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July 16, 2024

Dear Dr. Macedonio,

Please find here a revised draft of the manuscript entitled *Volcanic risk ranking and regional mapping of the Central Volcanic Zone of the Andes* by Reyes-Hardy, M. P., Di Maio, L., Dominguez, L., Frischknecht, C., Biass, S., Freitas Guimarães, L., Nieto-Torres, A., Elissondo, M., Figueroa, M., Amigo, Á., García, S., & Bonadonna, C., which we hope adequately includes all revisions.

We believe the suggestions provided by the three reviewers greatly improved the quality of the original version of the manuscript. Each change has been tracked in the new version of the text to highlight the revisions. A rebuttal was also added in this letter in order to reply point by point to the comments of the reviewers.

We hope that you will find the modified version of our manuscript suitable for publication in Natural Hazards and Earth System Sciences.

Sincerely,

Maria-Paz Reyes Hardy on behalf of the authors

Reviewer 1

This manuscript represents a significant contribution to the current sate-of-the-art of the volcanic risk in the Central Volcanic Zone of the Andes, making a deep revision of the available data in the literature, considering many different parameters of the active and potential active volcanoes of the region, and showing the data in high quality and synthetic maps. It is quite well built, however, some parts of the results, discussions and conclusions could be a little bit improved to transmit in a clearer and more effective way, the most important and remarkable findings. Please find attached a pdf document with my specific comments.

Indeed, the paper address relevant scientific questions to catalogue the many potential active volcanoes of the CVZA, considering exposed population, infrastructures, but also parameters like vulnerability or resilience. It is a useful review to put together a lot of data in well-structured article. But sometimes, there is an overuse of tables that sound repetitive and make slow the smoothy reading flow and make easy to lose the thread of the history.

Despite the conclusion are sufficiently supported by results, I think they can be write in a more direct way to highlight the original outcomes of the research. And above all, some parts of the discussions looks repeating the results, the authors could squeeze much better the data and go further with the interpretations, not only "re-read" what the maps and numbers are saying, but giving more breaking statements.

The title, abstract, methods are clear, concise, accurate and reproducibly. The formulas are well used, but in my opinion, in conclusions they shouldn't be cited and force the reader to go back to the methods chapter to understand it. The conclusions must stand alone, otherwise the thread is cut. For example, if saying which are the riskiest volcanoes depending the 3 and 4-factor VRR, specify that the 3 considers vulnerability and 4 resilience, are only 2 more words and help the readers.

The figures are large enough but the labels and some details are too small (see pdf). The colours of the maps could contrast better. References looks fine. The discussions could be shortened if focusing only in interpretations and avoid repetitions of results text. The technical and english language is good, but can be improved in some parts (see pdf). The supplementary material is appropriate and show a lot of data in which the research is based on.

Response: We appreciate the valuable feedback on our manuscript. We have reorganized the introduction and improved the results, discussion, and conclusions to best present our findings. We have also compiled a rebuttal letter to address each specific comment.

It is important to clarify that, as explained in the Methods section, we compared six catalogues that had already classified volcanoes by type, and we used their best selection to compile our list of active and potentially active volcanoes. We then considered four risk factors (i.e., hazard, exposure, vulnerability, and resilience) to find the volcanoes of the CVZA associated with the highest risk. We appreciate that tables 1-3 may seem repetitive. Therefore, we moved Tables 1 and 3 to Supplementary Material 2, as suggested. We have kept Table 2 in the manuscript, since we

considered that this table helps the reader to appreciate the different road classifications and the necessity to use a homogeneous taxonomy across countries.

We have also restructured both discussion and conclusions to highlight the original outcomes of the research and avoid repeating the results. We have also expanded some parts of the discussion and introduced some specific recommendations on how to reduce vulnerability and increase resilience for target volcanoes. In particular, the discussion about active and potentially active volcanoes has been shortened and redistributed between introduction, methods and results. Following your suggestions, we have modified the text when referring to the VRR equations to make the reading smoother.

Finally, colors of the number of Holocene eruptions on the regional maps, as well as labels of all maps have been modified to improve visibility. All spelling and grammar errors have been corrected.

- **Comment 1:** *Lines 29-30: For example? if you begin the introduction giving that much importance to the fact of the volcanoes location along international borders, explain better the implications.*

  Response: Thank you for pointing this out. We have included some examples (line 61-63).

- **Comment 2:** *Line 31: Ok, the altitude is important, but in the first sentences of the introduction I would expect information about the hazard in a paper of NHESS (as you put in the abstract)*

  Response: We have incorporated your suggestion (lines 42-46), thank you.

- **Comment 3:** *Line 32: It is fine, but for a reader with not much time, would be better start with the hazard related stuff*

  Response: We agree, we have incorporated your suggestion (lines 38-46).

- **Comment 4:** *Lines 34-40: This info about antecedents is fine, but first I would introduce why these studies, so talk about the many active volcanoes understudied in the first lines*

  Response: Thank you, we have reorganized the introduction and we have incorporated your suggestion (lines 48-49).

- **Comment 5:** *Lines 40-44: These should be the second and third sentences on the first paragraph*

  Response: We moved this sentence to lines 50-52.

- **Comment 6:** *Line 48: Is the name of this cite necessary? Perhaps put the name of the first author and et al? or an acronym if is a technical report?*

Response: Thank you for this suggestion. We have changed "Ranking de riesgo específico para volcanes activos de Chile, 2023" by "SERNAGEOMIN, 2023" throughout the revised manuscript.

- **Comment 7:** *Line 51: I understand it is a technical report, but perhaps after the first cite you can use an acronym like RrEVAC, I don't know, it is just a suggestion trying to make the read flowing smother.*

  Response: Thank you for this suggestion. We have modified this reference accordingly.

- **Comment 8:** *Lines 50-55: Why explaining the ranking of these 2 countries together? it would be better explain the chile classification first in one sentence, and in a next sentence the argentinian one, making it clear and easier to the reader as you did for Peru.*

  Response: Thank you for this suggestion, we have separated the ranking explanation per country (lines 84-88).

- **Comment 9:** *Lines 80-81: Can it depend on the ridges location between plates and segments?*

  Response: Agree, we have incorporated a general statement about this (lines 122-123).

