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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 time of eruption. This is especially the case in densely populated cities close to volcanoes like Goma in the East of the Democratic Republic of Congo 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 2,224 adults from height 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 survey's results shows that the risk perception varies less with demographic and contextual factors than with cognitive and psychological factors. 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 neighbourhood. Therefore, collective memory of past events in the impacted areas does play a role. Evidence from this study will help to develop well-targeted 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, the risk perception involves the processes of collecting, selecting and interpreting signals about uncertain impacts of natural events, activities or technologies (Slovic et al., 2004). These signals may refer to direct observations (e.g. witnessing a hazard) or information from other sources (e.g. reading about hazard newspapers) (Paton et al., 2008). Therefore, risk perception is related to personal understanding of natural hazard processes and prior experience (Gaillard and Mercer, 2013; Barclay et al., 2015) which in turn are filtered by socio-demographic factors, worldview and affective judgments (Dieckmann et al., 2021; Haynes et al., 2008; Wachinger et al., 2010; Weber and Slovic, 2002).

Bubeck et al. (2012) states that a proper approach to risk requires both good science and good judgement. Thereby, Favereau et al. (2018) point out that actions and reactions, specifically to

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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 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 is a component of most theories about protective behaviour (Brewer et al., 2007), such as the Protection Motivation Theory (PMT) (Rogers, 1975). 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; Rainear and Christensen, 2017). 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 population's acceptance and choices regarding risks and whether risk perception is contrasted in specific neighbourhood or sub-group 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 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 counts more than one 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. (2020a) evaluated the social vulnerability to volcanic hazards from Nyiragongo volcano in a context of data scarcity. In Michellier et al. (2020a), the 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 characterizing the risk perception of people from different neighbourhoods across the city, looking at multiple volcanic hazards, and analysing the potential relationship to demographic, 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. After defining the concepts of risk perception and its individual indicators, the collection and analysis of the survey data is 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 population living near volcanoes like those in Goma.

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2. Theoretical background of the study

While it began to be studied in the 1960's, particularly in the context of nuclear risk (Martin, 1989), the risk perception related to natural hazards has received increasing attention over the last two decades (Donovan, 2019). Bubeck et al. (2012) noticed that the definition of risk perception remained for a long period ambiguous 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 perceived likelihood of being personally impacted by a hazard (perceived vulnerability) and the perceived likelihood of a hazard as well as the severity of its impacts on the inhabited area (perceived severity) (Barclay et al., 2015; Botterill, 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 they 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 quantitative appraisal about the current and likely risk of various hazards and the desired level of regulation of each risk (Lechowska, 2021). 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 the 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).

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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 is sharing the border with the town of Gisenyi 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 three 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 to the growth of the population (Van Praag et al., 2021). Therefore, the city is constantly expanding but it is bounded (Fg.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 one million inhabitants (INS, 2021). Urban growth is associated with an increase in population 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 respectively on the northern and southern flanks. The volcanic field of Nyamuragira surrounds that of Nyiragongo, and both undergo permanent CO_2 degassing (Smets et al., 2010; Smets et al., 2015a). Since the early 1900's, an active lava lake has characterized 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, that came out from eruptive fissures and headed south towards the city of Goma (Fig. 1).

Two historical eruptions impacted the city before our survey in 2020. On 10 January 1977, the first one poured lava flows 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 rebels occupation (Komorowski et al., 2002). This new flank eruption, which generated lava flows emerging from the reopening and extension of the 1977 fissures, was larger and more destructive than that of 1977 (Wisner, 2017). In less than 24 hours, Goma was crossed by two lava flows, one of which reached Lake Kivu (Schmid et al., 2002). Komorowski et al., (2002) estimates that 40 people died and 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%.

