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## Reply on RC2

Blaise Mafuko Nyandwi et al.

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Author comment on "Differences in volcanic risk perception among Goma's population before the Nyiragongo eruption of May 2021, Virunga volcanic province (DR Congo)" by Blaise Mafuko Nyandwi et al., Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2022-217-AC2>, 2022

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### Revisions made

- In the manuscript, and on line 18 of the abstract, you mention "height representative"neighbourhoods – could you clarify what this means?

Line 18 in reviewed manuscript:

Sorry, this was a typo: we meant 'eight' not 'height'. This has been corrected.

- In the Introduction, you discuss the PMT threat appraisal, but it would be good to add a line outlining the other models in this space and being more explicit as to why PMT was chosen over the other models that exist for risk perception and action (e.g., Community Engagement theory, Paton, 2013; Protective Action Decision Model, PADM, Lindell & Perry, 2012, or theory of planned behavior, Vinnell et al 2021). These do not need to be discussed extensively, but the PMT needs to be placed in the wider context of them.

This section has been added:

Lines 45-53 in reviewed manuscript:

"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 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 been barely used to study volcanic risk so far (Kothe et al., 2019)."

- In paragraph ending line 62 – could you add to that sentence the typical volumes/speeds/durations of lava flows seen previously at Nyiragongo – this will help

add some contextual understanding.

Details about volumes/speeds/durations of the two historical eruptions was added in section 3.1. (Study area) instead of adding them into the introduction as was recommended.

Lines 149-169 in reviewed manuscript:

"Nyiragongo is a stratovolcano in the Virunga volcanic province (Pope 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<sub>2</sub> 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 (i.e. speed of the order of 6 to 20 km/h in 1977 and less than 10 km/h 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 m<sup>3</sup> of lava flows over 15 km<sup>2</sup> (including 4.9 km<sup>2</sup> 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 rebels occupation (Komorowski et al., 2002). This new flank eruption, which generated lava flows, was larger (25 million m<sup>3</sup> over 14 km<sup>2</sup>) and more destructive than that of 1977 (Wisner, 2017; Wauthier et al., 2012; Smets et al., 2015a). 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%."

- In line 89 and elsewhere I think there needs to be a bit more care in the description of vulnerability and how that relates to exposure, these are different concepts but at times it felt they were being conflated.

Additional details have been added to the definition of vulnerability and in the hole manuscript 'perceived' was added when appropriate, to differentiate "perceived vulnerability" and "vulnerability".

- In paragraph starting line 120, I think you could add more here on the privilege needed to prepare and what that means for risk perception and actions (e.g., Blake et al 2017,

<https://linkinghub.elsevier.com/retrieve/pii/S221242091730242X> ), plus also it's worth mentioning here or elsewhere that a significant limitation of many existing risk

perception studies is that participants come from WEIRD demographics (Western, Educated, Industrialised, Rich, and Democratic ; see Henrich et al, 2010

<https://doi.org/10.1017/S0140525X0999152X> or Jones, 2010

<https://www.science.org/doi/10.1126/science.328.5986.1627> ), which is important to

consider when relating the findings here to that existing body of work. (Also in

paragraph starting line 444)

We stressed this fact in our introduction by mentioning that our study help to reduce the limitation of risk perception studies by adding this sentence:

“In addition, this study helps to contrast the most existing risk perception studies in which participants come from western countries (Henrich et al., 2010; Barrett, 2020)”.

The same idea is stressed in the discussion section (5.1) and conclusion:

### **Discussion:**

Lines 451-467 in reviewed manuscript:

“Considering the demographic factors that control risk perception in other volcanic environments around the world, mostly assessed in western countries (Barrett, 2020), family considerations do 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 concerned by the household vulnerability to external hazards and its 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 of the household or community. Thereby, risk perception is influenced by the household’s sense of responsibility and desire for well-being. Risk assessment and development of DRR strategies at the household level should be prioritised over those at the individual level”.

### **Conclusion:**

Lines 596-616 in reviewed manuscript:

“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 general, the perception of volcanic risk by the population of Goma was high. Volcanic hazards are perceived to be more a 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 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 (Somestad 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.

- Line 178, and elsewhere in results: could you explain the aggregation process for the indicator more? How were they aggregated? And why were they aggregated in that way?