- **Comment 10:** *Figure 1: Include the acronym NVZA next to the grey triangles volcanoes, even if it's in the legend, you have space to put it and it will help the readers to localise everything faster. The quality of the figure is not good to see the details. Labels such plate names, ridges, and segments can be increased for better readability (you have plently space). CVZA, SVZA, AVZA idem.*

  Response: We have incorporated the acronyms next to each volcanic zone, increased the size of all labels as well as the figure resolution.

- **Comment 11:** *Line 104: I don't know if this EGU journal has a rule on which english must be used, in case is British english, should be catalogues (catalogs is american english)*

  Response: Thank you we have changed "catalogs" by "catalogues" throughout the revised manuscript.

- **Comment 12:** *Lines* 106-107: *(such? Infrastructures? Put some example)*

  Response: We have included some examples (lines 145-146).

- **Comment 13:** *Lines 110-113: Very long sentence, split in two and by subjects*

  Response: We simplified the paragraph as suggested (line 148-150).

- **Comment 14:** *Line 125: Salts pans?*

Response: Salt pans (or salt works). These are undrained natural depressions in which water gathers and leaves a deposit of salt after evaporation.

- **Comment 15:** *Table 1: The columns are not well aligned*

  Response: Columns are well aligned now, thank you.

- **Comment 16:** *Lines 143-144: These details can be read in the table*

  Response: We moved this table to Supplementary material 2.

- **Comment 17:** *Line 144: Table 1 appears before to be cited (in the previous page).*

  Response: Thank you very much. We moved this table to Supplementary material 2.

- **Comment 18:** *Table 2: You could add "network" as a heading of the first column, then don't need to write again the word network for each road (primary, secondary, urba, etc).*

  Response: Modified, thank you for this suggestion.

- **Comment 19:** *Lines 153-155: This sentences is hard to understand.*

  Response: The sentence has been rearranged, thank you.

- **Comment 20:** *Lines 156-157: It sounds repetitive because you already have cited this infrastructures at the beginning of the subchapter 2, which is quite confusing due to the text is sparse between many tables. Tables serve to show data easier, but in this case, I feel the overuse are complicating the correct following of the thread of the text.*

  Response: We modified the sentence and moved this table to Supplementary material to avoid repetition, the overuse of tables and to facilitate the reading (lines 226-229).

- **Comment 21:** *Table 3: Avoid split tables into different pages, you can move text upwards to leave table 3 complete in the next page. for example, what else is giving this table that is not already said in the text? cites of other works? it is really worth? I lost the thread of the history you are explaining…police and fire station, health centers, etc. is already listed in the text (and twice). and come on, this is only the methodology, enumerate once, cite works and move tables to SM.*

  Response: We moved Tables 1 and 3 to Supplementary Material 2. However, we have kept Table 2 in the manuscript to facilitate exposure classifications.

- **Comment 22:** *Lines 174-175: How do you know these unrest activity for holocene-pleistocene volcanoes? I thought that it is only to know that for historical activity*

Response: Unrest activity refers to the occurrence of physical phenomena that could indicate volcanic activity, even though the volcano has not had an eruption within the last 1,000 years. Seismicity, degassing and deformation are the 3 common signals considered by several authors (as stated in lines 74-78). The information about the signs of unrest for each volcano comes from several sources summarised in Supplementary material 1 and Table 1 (and detailed in Reyes-Hardy, M.-P., Di Maio, L. S., Dominguez, L., Frischknecht, C., Biasse, S., Guimarães, L., Nieto-Torres, A., Elissondo, M., Pedreros, G., Aguilar, R., Amigo, Á., Garcia, S., Forte, P., and Bonadonna, C.: Active and potentially active volcanoes of the Central Volcanic Zone of the Andes (CVZA), Arch. Ouvert. UNIGE, 123, https://doi.org/10.13097/archive-ouverte/unige, 2023. → "Report – Version 2" in https://archive-ouverte.unige.ch/unige:172413).

- **Comment 23:** *Lines 186-187: I count more than these in the SM4*

  Response: We improved the format of the table in supplementary material 4 to hopefully clarify the number of parameters used since this could get to confusion.

  The nine hazard parameters are: 1) Volcano type, 2) Maximum VEI, 3) Recurrence rate of events with VEI ≥3, 4) Types of volcanic hazards (considering: i) PDCs, ii) lava flows, iii) lahars, iv) tsunamis, and v) phreatomagmatic/phreatic explosion potential), 5) Collapse potential, 6) Primary lahar source, 7) Seismic unrest, 8) Ground deformation, and 9) Active fumaroles or magmatic degassing.

  The nine exposure parameters are: 1) Population density (by looking at four radii from the central volcano or inside volcanic field), then first appearance for 2) Residential buildings, 3) Transportation infrastructure, 4) Power infrastructure, 5) Water infrastructure, 6) Telecommunication infrastructure, 7) Emergency facilities, 8) Critical facilities, and 9) Economic activities.

  The 10 vulnerability parameters are: 1) Typology of buildings (by looking at four different radii from the central volcano or inside volcanic field), 2) Proximity to geographic border, 3) Lack of redundancy (considering four categories of infrastructures and two types of facilities), 4) Restrict accessibility to (considering three categories of infrastructures and two types of facilities), 5) Age (considering two different categories), 6) Disability, 7) Ethnicity, 8) Unemployment rate, 9) Education level, and 10) Economic activities (considering four different radii from the central volcano or inside volcanic field).

  The 13 resilience parameters are: 1) Hazard map, 2) Potential impact/risk assessment, 3) Engineering mitigation structures, 4) Hazard-based land use planning, 5) Monitoring system, 6) Early warning system, 7) Insurance coverage, 8) Educational activities (for population), 9) Exercises or simulations for operational institutions, 10) Exercises or simulations for population, 11) Successful evacuation in case of past eruption, 12) Shelters availability, and 13) Evacuation plan.

- **Comment 24:** *Line 189: Shorter, easier and clearer.*

Response: Agree, thank you.

- **Comment 25:** *Lines 201-202: What classification has been used to catalogue each volcano? cite?*

  Response: As explained in the Methods section we compared six existing catalogues that had already classified volcanoes by type and used the best agreement (lines 154-161).