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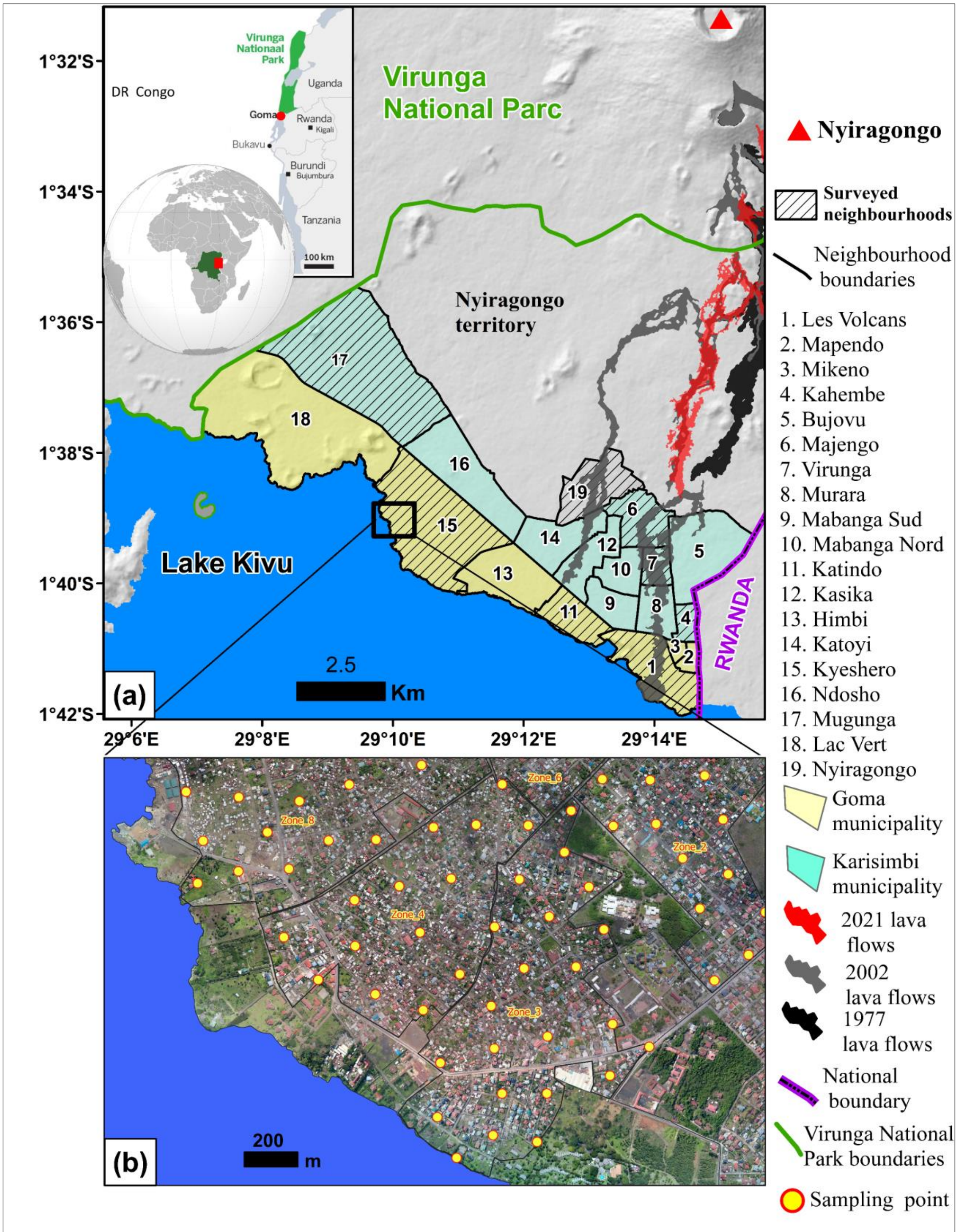

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162 *Fig. 1: (a) The city of Goma and the surveyed neighbourhoods with a SRTM-1 DEM ((c)*
163 *NASA/NGA) updated with the 2016 topography of the Nyiragongo crater (Delhaye and Smets,*

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2021), (b) Exemple 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.

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 5-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:

1) Demographic profile of participants: 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) The risk perception was assessed as an aggregated indicator of perceived severity and perceived vulnerability (Fig.2). On the one hand, perceived severity is conceptualized 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. Both indicators were generated from the aggregation of answers to multiple questions related to a range of volcanic hazards and potential impacts (Fig. 2). Before aggregating the values, the internal consistency of answers was checked using the Cronbach's alpha coefficient (Fig. 2). Aggregation for risk perception indicators was done according to the coefficient of variation (CV); for CV $< 25\%$, aggregation was done by mean and CV $\geq 25\%$ by median.

3) Perceived source of risk: A set of potential sources of risk related to the technological, socio-economic, 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) 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 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. 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.

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5) Status induced by the reception of risk information: anxiety (to what extent information regarding volcanic risk induces degree of nervous condition) and comprehension (perceived extent of understanding volcanic risk information).

6) Trust in authorities in charge of volcanic risk management and interest in seeking information.