Explanation of the aggregation process is added in the methodology section (3.2) as follows:

Lines 191-198 in reviewed manuscript:

"To better capture the risk perception of a person living in an area potentially threatened by a range volcanic hazard 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 indicator, an aggregation of responses obtained is required. Before aggregating the values, the internal consistency of answers was checked using the 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  $CV > 25\%$  or by median when the  $CV \geq 25\%$ ."

- Line 194 – it will read a bit clearer to reframe this paragraph like the previous 3, so what is being assessed is upfront.

Related to that – line 200 discusses "the availability of environmental cues" – I struggled to understand quite what was being asked of participants here. Clarification will help.

Clarifications were added to the paragraph:

Lines 205-215 in reviewed manuscript:

"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., is the participant 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."

Line 320 to 322 is a really important finding – I would highlight this more in abstract /conclusion etc – plus in discussion briefly explore why this might be and what the implications of this finding are.

Based on your recommendation, we have highlighted these findings in the abstract, as in the conclusion.

**Abstract:**

Lines 149-169 in reviewed manuscript:

"Statistical analysis of survey's results shows that the risk perception was high (mean=3.7 on 5-point Likert scale) and varies less with demographic and contextual factors than with cognitive and psychological factors."

### **Conclusion:**

Lines 596-599 in reviewed manuscript:

"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 general, the perception of volcanic risk by the population of Goma was high"

- Line 253 – you mention informed consent, but can you please include information on the ethics process? (low risk notification or full review, etc)

Ethical considerations for the research protocol are specified in the ethical statement at the end of the manuscript.

Considering that participants may include non-literate individuals, asking them for written approval, even though assisted by a designed representative, would be a source of psychological harm.

Based on several years of experience, the University of Goma recommends to its researchers that oral rather than written consent be obtained for a survey among the general population in Goma. Thus, for our survey, verbal informed consent was obtained from the participants prior to the survey.

- Paragraph starting 387 needs a bit of rewording for clarity.

Thank you for point this out, the paragraph has been rewritten as:

Lines 397-402 in reviewed manuscript:

"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 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 availability of precursory signals of volcanic hazards occurrence."

- Line 435: what do you mean by "restricted" family?

By "restricted" family, we meant "nuclear family". We changed into "nuclear family".

- Line 528/529 seems to contradict line 508/509 – can you clarify?

Lines 540-541 in reviewed manuscript:

Indeed, there was a contradiction. We reworded the sentence as: "The variation in risk perception between neighbourhoods does not differ depending on whether the

neighbourhood is far from the volcano or not”.

- Line 540 – what do you mean by ‘stigma’ of the lava flows?

Line 550 in reviewed manuscript:

Thank you for your question. ‘Stigma’ means here marks. We reworded into “signs of impacts” to make it clearer.

- Line 549/550 – this is another area where I think the severity of impact (and vulnerability to that impact) might be being conflated by participants with likelihood. See comment above re: line 372 on outcome severity affecting likelihood perceptions.

Lines 567-568 in reviewed manuscript:

To limit the confusion, we reworded as: “In addition, people perceive the concern of losing their assets more than the fear of being personally impacted”

- Line 558: So, could a potential reason for this be that the fear of potential poverty is higher than the fear/concern of risk to life? Does this relate to more collective vs individual thinking and impact on family group? If relevant, here and elsewhere there could be a bit more discussion of collectivist and individualistic cultures, and what that means for risk perception and action (e.g., Note this very recent article by Wu & Zhong, 2022, that may be useful [https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=4129159](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4129159) ), and how that can also impact comparisons between studies conducted in different cultural contexts. Also is insurance common or rare? That would impact this finding too.

Thank you for this suggestion that we consider useful; we have taken it into account by mention the collectivist approach of risk in section 5.1:

Lines 451-467 in reviewed manuscript:

“Considering the demographic factors that control risk perception in other volcanic environments around the world, mostly assessed in western countries (Barrett, 2020), family considerations do 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 concerned by the household vulnerability to external hazards and its 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 of the household or community. Thereby, risk perception is influenced by the household’s sense of responsibility and desire for well-being. Risk assessment and development of DRR strategies at the household level should be prioritised over those at the individual level.”