- **Comment 26:** *Lines 204-205: These 3 without eruptions younger than 1000 years are showing the unrest activity currently?.*

  Response: It is difficult to affirm which volcanoes have currently unrest activity since monitoring information is not available. In our knowledge, only Lastarria was being monitored with permanent equipment (i.e., seismic and surveillance camera) but there is no longer access to this information through the SERNAGEOMIN's website.

  However, according to published information, these three volcanoes (i.e., Uturuncu, Lastarria, and Cerro Blanco) have records of seismicity, ground deformation and degassing during the past recent decades (Reyes-Hardy et al., 2023 à "Report – Version 2" in https://archive-ouverte.unige.ch/unige:172413):

  - Uturuncu: Large-scale ground deformation was observed beginning in May 1992 (Pritchard and Simons, 2002) surrounded by subsidence to create a sombrero- shaped deformation pattern (Fialko and Pearse, 2012; Henderson and Pritchard, 2013; Hickey et al., 2013), indicating, along with seismicity detected in 2009-10 (Jay et al., 2012), that a magmatic system is still present. Active fumaroles (Sparks et al., 2008) and geothermal fields in the region also suggest active magmatic activity (de Silva, 1989). Thus, despite the Uturuncu last erupted 250,000 y.a. (Muir et al., 2015), the volcano has been deforming for at least 50yrs, at a rate of up to 1 cm/yr between 1992 and 2004 (Gottsmann et al., 2017; Henderson et al., 2017; Pritchard et al., 2018), suggesting that the volcano might be a potentially active volcano.

  - Lastarria: There are records of ground deformation since 1997 (Pritchard and Simons, 2002; Froger et al., 2007; Ruch et al., 2008, 2009; Anderssohn et al., 2009) probably related to a growing magmatic chamber located about 10 km deep and magmas in the process of ascent from the asthenospheric wedge, which would feed a potential magmatic reservoir (Ruch and Walter, 2010; Budach et al., 2011). There are records of observed seismic unrest (Lara et al., 2011; Spica et al., 2012; Pritchard et al., 2014) and fumarolic and magmatic degassing (Naranjo, 1985; Aguilera, 2008, Aguilera et al., 2012, 2016; Robidoux et al., 2020; Inostroza et al., 2020b). Additionally, it displays continuous thermal anomaly hotspots (Jay et al., 2013).

  - Cerro Blanco: There is evidence of ground deformation (Pritchard and Simons, 2002, 2004; Viramonte et al., 2005b; Brunori et al., 2013; Henderson and Pritchard, 2013; Vélez et al., 2021), it is subsiding with an average velocity of 0.87 cm/year (Báez et al., 2015). There

are records of seismic swarms during the years 2007-2009 in the upper crust (Mulcahy et al., 2010) and it hosts an active, small geothermal field, fumaroles, diffuse degassing of CO2, hot springs and mud volcanoes (Viramonte et al., 2005a; Chiodi et al., 2019; Lamberti et al., 2021).

- **Comment 27:** *Table 4: Put this table in the same page as two "columns", one next to the other.*

  Response: Thank you for this suggestion. This table has been modified to include information suggested by reviewer 2. The format now does not fit a “two columns” table.

- **Comment 28:** *Line 220: Is this the caldera you mentioned earlier?*

  Response: Yes, it is.

- **Comment 29:** *Figure 2: With this colours by transparency over the purple colours of population is complicate to understand how many eruptions per volcano. why don't use clear different colours (e.g. red, green, blue and yellow)? or at least reduce the uncertainties due to the transparency. I understand design is important, but the most important for a map is expressing the information clear. These colours are not clear in the map. and how you know that a volcano has at least eruption during the last 1000 years if there is no data available? For example, to Lascar volcano, Parinacota o El Misti? If there is any record talking about an historic eruptiion or similar, I didn't put "no data". Or is this the colour to "no data" volcanoes? however, I understant that for no data is a pentagon, but this is too small within a map rich in information. you can still use a pentagon but larger, wich is already enough different from the VEI cercles*

  Response: We modified the colors of the number of Holocene eruptions on the regional maps to improve contrast as possible.

- **Comment 30:** *Lines 294-298: No way, a 6 lines sentence is too much.*

  Response: The paragraph has been rephrased and also moved to the introduction (lines 74-78).

- **Comment 31:** *Lines 298-300: This sentence is not clear. how the erosion affect the available geochronological data or historical records? reword necessary. explain better the relation between the arid erosive conditions to the geomorphology of pleistocene and/or holocene deposits*

  Response: Thank you, the sentence has been deleted, it is clearer now in the introduction (lines 55-58).

- **Comment 32:** *Line 302: Repetitive, you are starting this paragraph how you finish the precedent*

Response: This paragraph has been moved to section 3.1 (lines 152-154).

- **Comment 33:** *Lines 313-320: This part sounds to me more like an introduction of a research article than a discussion*

  Response: Thank you, we moved this paragraph to section 3.1 (lines 152-161).

- **Comment 34:** *Line 331: Why you don't take this good opportunity to baptise this unnamed volcano?*

  Response: We thank the reviewer for this suggestion. However, giving a name to a volcano is subject of a complex debate in the scientific community and local stakeholders that goes beyond the scope of this research.

- **Comment 35:** *Lines 353-358: Explain more details in this paragraph of why that happens, otherwise is similar of what you put in the results chapter*

  Response: We expanded this explanation, thank you (lines 361-363).

- **Comment 36:** *Lines 360-362: I don't understand this very short, isolated paragraphs. Discussions should take arguments in more deep detail, not that superficial*

  Response: Thank you for pointing this out, we agreed and expanded this explanation (lines 367-379).

- **Comment 37:** *Lines 366-369: This kind of explanations is what I expect in a discussion, which I miss two paragraphs above*

  Response: Thank you, we have taken this into consideration (lines 361-363).

- **Comment 38:** *Line 445: Why don't use this instead than that many (())*

  Response: Thank you very much. We have changed "()" by "-" throughout the revised manuscript.

- **Comment 39:** *Lines 479-483: And where is the relation with some volcano?*

  Response: The relation with volcanoes is specified in the results section. We think for conclusions it is more appropriate to give a summary for each dimension of exposure analyzed separately (i.e., population, transportation, and facilities density per km^2). However, we have incorporated a paragraph underlying the most threatening volcanoes in relation with all three dimensions of exposure analyzed in the regional mapping (lines 535-537).