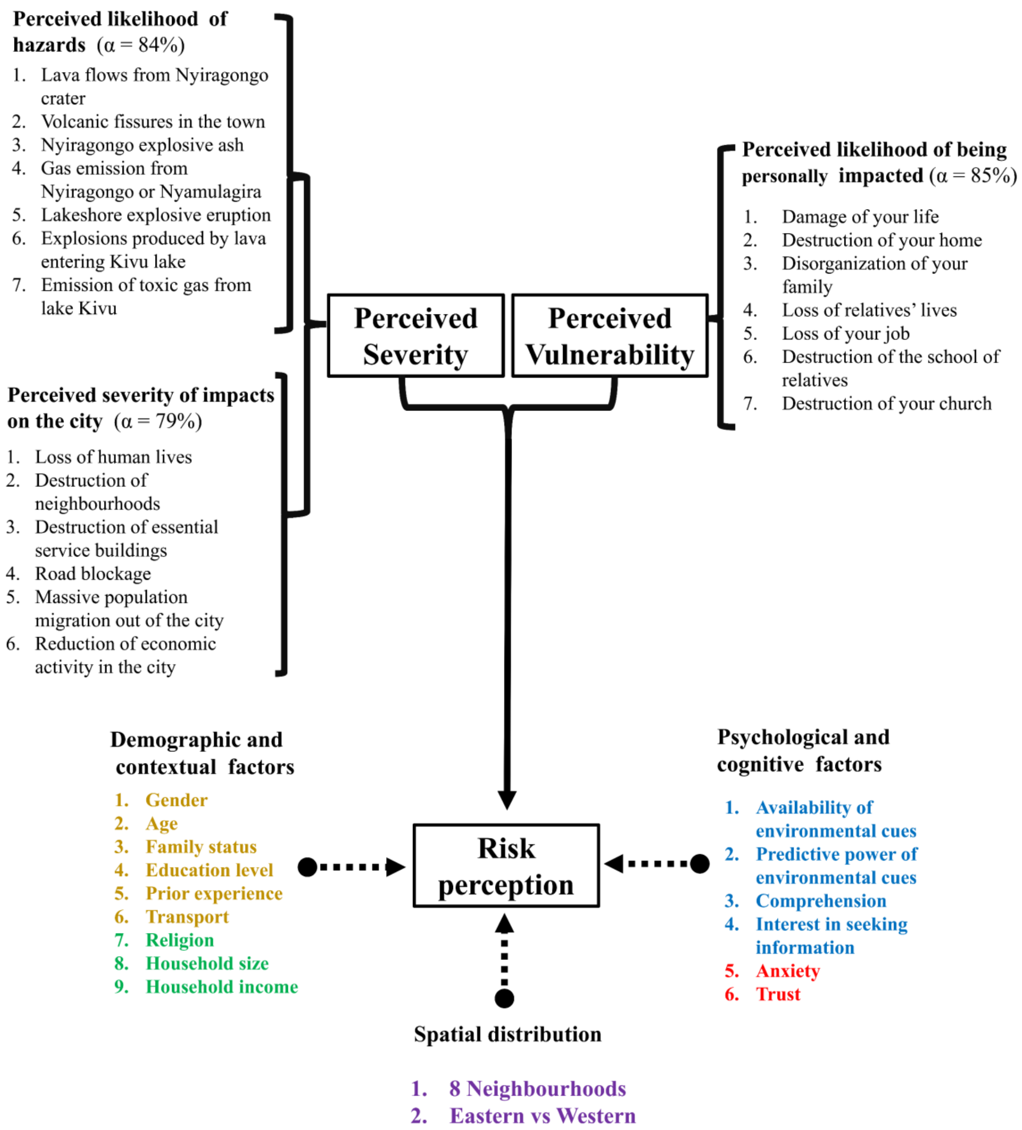

Fig. 2. Overview of the variables used in this research to derive an aggregated risk perception indicator from indicators of perceived severity and perceived vulnerability, and the potential controlling factors for highlighting differences in risk perception. Demographic factors are

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highlighted in orange, contextual in green, cognitive in blue, psychological in red and spatial in pink. 'α' represents the Cronbach's alpha index measuring the internal consistency of a set of answers.

3.3. Participants

The survey was conducted in seven out of eighteen 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 2,224 adults from the general population were surveyed. The size of sampling was calculated from the following statistical formula (Krejcie, R.V., & Morgan, 1970):

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

With:

- n: sample size
- N: population of the entire city
- P: population proportion (assumed to be .50 since this would provide the maximum sample size)
- t_p^2: the table value of chi-square for 1 degree of freedom at a confidence level (3.841).
- y: e the degree of accuracy expressed as a proportion (.05)

According to the 2020 report of the National Institute for Statistics (INS) of the North Kivu province, the population of Goma exceeded one million inhabitants in 2020 (INS, 2021). With a 50% of variance of population, 3% margin of error and 99% of confidence level, our survey's sample size should be 1,831 individuals. The 2,224 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 .01 to .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

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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. The questionnaire was accompanied by informed consent. A survey day started early in the morning (7 a.m. local time) and was also conducted during weekends, to meet parents and working adults. Each interview lasted about thirty-five minutes.

3.5. Data analyses

Descriptive statistics were used for categorical variables, such as demographic and risk perception (Harpe, 2015). Non parametrical test of Wilcoxon-Mann-Whitney (for two-group variables) or Kruskal-Wallis (for multi-group variables) were 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) correlation was used to measure the correlation 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 were fewer men than women among the participants and most of them were parents. The majority lives in large households: half of the households surveyed counts four to seven persons and 30% have eight to eleven 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. The high rate of participants who did not experience the 2002 eruption is an indication of the high migration reported in Goma. The table A in appendix shows differences in demographic characteristics of participants between neighbourhoods. In general, households with very low income live mainly in Karisimbi municipality and the territory of Nyiragongo. In Mugunga neighbourhood, one third of participants are not educated, and this proportion falls to 1.7% in Katindo or 4% in Les Volcans neighbourhood. To summarise, there are strong economic contrasts, and the samples are homogenous in term of demographic characteristic (age, gender, household size).

