	p value		
Risk perception	$\chi^2 = 109.6$	7	0.0000	W = 694475	0.0000		
Perceived severity	$\chi^2 = 43.3$	7	0.0000	W = 639979	0.0000		
Perceived vulnerability	$\chi^2 = 121.8$	7	0.0000	W = 704505	0.0000		

Table 5. Results of Wilcoxon and Kruskal–Wallis tests testing the spatial differences in risk perception. *W* indicates the Wilcoxon rank sum test and χ^2 the value of Kruskal–Wallis's chi-squared test.

so much individual experience as collective memory of the event that affects the risk perception in a specific neighbourhood. For example, during the survey in the Virunga neighbourhood, an old man told us

my neighbour used to tell me that in 2002, the volcanic eruption had surprised them with a red-hot cloud and a puff of heat. After the eruption they returned in our neighbourhood, built on lava flows. Now, those who experienced the eruption and us who did not, all of us live in the likely path of lava flow.

Participants' socioeconomic vulnerability may also affect their perception of risk. Barclay et al. (2015) realised that in most cases high conditions of vulnerability of an individual usually lead to a high level of their risk perception. For instance, Khan et al. (2019) indicate that the physical vulnerability of buildings of an inhabitant is positively and significantly correlated with their perception of earthquake risk. In Goma, Michellier et al. (2020) found that the social vulnerability of the population of Goma is high in the peripheral neighbourhoods of the city, like Mugunga, a part of Kyeshero and the Nyiragongo territory. In contrast, our results indicate that the mean level of perceived vulnerability in these peripheral neighbourhoods is low (Fig. 5b). Therefore, spatially, our results show that perceived vulnerability is weakly related to the social vulnerability index. However, the perception of being personally at risk is negatively correlated with household income. In addition, people consider losing their assets as more concerning than being physically impacted (Fig. 4b and c). As a result, the vulnerable population in the peripheral neighbourhoods of Goma is also the one that feels the least concerned by volcanic risks. Blaikie et al. (2004), Van Praag et al. (2021) and Michellier et al. (2020) highlight that in Goma social vulnerability is underpinned by political context, armed conflicts, limited access to livelihoods and dependent economies so that people are more concerned by daily survival than natural hazards (Fig. 3). Another explanation of the low perceived vulnerability in the peripheral neighbourhoods could be that these neighbourhoods are far from the path of historical lava flows.

5.3 Limitations and perspectives

This study is affected by several limitations, one of which is the demographic characterisation of respondents that did not consider the housing tenure of respondents (ownership vs. rental) and the duration of residence in a specific neighbourhood. A qualitative approach through focus groups and interviews could help to capture local interpretations of the volcanic risk depending on culture. Our survey formulation of perceived vulnerability might have led to misinterpretation between the likelihood or the impact. Thus, multiple phrasing should be tested for the same concept.

Future research on risk perception in Goma should also consider (1) the impact of the population growth by highlighting differences of risk perception according to migration status, (2) the impact of false alarms spread by social media on risk perception, (3) the relationship between perceived vulnerability and scientifically assessed social vulnerability, and (4) the influence of risk experiences in general (vicarious, life difficulties, disaster experience, experience of insecurity related to civil wars or criminality) on volcanic risk perception. As our survey was conducted prior to the 2021 eruption crisis, it would be needed to study how this eruption and the associated evacuation have affected the risk perception of inhabitants. Finally, it would be relevant to further analyse how the highlighted contrasts in risk perception impact a population's preparedness and reaction during a volcanic crisis.

6 Conclusion

By describing the risk perception of 2224 inhabitants of Goma prior to the May 2021 eruption of Nyiragongo, we highlight the main factors controlling risk perception and its spatial distribution in the city of Goma. In general, the perception of volcanic risk by the population of Goma was high. Volcanic hazards are perceived to be a bigger threat for the city and its functioning, rather than for the individuals themselves. In contrast to other populated volcanic areas, distance does not significantly affect the risk perception, but a variation between the historically impacted eastern zone and the rest of the city is noted. Demographic factors are not the key factors shaping risk perception but rather cognitive and psychological ones. Furthermore, unlike studies in other volcanic areas, the experience of a past volcanic eruption is not a key factor in shaping risk perception at an individual level; however, the spatial difference in risk perception suggests that collective memory of past events in areas affected by a previous eruption does play a role. Cognitive factors and the family context are the key factors shaping the volcanic risk perception in Goma. Therefore, to enhance risk perception in the perspective of motivating the population to be well informed and to be prepared to face the volcanic risk, awareness-raising tools that strengthen the knowledge of inhabitants and the collective memory beyond the directly affected neighbourhoods would be essential. In addition, risk assessment and development of DRR strategies at the community level should be prioritised over those at the individual level in opposition to most risk perception studies conducted in western countries (Sommestad et al., 2015; Brewer et al., 2007; Bamberg et al., 2017). Another further study testing the impact of tools to improve knowledge of volcanic phenomena would provide a better understanding of how psychological and cognitive factors can influence risk perception through risk-awareness raising.

This study also discusses how the risk perception contrasts with the vulnerability of the population of Goma as assessed by scientific methods. Indeed, we highlighted that the factors determining the social vulnerability index are not necessarily those that make the population perceive that they are vulnerable or at risk. Moreover, we pointed out that people living in the peripheral neighbourhoods, far from the historically impacted path of the lava flow, have a low perception of their likelihood of being impacted. An unexpected eruption of Nyiragongo, like the one in May 2021, with a different lava path from the one taken by the eruptions of the last century, would affect a population that considers itself not highly vulnerable. It is therefore urgent to disseminate the map of lava flow probability. Finally, considering that the occurrence of a new event changes risk perception, a followup study assessing the evolution of the risk perception after the eruption of May 2021 is highly needed. As a perspective, more research about risk perception should be conducted in the Global South, as in the case of Goma. It could help to better understand the difference of risk perception between individualist and collectivist cultures. As a result, this could lead to a better balance of factors controlling risk perception globally.