- **Comment 40:** *Line 492: How? you stating what to do but nothing about how*

  Response: Thank you, we incorporated your suggestion in section 5.1 (lines 403-418).

Reviewer 2

The MS is an interesting and important contribution concerning volcanic risk in the Central Volcanic Zone of the Andes. It identifies 59 active / potentially active volcanoes in the region, analyses a wealth of data and presents two main results or products: a set of maps that depict the spatial relations between the volcanoes and elements at risk (population, infrastructure), and volcanic risk rankings that integrate hazard, exposure, vulnerability and resilience. I think that the MS can be considered for publication after a moderate revision. Below I list my main comments and in the annotated PDF I have added several other minor/moderate comments.

-Throughout the MS I find that there is too scarce a consideration with regards to absolute ages. Given that most volcanoes in the CVZ lack historical eruptions, having good radiometric ages is key to evaluate how active or potentially active a volcano might be. However, there are few young ages, in part because of the arid climate that makes it difficult to carry out C14 dating. But there are however available ages, not only Holocene ages (for example Lastarria has some C14 ages, Socompa has a Holocene zircon double-dating age) but also ages < 100 ka which are of interest (i.e., a 'Pleistocene' volcano with ages < 100 ka I think should be considered more potentially active than a 'Pleistocene' volcano lacking ages or with ages of, say, 500 ka or 1 Ma). I think that some of this should be presented and discussed in the MS. Also, in Sup. Mat. 1 it would be good to add the available radiometric ages for each volcano.

-It is not clear why 1000 years is chosen as the limit to consider volcanoes for the VRR. Also, why 3 signs of unrest and not only one or two? As stated in section 5.2, you are excluding possibly highly impactful volcanoes with these constraints. Maybe it would be worth stating that in the future it is desirable to carry out the VRR on all 59 volcanoes.

-Although I understand that details have been given in Reyes-Hardy et al. (2023), I think that some more information should be provided as to how and from what sources the data given in Sup. Mat. 1 was obtained. Maybe a doc file with this information could be added as a supplement. Some questions concerning Sup. Mat 1: why aren't radiometric ages given? What are the sources of volumes and areas? A footnote says that the number in parenthesis is number of eruptions confirmed by GVP, then what is the other number, eruptions according to who? What are the sources for the Holocene products lists of 'yes' or 'no'? How was sector collapse potential evaluated? Also, shouldn't columns of unrest signals be added to this table?

-Tables 1 to 3 are not really necessary in the main text, they could go as supplementary material.

-Table 4 is rather poor, it would be much better to give a more complete table for the main text, with several columns, summarizing the Sup. Mat. 1 table, i.e.: lat-lon, country, type, age, if had eruptions in last 1000 years, signs of unrest, number of Holocene eruptions, maximum VEI.

-Most of Section 5.1 is not really a discussion but rather more for intro, methods or results. It is not clear what is the point or goal of this section, what is the take-home message? I think the issue of how to identify active and potentially active volcanoes in this region is important and warrants

a discussion, but it should be re-written, keeping in mind the problems of arid climate (difficulty in determining how young volcanoes are based on morphology, difficulty in C14 dating), un-even intensity in glaciation (more intense towards the north, almost non-existent towards the south of the CVZ), scarce young ages, the fact that many/most volcanoes in the region have not been historically active and in turn volcanoes in this region can have very long repose periods. Something that could be highlighted is that, given the challenges, the list of 59 volcanoes (and also the list of 19 considered as 'more active') is not final or definitive, but can change depending on future studies, in particular new ages, that can push volcanoes in or out of the lists.

-Section 5.2 is nice, but in parts a bit repetitive of the results, it could be shortened a bit and in turn some further interpretations/discussions could be added (see comments in PDF).

-Section 5.3 is nice, see a few comments in PDF.

-The first four bullet points of the conclusions should be re-written (see comments in PDF).

Response: We are grateful to the reviewer for insightful comments on our paper. We integrated changes to reflect all suggestions provided.
Regarding absolute ages, we agree it would have been interesting to include this aspect in our database. However, as explained in the Methods section, we compared six existing catalogues that had already classified volcanoes by type and activity, and we used their best agreement to compile our list of active and potentially active volcanoes. Based on these volcanoes, we applied the existing Volcanic Risk Ranking methodology that considers the recurrence rate as being more informative of the volcanic hazard than absolute ages. For this reason, we have not included absolute ages but recurrence rate and records of the last eruption in our study.

The criteria of selection of volcanoes to apply the VRR methodology has been expanded, as it was suggested. Nieto-Torres et al., 2021 found that results for Mexican volcanoes were independent on the analyzed time window of eruption occurrence (i.e., <1 and <10 ka). Additionally, Guimaraes et al. (2021), who first applied this methodology on Latin American volcanoes, used the threshold of 1ka as these eruptions are the best constrained and described in the eruptive records. The grouping of volcanoes based on the age, most recent eruptions and eruption periodicities, has also been previously used to rank volcanoes in a general order of "decreasing concern" (e.g., Bailey et al., 1983) and currently the occurrence of eruptions within the last 1,000 years represents one of the controlling factors in developing strategies to increase resilience (Nieto-Torres et al., 2021). In this work, we applied the same methodology to the CVZA. However, we appreciate that focusing on the VRR analysis of the last 1,000 years of volcanic activity might exclude potential impactful volcanoes. Therefore, we constrained this aspect by integrating into the VRR analysis all the volcanoes presenting records of 3 signs of unrest (i.e., Uturuncu, Lastarria, and Cerro Blanco). Unrest signs include seismic, ground deformation, and degassing (details are available in the Supplementary Material 1). Due to lack of information for many of these volcanoes, the analysis of all 59 volcanoes remains a task to be addressed in the future as our knowledge of the CVZA

volcanoes and its surroundings improves (we stated this limitation in the discussion, lines 377-379).

Following your suggestion, references for the number of eruptions are specified in Table 1. All other sources considered in Supplementary material 1 are specified in the open access report of Reyes-Hardy et al. (2023) ("Report – Version 2" in https://archive-ouverte.unige.ch/unige:172413). This report includes a brief one-sheet description of each of the 59 identified volcanoes, describing physical characteristics, eruption frequency and hazard types (with associated references).
Tables 1 and 3 were moved to Supplementary Material 2. Table 2 was kept in the main text in order to homogenize the different datasets. Table 4 (now Table 1) has been modified to show all suggested characteristics.