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Table 1. Demographic profile of participants

Gender	n	%
Female	1231	55.4%
Male	993	44.6%
Age	**n**	**%**
18-30 years old	888	39.9%
31-45 years old	914	41.1%
46-65 years old	365	16.4%
Over 66 years old	57	2.6%
Household size	**n**	**%**
1-3 persons	277	12.5%
4-7 persons	1133	50.9%
8-11 persons	685	30.8%
Over 12 persons	129	5.8%
Household monthly income	**n**	**%**
0-250US$	1262	56.7%
251-500US$	645	29.0%
501-750US$	213	9.6%
Over 750US$	104	4.7%

Prior experience	n	%
No	1204	54.1%
Yes	1020	45.9%
Education	**n**	**%**
No educated	172	7.7%
Primary level	239	10.7%
Secondary level	1052	47.3%
Graduated	761	34.2%
Family status	**n**	**%**
Grandparent	48	2.2%
Parent	1472	66.2%
Child	591	26.6%
Other relationship	113	5.1%
Transport	**n**	**%**
No	1570	70.6%
Yes	654	29.4%

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 the physical insecurity, at the same level as personal economic insecurity, and above other environmental or health threats.

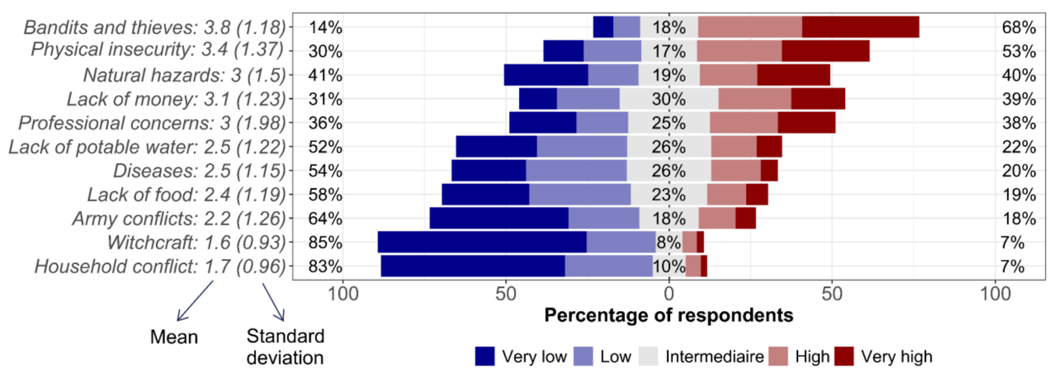

Fig. 3.: Level of perceived likelihood of hazards as potential source of harm to the respondent. After converting the Likert scale into a numerical scale (Very low= 1 to Very high= 5), the mean indicates the average perceived level of likelihood of occurrence of each hazard with a range of variation 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/impact. The percentages on the left represent the proportion of those who perceive this likelihood to be

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low and very low. The middle percentages represent the proportion of the population with an intermediate perception level of the likelihood.

When evaluating perceived severity, there is no major variation in the levels of perceived likelihood of 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 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 scenario 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 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 to 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.