- It would be good to include a bit more in the discussion on the limitations and future research needed – some is scattered throughout the manuscript, but a more explicit (and slightly expanded) section on limitations and future research would be good.

A section on limitations and perspective have been added to the manuscript. In addition, a paragraph about risk perception studies perspectives was added in conclusion section:

Lines 575-593 in reviewed manuscript:

### **5.2.3. Limitations and perspectives**

This study is affected by several limitations, one of which is the demographic characterization of respondents that did not consider the housing tenure of respondent (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; (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 has affected the risk perception of inhabitants. Finally, it would be relevant to further analyse how the highlighted contrasts in risk perception impact population's preparedness and reaction during a volcanic crisis.

### **Conclusion:**

Lines 627-630 in reviewed manuscript:

"As a perspective, more research about risk perception should be conducted in the Global South, as in the case of Goma. It could help 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."

- Lastly, there were a few places where there were some minor grammar errors (e.g., missing bridging words like 'the' or needing pluralisation) – it would be good to run through a grammar checker a final time before final submission.

The hole manuscript was grammar checked.

### **Responses to comments without modification of the manuscript**

- Line 139 – it is amazing to read of the city doubling since 2002, I wondered what that meant for risk perception and community and generational knowledge of risks. Is this growth predominantly from migration, or birth/family growth? If the former, that could have a significant impact on risk knowledge and perceptions.

I'm not aware about research comparing family growth and migration for Goma extension.

However, Pech Lisa and al. ([https://doi.org/10.1016/j.landusepol.2021.105711/](https://doi.org/10.1016/j.landusepol.2021.105711)  
<https://doi.org/10.1016/j.polgeo.2018.08.006> ) point out the importance of migration in a context of conflict around the city of Goma. This reference is mentioned in section 3.1 introducing the study area.

We discussed the impact of migration in comparing the perception of respondents who were living in Goma in 2002 and others who came later (section 5.2.2).

- Line 174 – in future it could be useful to include in the survey demographics the ownership vs rental status of homes, and the duration of time living in home/neighbourhood/city. This can provide a further factor to investigate with regards to risk perception.
- The authors might be interested in future in exploring the notion of vicarious experience a bit more. I note that this has been cited in the references, but it could be discussed / referenced a little bit more as this will relate to the risk perceptions of the different neighbourhoods. (e.g., Becker et al., 2017, <https://www.sciencedirect.com/science/article/pii/S2212420916303296> which discusses at length prior experience for earthquake preparedness and discusses life vs. vicarious experience on risk perception)

Thank you for the suggestions. We will consider these suggestions into account for our future research; we have mention some of these elements as future perspectives (line 597/598).

- Figure 2 is a great figure, really informative and clear!

Thank you very much for your appreciation

- Line 372 – 376 is such an interesting finding: are they more concerned about loss as they have more to lose? Are they actually rating for impact rather than likelihood in their responses and conflating these two concepts? The influence of 'outcome severity' is discussed in the communication literature, and may(?) be contributing to this result too? (e.g., Bruine De Bruin et al., 2000; Patt & Dessai, 2005) In addition, I wondered if the phrase "perceived likelihood of being personally impacted" is directing them towards the impact more than the likelihood (assuming this was the phrase in the survey). Perhaps future research could test out different phrasings for this question.

We did not plan to verify the differences of rating between the likelihood or the impact. We are going to consider this as a limitation of our study (line 593-595)

- Line 493 – this is interesting as false alarms can also lead to normalisation of the risk (see e.g., Shepperd et al 2013 <https://doi.org/10.1177/1745691613485247>, Mileti & O'Brien, 1992 <https://doi.org/10.1525/sp.1992.39.1.03x0062j> ) which would be associated with a reduction in anxiety.

In our study, we did not focus on analysing the impact of false alarms on risk perception. However, we cited Militi & O'Brien (1992) (line 518) to highlight this issue. We consider this as a limitation of our study and a question to be studied in the future.

- Line 505 – I wondered if there had been any felt earthquakes experienced? If so, when and how large? This would also impact risk perceptions.

The city belongs to the African rift valley, and it is common to experience earthquakes even out of the volcanic area; however, there was no major earthquake (large magnitude) that could have influenced the risk perception directly prior to our survey.