We have also restructured some sections as suggested. In particular, the original Section 5.1 was redistributed across introduction, methods and results. We modified parts of Section 5.2 (now section 5.1) to avoid repetition and expanded on the explanations/interpretations of our main results, as well as on the criteria of volcano selection for the VRR method.
Finally, we modified the conclusions and better discussed the criteria behind volcanic risk rankings.

- **Comment 1:** *Lines 16: I think just 'Puna'*

  Response: Thank you for pointing this out, we deleted "de Atacama" in line 21.

- **Comment 2:** *Lines 18-19: Also, could highlight that there is a scarce historical record going back to only few centuries, and a difficulty in identifying which volcanoes have had Holocene activity, this in turn linked with arid climate, and also that there are relatively few young or Holocene absolute ages, again in part related with arid climate (difficult to apply C14 dating).*

  Response: We thank the reviewer for these suggestions, we incorporated them in the abstract (lines 23-25) and introduction (lines 55-58).

- **Comment 3:** *Line 28: I'd rather say that it is one of four active zones*

  Response: Thank you, we deleted "most" in line 36.

- **Comment 4:** *Lines 28-30: This is important, but I recommend to state it differently, separate from the first sentence. After a first general sentence, you could state more clearly the challenges of studying/evaluating/monitoring the volcanoes of the CVZA: the high elevation, the difficult accesibility, the problem of sharing country borders. Also, the arid climate, which makes it difficult to determine volcano relative age via morphology and also to date young/Holocene deposits with the C14 method.*

Response: We agree, we have restructured the introduction and incorporated the suggested details accordingly (lines 48-63).

- **Comment 5:** *Line 35: this list of references is a bit arbitrary, some are not really so pertinent. I recommend to list fewer references focussing only on the key regional papers. Add accents.*

  Response: Thank you, we refer the reader now to Aguilera et al. (2022) and Forte et al. (2021) for an extended reference list by country (lines 50-52).

- **Comment 6:** *Line 50-51: should state how many of these are in the CVZA.*

  Response: We incorporated your suggestion, thank you (lines 88-89).

- **Comment 7:** *Line 52: divided the volcanoes...*

  Response: This sentence has been removed.

- **Comment 8:** *Lines 74-75: Should add reference to the Global Volcanism Program*

  Response: Thank you, we have incorporated the suggested reference (line 117).

- **Comment 9:** *Lines 80-81: I think you should add some general statement on the subduction of ridges (Nazca, Juan Fernandez) and their possible role in generating flat-slab segments without volcanism.*

  Response: Agree, we have incorporated your suggestion (lines 121-123).

- **Comment 10:** *Line 90: of*

  Response: Modified, thank you (line 134).

- **Comment 11:** *Line 112. showing any one of the three signals or all three signals?.*

  Response: We mean records of all three signals. We have included this clarification throughout the manuscript.

- **Comment 12:** *Line 118: of the active and potentially active volcanoes.*

  Response: We have incorporated your suggestion (line 158).

- **Comment 13:** *Lines 136-137: not clear where in the Sup Mat you apply this correction? Also not clear how you perform this correction, maybe give some more detail. Also, why is it that in Sup Mat 2 not all volcanoes are listed?*

  Response: The correction is based on the distribution and density of population centers, which are detected by satellite images and then analyzed. Being this data used to rank exposure and

vulnerability, the information in the Supplementary material 2 covers only the 19 volcanoes included in VRR.

- **Comment 14:** *Lines 144-145: isn't it five classes?*

  Response: Yes, thank you for pointing this out, we did a mistake. Now it is corrected (line 216).

- **Comment 15:** *Line 170: In figs S2 to S4 should eliminate from references the symbols of num Holocene eruptions and VEI, as these are not mapped. Also, in figure legends should state what it is that you are highlighting with the boxes and yellow text.*

  Response: Agree. We deleted the symbols of number of Holocene eruptions and VEI and incorporated a brief explanation about what the grey boxes with yellow text are highlighting in each figure of SM3.

- **Comment 16:** *Line 174: Should say how many volcanoes were considered, 19 right?*

  Response: Thank you for this suggestion. We have incorporated the number of considered volcanoes (line 243).

- **Comment 17:** *Line 175: not clear if you are considering the volcanoes having any one of these three signals or only the ones having all three signals?*

  Response: Thank you for this question. In fact, we are considering only the ones having records of all three signals. It is specified now in line 244.

- **Comment 18:** *Line 180: spell out*

  Response: Thank you for this suggestion, it is spelled out now (line 249).

- **Comment 19:** *Line 187: The scores were normalized based on...*

  Response: This sentence has been rephrased (lines 251-253), thank you.

- **Comment 20:** *Line 193: not clear, which are the risk factors?*

  Response: We have now mentioned which are the risk factors (lines 258-259).

- **Comment 21:** *Line 199: Table 4 is rather poor, it would be much better to give a more complete table for the main text, with several columns highlighting the main charactersticis of each volcano: lat-lon, country, type, age, if had eruptions in last 1000 years, signs of unrest, number of Holocene eruptions, max VEI.*

  Response: Thank you. We have incorporated the characteristics suggested, specifying all their sources (Table 1, lines 174-196).

- **Comment 22:** *Lines 202-205: these things should be shown in the table*

  Response: This table has been modified to show all suggested characteristics.

- **Comment 23:** *Line 222: areas*

  Response: Corrected, thank you (line 283).

- **Comment 24:** *Line 283: ones can...*

  Response: This sentence has been deleted.

- **Comment 25:** *Line 286: can.*

  Response: Modified, thank you. Also, we moved this paragraph to the introduction (lines 68-70).

- **Comment 26:** *Lines 291-292: could add the age values to distinguish between the classes.*

  Response: This sentence has been deleted.

- **Comment 27:** *Line 292: very long sentence, try to cut in 2 or 3 sentences.*

  Response: We have modified the sentence as suggested. Also, we moved this paragraph to the introduction (lines 74-78).

- **Comment 28:** *Line 295: I don't think this citation is logical here, more logical would be to cite GVP, who say that a volcano is active if had activity in Holocene.*

  Response: We understand and removed this citation. Also, we simplified and moved this sentence to the introduction (line 74-78).