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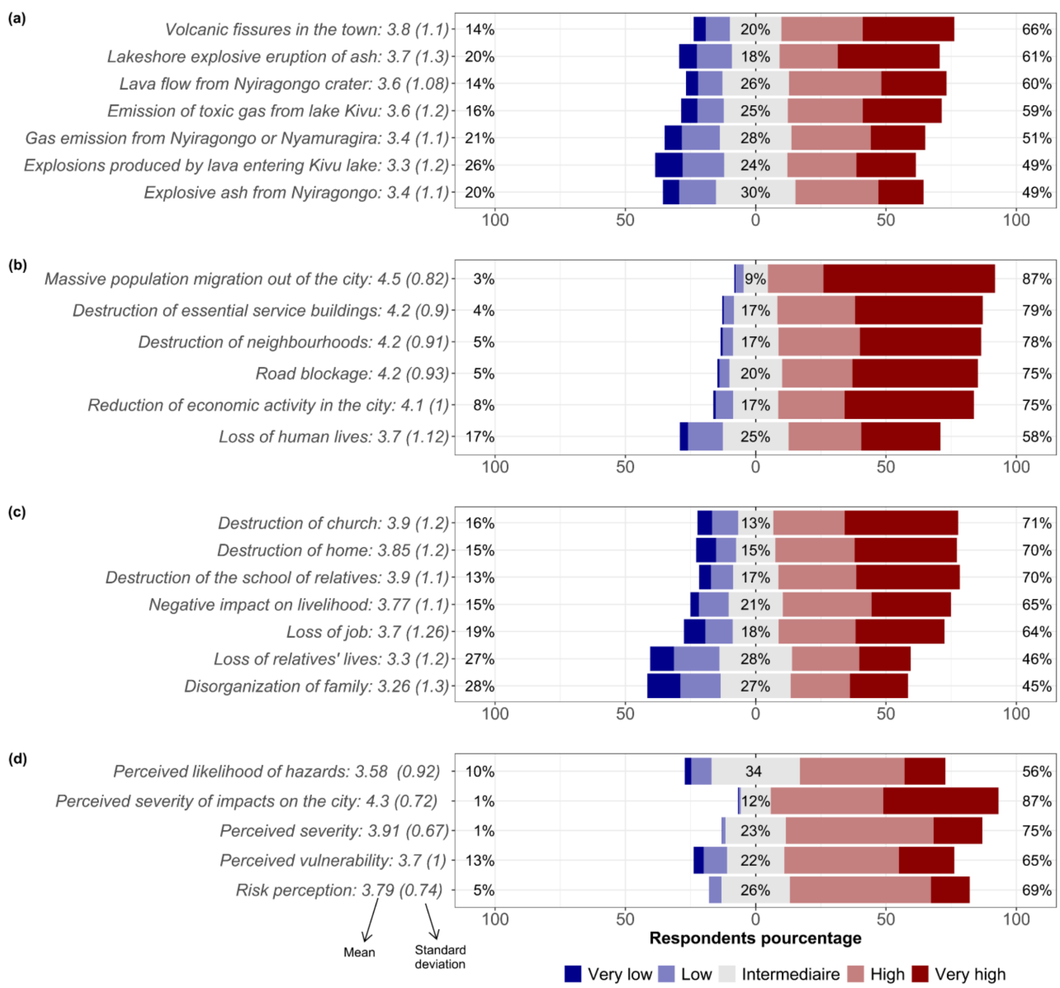

Fig. 4. (a) Perception of likelihood of hazards; (b) Perception of severity of impacts on the city; (c) Perception of likelihood of being personally impacted; (d) Aggregated indicators.

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., older age group having a slightly higher risk perception, family status, and prior experience of a volcanic eruption (Figs. 5a, b, c). The results interestingly highlight that respondent from households with lower income tend to have a higher risk perception than respondents from wealthier households.

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Moreover, the positive relationship between risk perception and anxiety suggests that the high-risk perception among the population of Goma induce fear of 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.

*Table 2. Results of Wilcoxon and Kruskal-Wallis tests testing the control of different variables on risk perception (**** p value < 0.0001, *** p value < 0.001; ** p value < 0.01; * p value < 0.1, n.s: no-significant, df: degree of freedom). W indicates Wilcoxon rank sum test and χ^2 the value of Kruskal-Walli's chi-squared test.*

Factors	Test value	df	p value
1. Demographic			
Gender	W = 621255		n.s
Prior experience	W = 555810		***
Transport	W = 510589		n.s
Age	χ^2 = 6.38	3	**
Education level	χ^2 = 2.57	3	n.s
Family status	χ^2 = 13.797	3	***
2. Contextual			
Religion	χ^2 = 3.8	8	n.s
Household size	χ^2 = 4.8	3	n.s
Income	χ^2 = 25.0	3	***

Factors	Test value	df	p value
3. Cognitive			
Availabilitity of environmental cues	χ^2 = 269.4	4	****
Predictive power of environmental cues	χ^2 = 244.7	4	****
Comprehension	χ^2 = 94.8	4	****
Interest in seeking information	χ^2 = 162.8	4	****
4. Psychological			
Anxiety	χ^2 = 314.7	4	****
Trust	χ^2 = 5.8	4	n.s