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Appendix A

Table A1.	Detailed	overview	of the	participant	demographic	characteristics	across neighbourhoods.

	Karisimbi municipality									Goma municipality						Nyiragongo territory			
	Kahembe $(n = 270)$		Kahembe $(n = 270)$		Mug (<i>n</i> =	gunga 275)	ingaMajengo (275) $(n = 276)$		Vir $(n =$	Virunga $(n = 286)$		Katindo $(n = 271)$		Kyeshero $(n = 290)$		Les Volcans $(n = 266)$		Nyiragongo $(n = 290)$	
	n	%	n	%	n	%	n	%	n n	%	n	%	n	%	n	%			
Age																			
18–30 years 31–45 years 46–65 years Above 65 years	108 106 45 11	40.0 39.3 16.7 4.1	107 129 32 7	38.9 46.9 11.6 2.5	120 114 32 10	43.5 41.3 11.6 3.6	141 89 49 7	49.3 31.1 17.1 2.4	109 95 56 11	40.2 35.1 20.7 4.1	118 111 57 4	40.7 38.3 19.7 1.4	94 122 46 4	35.3 45.9 17.3 1.5	91 148 48 3	31.4 51.0 16.6 1.0			
Household size																			
1–3 persons 4–7 persons 8–11 persons Over 12 persons	33 155 67 15	12.2 57.4 24.8 5.6	35 139 95 6	12.7 50.5 34.5 2.2	37 127 94 18	13.4 46.0 34.1 6.5	35 133 93 25	12.2 46.5 32.5 8.7	35 134 80 22	12.9 49.4 29.5 8.1	35 134 101 20	12.1 46.2 34.8 6.9	40 158 58 10	15.0 59.4 21.8 3.8	27 153 97 13	9.3 52.8 33.4 4.5			
Income																			
USD 0–250 USD 251–500 USD 501–750 Above USD 751	191 65 10 4	70.7 24.1 3.7 1.5	226 47 2 0	82.2 17.1 0.7 0.0	200 72 4 0	72.5 26.1 1.4 0.0	173 88 20 5	60.5 30.8 7.0 1.7	91 110 48 22	33.6 40.6 17.7 8.1	132 100 46 12	45.5 34.5 15.9 4.1	39 88 78 61	14.7 33.1 29.3 22.9	210 75 5 0	72.4 25.9 1.7 0.0			
Education																			
Not educated Primary level Secondary level University level	20 46 139 65	7.4 17.0 51.5 24.1	59 48 144 24	21.5 17.5 52.4 8.7	19 30 154 73	6.9 10.9 55.8 26.4	13 21 141 111	4.5 7.3 49.3 38.8	3 13 100 155	1.1 4.8 36.9 57.2	23 29 120 118	7.9 10.0 41.4 40.7	7 7 80 172	2.6 2.6 30.1 64.7	28 45 174 43	9.7 15.5 60.0 14.8			
Gender																			
Female Male	151 119	55.9 44.1	170 105	61.8 38.2	150 126	54.3 45.7	170 116	59.4 40.6	145 126	53.5 46.5	148 142	51.0 49.0	121 145	45.5 54.5	176 114	60.69 39.31			
Prior experience																			
No Yes	119 151	44.07 55.93	185 90	67.3 32.7	137 139	49.6 50.4	141 145	49.3 50.7	129 142	47.6 52.4	147 143	50.7 49.3	163 103	61.3 38.7	183 107	63.10 36.90			
Transport																			
No Yes	220 50	81.5 18.5	246 29	89.5 10.5	231 45	83.7 16.3	226 60	79.0 21.0	136 135	50.2 49.8	191 99	65.9 34.1	76 190	28.6 71.4	244 46	84.14 15.86			
Family status																			
Grandparent Parent Child Relative	4 187 72 7	1.5 69.3 26.7 2.6	3 217 50 5	1.1 78.9 18.2 1.8	6 182 83 5	2.2 65.9 30.1 1.8	8 167 102 9	2.8 58.4 35.7 3.1	9 155 81 26	3.3 57.2 29.9 9.6	5 187 80 18	1.7 64.5 27.6 6.2	8 149 76 33	3.0 56.0 28.6 12.4	5 228 47 10	1.72 78.62 16.21 3.45			

Data availability. The raw and processed data from the co-authors' research findings cannot be shared at this time, as these data are also part of ongoing PhD research. The data are on Zenodo (https://doi.org/10.5281/zenodo.7638998; Mafuko Nyandwi, 2023) and may be made public once the doctoral research is completed. The research design and questionnaire design (in French) are available upon request from the corresponding author.

Author contributions. BMN, CM and MK conceived the study. BMN conducted interviews, designed questionnaires, analysed the data and wrote the original draft of the manuscript, with key input and revisions from CM, MK, FMH and FK. CM and FMH provided technical advice for data collection.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. The HARISSA (Natural HAzards, RISks and Society in Africa: developing knowledge and capacities) project, under which this research was conducted, was approved by the Congolese national government (Ministry of Research and Technology) and local authorities. The survey questionnaire and research protocol were approved in terms of ethical considerations by the academic office of the University of Goma and local authorities at the municipality and neighbourhood levels in Goma. Verbal informed consent was obtained from the survey participants for their anonymised information to be published in this article.

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