- **Comment 29:** *Lines 296-297: volcanoes have also been assumed active based only on their youthful morphology.*

  Response: We have incorporated this, thank you. Also, we moved this sentence to the introduction (line 72).

- **Comment 30:** *Line 302: however, many of the analyzed volcanoes have absolute ages. I think these should be considered in the MS.*

  Response: We would like to highlight that we didn't focus on radiometric ages as they were not needed for the purposes of our study. Even though very important, for the VRR methodology used in this study, last eruption records and recurrence rates are more informative for risk analysis, in agreement with Freitas Guimarães et al., (2021).

- **Comment 31:** *Line 306: not clear.*

  Response: This sentence has been deleted.

- **Comment 32:** *Lines 306-307: Should add references.*

  Response: This sentence has been deleted.

- **Comment 33:** *Line 310: I don't think any CVZA was wholly formed during the Holocene. These are volcanoes that started forming during the Pleistocene and continued active during the Holocene.*

  Response: This sentence has been deleted.

- **Comment 34:** *Lines 313-314: not clear, and the reference should go at the beginning of this part concerning satellite image analysis.*

  Response: This sentence has been deleted.

- **Comment 35:** *Lines 314-320: all this is more for methods and results.*

  Response: Thank you, we modified this paragraph and moved it to sections 3.1 (lines 154-161).

- **Comment 36:** *Line 322: all this paragraph is more results than discussion.*

  Response: This sentence has been deleted.

- **Comment 37:** *Line 325: not clear, the same as Aguillera and/or as the risk rankings? Furthermore, you analyze 59 volcanoes, so not the same as 62*

  Response: We agree in this confusion originated in the information updates. Before the last update of the volcano lists of SERNAGEOMIN and SEGEMAR by the end of 2023, this number was the same as Aguilera et al., 2022 (n= 62) as you can verify in "Report – Version 1" https://archive-ouverte.unige.ch/unige:172413, where we used Elissondo et al., 2016 and SERNAGEOMIN, 2020. After the 2023 update, the number of volcanoes was reduced to 59 ("Report – Version 2" https://archive-ouverte.unige.ch/unige:172413, where we used Elissondo and Farías, 2024 and SERNAGEOMIN, 2023 (i.e., the updated lists of SEGEMAR and SERNAGEOMIN respectively). To avoid confusions, we used 59 volcanoes throughout the manuscript.

- **Comment 38:** *Line 330: why not? what criteria?*

  Response: The report that details all these new criteria is in preparation by SERNAGEOMIN and should be accessible soon. From personal communications, Pular-Pajonales was removed

as it was last active in the Lower to Middle Pleistocene (300 ka), its historical activity was discarded, and it shows glacial erosion. Chascon-Purico complex was removed because its most recent recorded activity is in the Middle Pleistocene (180 ka ago) at Chascon (Burns et al., 2015) and has a post-glacial appearance. Colachi because its most recent activity was in the Upper Pleistocene (54 ±17 ka) in a dacitic dome (personal communication between SERNAGEOMIN and Moyra Gardeweg) and shows post-glacial aspect. And Caichinque because of its preglacial morphology. So far, we can only have access to the outcome of this work: SERNAGEOMIN (2023). Ranking de riesgo específico para volcanes activos de Chile 2023. Available at: https://rnvv.sernageomin.cl/wp-content/uploads/sites/2/2023/10/Ranking-2023_tabloide_20231012.pdf. Unfortunately, the report itself has not been published yet. Therefore, this sentence has been deleted.

- **Comment 39:** *Line 332: correct spelling is Purulla*

  Response: Thank you for this suggestion, it is correctly spelled now throughout the whole manuscript.

- **Comment 40:** *Line 333: Argentina*

  Response: This sentence has been deleted.

- **Comment 41:** *Lines 342-343: I don't think such detail needed*

  Response: These details have been deleted.

- **Comment 42:** *Line 355: Both El Misti and Parinacota actually have the same score of 10, should re-write this. Could discuss a bit more why this discrepancy; what is it in the VRR parameters/analysis that gives these volcanoes such relatively low rankings?*

  Response: Here we are referring to figure 5a where El Misti is located in the 10th position and Parinacota in the 7th position of the normalized hazard ranking. We expanded the explanation about the position of these volcanoes in the normalized hazard ranking (lines 361-363).

- **Comment 43:** *Lines 360-361: why did you focus on the last 1000 yrs? What is the basis of this?*

  Response: Thank you for this question. We have expanded this explanation in lines 367-379.

- **Comment 44:** *Lines 361-362: but this is only 3 more volcanoes; wouldn't it be worth also considering the volcanoes showing just one or two unrest signs?*

  Response: Whilst it is true that considering the volcanoes with 1 or 2 unrest signs, or even the 59 volcanoes of the CVZA, would have been interesting, here we apply the best compromise of considering 3 signs of unrest as the volcanoes most likely to erupt in the future. Compiling all the 41 parameters to rank hazard, exposure, vulnerability and resilience is quite challenging, in particular for the CVZA, due to the lack of accurate information. We prefer therefore stay

with the same criteria to avoid including false results due to the large uncertainties. The analysis of all 59 volcanoes remains a task to be addressed in the future as our knowledge of the CVZA volcanoes and its surroundings improves (we stated this in lines 377-379, and a discussion is presented in lines 367-379).

- **Comment 45:** *Line 378: close parenthesis*

  Response: Corrected, thank you (line 397).

- **Comment 46:** *Line 395: which is? Should develop further*

  Response: Thank you, we have modified and expanded this with a brief explanation (lines 427-428).

- **Comment 47:** *Line 408: but both consider eruption in last 1000 years right?*

  Response: Agree, thank you for this observation. In fact, to understand the main reason of this difference it is necessary to review the raw data of both rankings to actually identify that both hazard and exposure are scored higher in this work with respect of Guimarães et al. (2021) (i.e., 7.89 and 6.04 versus 6.31 and 5.62, respectively). In the case of hazard, it is because we scored the recurrence rate with 4 (since the eruption interval of events with VEI ≥3 is <50 years, following Nieto-Torres et al. (2021) and Guimarães et al. (2021) methodology) while in Guimarães et al. (2021) was scored with 1. We have modified this sentence to make it clearer (lines 439-440).