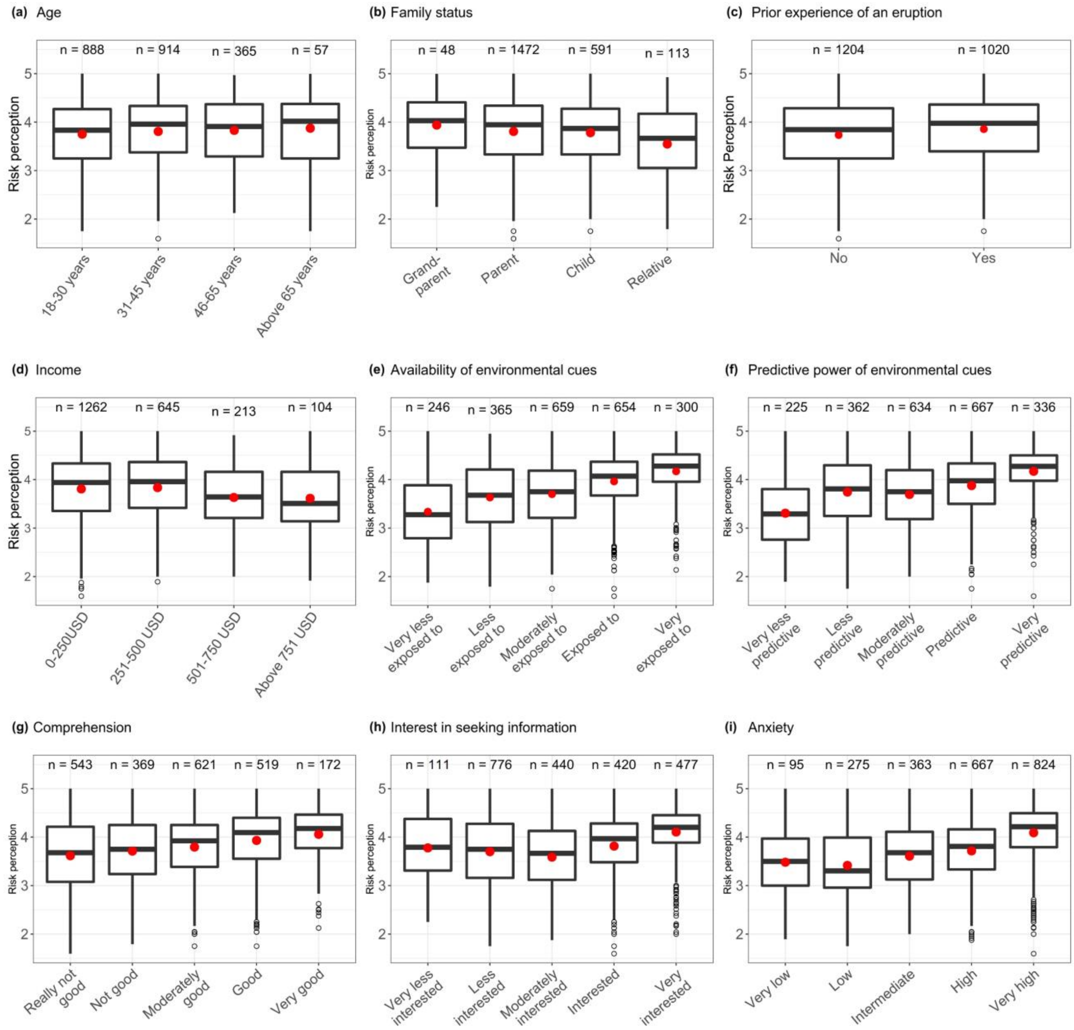

Fig. 5. The level of risk perception according to the determining factors. The level of risk perception is in numerical scale from 1 (very low) to 5 (very high). In each boxplot, the horizontal bold line represents the median, the red dot indicates the mean and the small circles the outliers. Apart from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

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

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eruption. With age and education level, these are the only demographic and contextual factors that have a significant correlation.

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

	Gender	Age	Household size	Household income	Education	Prior experience	Transport	Vulnerability	Severity
Gender									
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**			
Vulnerability	0.02	0.03	0.02	-0.08***	0.03	0.07***	0.01		
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***

*** p value < 0.001; ** p value < 0.01; * p value < 0.1

In turn, household income is correlated with education and availability of a mean 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, the household income influences the perceived vulnerability, not severity. Although risk perception is derived from the aggregation of severity and vulnerability, it is more correlated with vulnerability than severity. Indeed, perceived vulnerability has a high standard deviation, and therefore vary more between participants.

4.3.2. Cognitive and psychological factors

Correlation coefficients between cognitive and psychological factors with risk perception are indicated in the table 4. As expected, the correlation results suggest that Goma's population become anxious when they perceived the occurrence of hazards as likely, as well as when they perceive themselves as likely to be impacted by volcanic hazards. The trust in authorities is weakly and negatively correlated with risk perception, meaning that people with little trust in authorities have a high risk perception.

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

	Availlability	Predictive power	Comprehension	Interest	Anxiety	Trust	Vulnerability	Severity
Availability								
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***			
Vulnerability	-0.04	0.31***	0.13***	0.13***	0.28***	-0.12***		
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; * p value < 0.1

Both the comprehension and interest in seeking information about volcanic risk are positively correlated with the risk perception (r=0.20***). Specifically, the comprehension of volcanic processes leads more to the perceived likelihoods of hazards and their impacts on the city than to the perceived likelihood of being personally impacted. The perception of risk is positively and significantly correlated with the perception of the predictive power of environmental cues in contrast to how people perceive available these precursory signals and their power in predicting a volcanic eruption.