- **Comment 48:** *Line 411: but it would be interesting to compare their top five with your and Guimaraes's top five excluding the Peruvian volcanoes. Are the rankings similar? are there particular differences?*

  Response: This comparison is now enlarged (lines 450-456) and specified in the Table 4 of the current manuscript.

- **Comment 49:** *Line 447: two*

  Response: Modified (line 492).

- **Comment 50:** *Lines 448-449: these were not considered in Guimaraes? Or were given different scores in Guimaraes?*

  Response: The reason is that there were given different scores, we rephrased this explanation (line 492-493). But in fact, regarding Lullaillaco volcano, it has a lower hazard and vulnerability scores and higher exposure and resilience, leading to a lower overall VRR-2 in our work with respect to Guimarães et al. (2021). The reasons are that in our work 1) the maximum VEI of Lullaillaco is 2; 2) the eruption interval of events with VEI ≥3 is 0; 3) there is no evidence of Holocene pyroclastic flows from Llullaillaco; and 4) it has lahar potential. Therefore, our scores for these hazard parameters are 1, 0, 0, and 1, respectively. Whilst

Guimarães et al. (2021) scores are 2, 1, 1, and 0. Regarding exposure, in our work 1) population within 100 km radius from the main crater of Llullaillaco is >1 inhab/km2; 2) water and telecommunication infrastructures first appear in 100 km radius from the main crater. Therefore, our scores for these exposure parameters are 2,1, and 1. While in Guimarães et al. (2021) scores are 1, 0 and 0, respectively. The biggest differences for Llullaillaco are also found in the vulnerability factor. In our work 1) the proximity of Lullaillaco volcano to the geographic border is within 100 km, therefore scores 1; 2) since transportation, water, and telecommunication infrastructures, and emergency and critical facilities are > 1 within 100 km radius from the main crater, the lack of redundancy for these parameters score 0; 3) the power infrastructures are ≤ 1 within 100 km radius from the main crater, therefore the lack of redundancy scores 1; and 4) since the number of means of transportation to access to power, emergency and critical infrastructures are >1 within 100 km radius from the main crater, they score 0. Whilst in Guimarães et al. (2021) scores are 2, 1, 0, 1 and 1, respectively. Finally, regarding resilience, our updated information shows that there are hazard maps for Lullaillaco volcano (Amigo et al., 2012) therefore scores 2, while in Guimarães et al. (2021) scores 0.

- **Comment 51:** *Lines 474-476: but this is a recopilation of previous data; you should highlight your findings, i.e. say which are the more hazardous volcanoes, which pose greater risks considering population and infrastructure*

  Response: Thank you. We incorporated your suggestion (lines 535-537).

- **Comment 52:** *Lines 477-478: should make the link with the volcanoes that threaten these places*

  Response: We have incorporated a paragraph underlying the most threatening volcanoes in relation with all three dimensions of exposure analyzed in the regional mapping (lines 535-537).

- **Comment 53:** *Lines 479-482: again, relate with the volcanoes.*

  Response: See comment 52.

- **Comment 54:** *Line 488: for conclusions, state what they consider, do not refer to equation.*

  Response: Thank you, we have incorporated your suggestion (line 545).

- **Comment 55:** *Line 490: same, or say 'when resilience is considered'*

  Response: Thank you, we have incorporated your suggestion (line 547).

Reviewer 3

This manuscript is well documented and provides an important contribution to the Central Volcanic Zone of the Andes, which is approached from a disaster risk perspective that is relevant

to the aims and scope of the Journal. The regional mapping of active (and potentially active) volcanoes and applying a ranking that considers the interaction of hazard, exposure, vulnerability and resilience to assess volcanic risk contribute to broadening the understanding of disaster risk reduction in volcanic areas. In this sense, this work offers an opportunity to rethink the ways of assessing risk regarding the broad environmental, economic and social contexts with which a volcanic eruption interacts. This understanding deserves the general attention of the volcanology audience.

Therefore, I recommend its publication with moderate revision. To further enhance this work, I suggest some moderate changes that could be considered. The suggestions and comments (see PDF) are organised according to the structure of the paper to make the audience more familiar with the topic:

ABSTRACT: The summary concludes with a result. I recommend adding a sentence suggesting, as volcanologists, some ways to mitigate the risk in the identified areas, bearing in mind that such mitigation actions will typically fall on decision-makers and development processes. Therefore, the novelty of this ranking and methodology could also be translated into implemented recommendations. The same applies to the last sentence of the conclusion.

INTRODUCTION: In addition to the transboundary nature of this volcanic area, the socio-cultural and geographical composition that existed (and exists) prior to the states' formation and the area's transboundary nature is also important. The volcanic areas of this zone are characterised by being ancestrally and historically inhabited (but not only) by indigenous populations (Aymara, Quechua, Licanantay, etc.), and some authors have already studied this aspect in relation to volcanic risk (Melcher 2004; Romero & Albornoz, 2013; Petit-Breuilh, 2016; Ramos & Tironi, 2022; among others). Therefore, I suggest starting the introduction by mentioning that the central volcanic zone has been inhabited for centuries, even before the division of borders. Both qualities today involve "significant socio-cultural and cross-border challenges". Including this kind of background will bring this work on volcanic risk to the Earth and social science audience as well.
It is perhaps inappropriate to begin the paper by stating that it is "one of the most active areas in the Andes" compared to other volcanic zones, as its main characteristic is instead that it is an area that encompasses "a number of previously unrecognized, geologically young, potentially active giant ignimbrite centers and caldera systems, both in the Central Andes" (Stern, 2004), along the border of these countries. Moreover, the importance of the CVZA can be underlined by the fact that it has the "long record of voluminous silicic pyroclastic activity' associated with these giant systems 'has important implications for the safety of several major cities near the mouths of Andean canyons" (Stern, 2004, p.164).

The objective is missing in the introduction. I suggest stating the main objective of this work, what VRR's most relevant findings were, and why it is considered necessary to use it as an approach or method for the CVZA. This will give the reader an idea of how this new ranking differs from others.

METHODOLOGY: While the reader is asked to refer to the supplementary material for information on these concepts, the definition of Hazard and Resilience must be mentioned at least

once in this part of the Methodology. They are the central elements of this new approach to risk ranking that the authors are trying to promote and should be present.