4.4. Spatial differences in risk perception indicators

The spatial differences in risk perception indicators were assessed at two level: between neighbourhoods and between the western and the eastern parts of the city. 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 of the city. Participants living in the eastern neighbourhoods, affected by 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.

*Table 5. Results of Wilcoxon and Kruskal-Wallis tests testing the spatial differences in risk perception (**** p value < 0.0001, *** p value < 0.001; ** p value < 0.01; * p value < 0.1, n.s: no-significant, df: degree of freedom). W indicates Wilcoxon rank sum test and χ^2 the value*

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of Kruskal-Walli's chi-squared test.

	Test between neigbourhoods			Test between the east and west	
Indicators	**Test value**	**df**	**p value**	**Test value**	**p value**
Risk perception	χ^2 = 109.6	7	****	W=694475	****
Perceived severity	χ^2 = 43.3	7	****	W=639979	****
Perceived vulnerability	χ^2 = 121.8	7	****	W=704505	****

The maps in Figure 5 illustrate the differences in risk perception indicators per neighbourhoods. 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 severity and vulnerability perception follows the same pattern.

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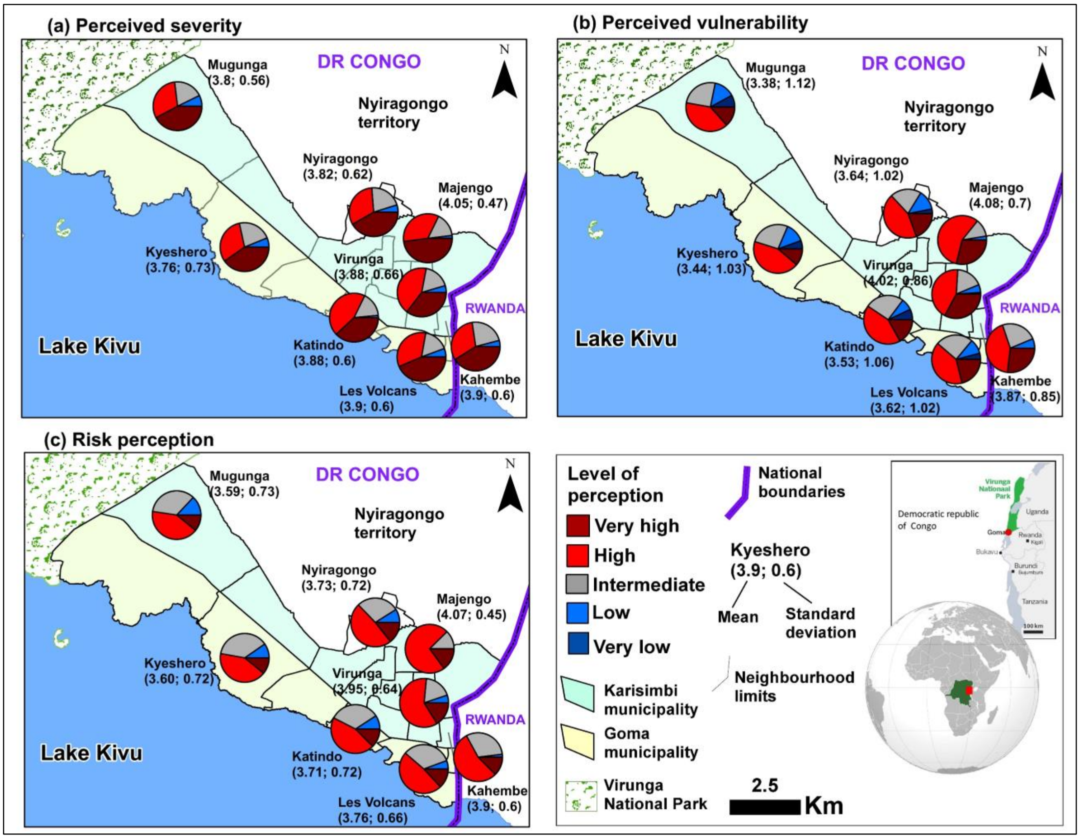

Fig. 6. Spatial variation of (a) perceived severity, (b) perceived vulnerability and (c) risk perception. The perception levels were converted into a numerical scale (Very low= 1 to Very high= 5). The mean indicates the average level of perception by neighbourhood with a range of variation within the 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 perception of severity, 27.03% for the perception of vulnerability and 18.04% for the perception of risk.

5. Discussion

5.1. Factors of volcanic risk perception

According to Chauvin (2018), Barclay et al. (2015) and Haynes et al. (2008), several socio-demographic factors (gender, age, level of education, level of income,…) 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 family (relatives) have a lower perception than older people and members of the restricted family (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 documented 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 assets loss or impact on livelihoods is higher compared to the perceived impact on lives (Figs 3, 4-b&c). This could be understood on the one hand as poor people having little to lose but a relatively large impact of, and on the other hand as rich people having many more assets and relatively small impact of loss. Indeed, the risk perception is negatively correlated to the income (table 3).

Considering the demographic factors that control risk perception in other volcanic environments around the world, family considerations does play a role in Goma. Reviewing socio-demographic factors of risk perception, Chauvin (2018) notes that gender is a determining demographic factor in controlling of risk perception in several cases; 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 his/her 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 oldest of the household) with limited resources is more concern by the household vulnerability to external hazards. Therefore, its risk perception level is higher than other family members. Thereby, risk perception is influenced by the household’s sense of responsibility and desire for the well-being. 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., 2020b), and in some inhabited neighbourhoods, there are localized 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 as good predictor (warning signs) of an imminent or starting eruption. 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 encourage inhabitants to further inform themselves on the volcanic activity. Both elements are associated to 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.

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5.2. Influence of prior disaster experience on risk perception

5.2.1. Homogenisation of the volcanic risk perception

In 2017, Michellier et al. (2020a) assessed Goma residents' judgement of whether their household was at risk from 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, this is in accordance with Perry and Lindell (2008); Merlhiot et al. (2018); (2) the experience of the 1977/2002 eruptions but without having suffered considerable personal damages as found also by Hall and Slothower (2009); (3) for those who have not experienced, the high risk awareness maintained by the Goma Volcano Observatory's communications combined with anxiety caused by false alarms spread by social media; and (4) the fact that Nyiragongo is an open system volcano, with regular gas plume and red glow at night (i.e., the activity of the volcano is well known for 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 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 had 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 population of Goma perceives the severity of volcanic hazards in almost the same way across the different neighbourhoods (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 Nyiragongo volcano, the constant 'visibility' of the threat and the knowledge that lava flows can extend to large distance cause a homogeneous risk perception. Furthermore, impacts from an eruption like the one of 2002 are expected to be high and affecting the whole city (fig. 4b).

In addition, Goma is not officially subdivided in risk zones in contrary to some volcanoes 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

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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 to not be a specific factor that pushes people living in different neighbourhoods of Goma to perceive differently the likelihood of occurrence of volcanic hazards.

Our results show that there are differences in both perceived severity and vulnerability between neighbourhoods and between the east and west and as resulting from them, risk perception varies in the same way. The highest level of risk perception is observed in the east of the city (Fig. 5c), i.e., the area that has been historically impacted by lava flows, but also the oldest inhabited area (Komorowski et al., 2002; Michellier et al., 2020a). Although the difference in the average perceived level per neighbourhood is limited in Goma, living in an area historically impacted by eruption influence 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 the 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 stigma of past eruptions are still visible (Gaillard and Dibben, 2007). In addition, Brody et al. (2008) note that the risk perception is high when people live in area assessed as at risk: they are likely to show a high level of environmental concern. In Goma, the stigma of the 2002 lava flows is still visible in the eastern neighbourhoods, and these events are part of the oral traditions, suggesting indeed that it is not 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' socio-economic vulnerability may also affect their perception of risk. Barclay et al. (2015) realized that in most cases high index vulnerability of a participant usually leads to a high level of the risk perception. For instance, Khan et al. (2019) indicate that the physical vulnerability of buildings of an inhabitant is positively and significantly correlated with his perception of earthquake risk. In Goma, Michellier et al. (2020a) found that the social vulnerability of the population of Goma is high in the peripheral neighbourhoods of the city, like Mugunga, part of Kyeshero and 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. Indeed, the perception of being personally at risk is negatively correlated with household income. In addition, people perceive the severity of losing their assets more than the likelihood of being personally impacted (Fig. 4b & 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. Wisner et al. (2005), Van Praag et al. (2021) and Michellier et al., (2020a) 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 concern by daily survival than natural hazard (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.

6. Conclusion

By describing the risk perception of 2,224 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 contrast to other populated volcanic areas, distance does not significantly vary the perception of risk, except for a variation between the historically impacted eastern zone and the rest of the city. Demographic factors are not the key factors shaping risk perception but rather cognitive and psychological factors. 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 differences in risk perception suggests that collective memory of past events in areas affected by a previous eruption does play a role. In addition, 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 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 household level should be prioritised over those at the individual level. 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 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 consider itself not highly vulnerable. It is therefore urgent to disseminate the map of probability lava flow. Finally, considering that the occurrence of a new event changes risk perception, a follow-up study assessing the evolution of the risk perception after the eruption of May 2021 is highly needed.

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Data availability

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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. Research design and questionnaire design (in French) are available on request from the corresponding author.

Author contributions

BMN, CM, 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 advises for data collection.

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 Congolese national government (ministry of research and technology) and local authorities. The survey questionnaire and protocol were approved 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 anonymized information to be published in this article.

Competing interests

The authors declare no conflict of interest.

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Appendix

Table A. Detailed overview of the participants demographics characteristics across neighbourhood

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

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