RESULT: Regarding using the 4-Factor VRR formula, could the authors explain the relevance of assessing each factor for each volcano? For example, it is not very clear that Misti tops the ranking of Normalized Exposure and Resilience simultaneously. On the other hand, it also needs to be clarified to determine a value (of H, V, E, R) for a volcano as a unit because depending on the distribution of the population in different flanks or sectors, it will vary. Finally, the authors need to mention how resilience is associated with a specific volcano, as resilience is the human or social characteristic within the formula, so there would be more or less resilient groups or villages around volcanoes. Moreover, resilience alone does not reduce risk; it must be associated with vulnerability reduction.

DISCUSSION: I suggest moving part of the discussion to the introduction for presenting conceptual definitions of active and potentially active volcanoes.

Here, it is mentioned that the regional mapping carried out can contribute to further risk analysis. Do the authors consider that they are already providing a risk analysis with these results and the method applied? If yes, it should be mentioned. On the other hand, "the VRR method provides an in-depth risk analysis", but some interpretations by the authors on the combination of the 4 factors are missing, apart from those done individually. I recommend then to improve this part of the discussion to mention "What is the risk for the different segments of the central volcanic zone?" or "Why does the identification of active or potentially active volcanoes not considered in other classifications contribute to a better understanding of CVZA risks?".
It is also mentioned that each country evaluates specific volcanoes. This idea is central to the paper. The authors should emphasise that they are interested in demonstrating the value of assessing risk on a regional scale and that, in the event of an eruption of CVZA volcanoes in a border zone, this type of "regional" risk analysis can significantly aid collaboration between countries in managing a volcanic emergency that may affect their populations (in different ways probably, e.g., tephra fall or PDCs).

CONCLUSION: What are the riskiest volcanoes in the CVZA? The authors could mention the 5 or 10 most risky volcanoes (or a number they consider appropriate) in the conclusion without breaking them down again by factor or element.

Finally, it would be ideal to conclude why it is important to rethink volcanic risk classifications (in this case, at the regional level), and how this could reflect DRR and mitigation measures tailored to the regional reality of the area: for instance, it is an area with very explosive volcanoes, with volcanoes whose history is partially unknown and may be potentially active, and with diverse populations around them that indeed share some socio-cultural and economic characteristics because they have been there since before the division of borders. Finally, because some of these volcanoes are located on the border, it is necessary to rethink the volcanic risk of the Central Andes at a regional level.

Response: Thanks for the insightful comments. Following your suggestions, we have modified the last sentence of the abstract and added some recommendations to mitigate the risk in the

discussion (e.g., volcanic hazard and risk/impact assessments, monitoring systems, educational activities, and implementation of early warning systems).

We modified the introduction to clarify the objectives and underline the importance of our study in the context of CVZA volcanoes.

In the Results, we better explain the importance of assessing each risk factor separately for each volcano. In fact, each risk factor has different implications, and, therefore, it is important to assess their specific contribution to the final risk ranking. Unlike previous rankings that only assess hazard and exposure parameters, this VRR strategy integrates hazard, exposure, vulnerability, and resilience for each volcano. Whilst the reviewer is correct in stating that the distribution of elements in the flanks of the volcano may not be homogeneous and that resilience can strongly change from one community to another, this VRR strategy accounts for the first appearance within a certain radius around the volcano. It is therefore independent of the spatial distribution, a limitation that could be addressed in future works.

The original section 5.1 has been removed and redistributed across the introduction, methods and results to provide conceptual definitions of active and potentially active volcanoes as suggested.

We clarified that our regional map of the CVZA provides a first step to quickly identify target areas that require a more detailed risk analysis and could be a helpful approach for stakeholders. We also better explained some key assumptions of the VRR strategy. For example, we explained that the analyzed elements at risk consider population, residential buildings and critical infrastructures potentially exposed within four radial distances (i.e., 5, 10, 30 and 100 km). These radii have been considered as they cover the most susceptible area to the impact of the different types of hazards (e.g. PDCs, lahar, tephra). In addition, the vulnerability factors help to differentiate volcanic systems with equal or similar threat, while the resilience factors allows to highlight volcanoes that require the implementation of risk reduction strategies. Finally, we better explain that we used previous catalogues and found the best agreement for the whole CVZA, rather than making our own classification of active and potentially active volcanoes.

Conclusions were expanded with a final paragraph summarizing why it is important to rethink volcanic risk classifications at the regional level. Indeed, we encourage the use of volcanic risk ranking at a regional level to highlight critical aspects. As an example, most CVZA volcanoes are located within less than 25 km from an international border and at least 20 of them are sharing borders. Consequently, a wide diversity of elements at risk might be affected in case of an eruption, which need to be treated at multiple spatial and temporal scales. Finally, regional volcanic risk assessments are needed to analyze the level of preparedness especially in the case of cross-border volcanoes. We, therefore, hope that our work motivates further collaborative studies and promotes cooperation amongst CVZA countries.

- **Comment 1:** *Line 28: It is perhaps inappropriate to begin the paper by stating that it is "one of the most active areas in the Andes" compared to other volcanic zones, as its main characteristic is instead that it is an area that encompasses "a number of previously unrecognized, geologically young, potentially active giant ignimbrite centers and caldera systems, both in the Central Andes" (Stern, 2004), along the border of these countries. Moreover, the importance of the CVZA can be underlined by the fact that it has the "long record of voluminous silicic pyroclastic activity' associated with these giant systems 'has important implications for the safety of several major cities near the mouths of Andean canyons" (Stern, 2004, p.164).*

  Response: We have modified the introduction to include specific features of the CVZA and facilitate the reading of the manuscript (lines 36-46).

- **Comment 2:** *Line 29: In addition to the transboundary nature of this volcanic area, the socio-cultural and geographical composition that existed (and exists) prior to the states' formation and the area's transboundary nature is also important. The volcanic areas of this zone are characterised by being ancestrally and historically inhabited (but not only) by indigenous populations (Aymara, Quechua, Licanantay, etc.), and some authors have already studied this aspect in relation to volcanic risk (Melcher 2004; Romero & Albornoz, 2013; Petit-Breuilh, 2016; Ramos & Tironi, 2022; among others). Therefore, I suggest starting the introduction by mentioning that the central volcanic zone has been inhabited for centuries, even before the division of borders. Both qualities today involve "significant socio-cultural and cross-border challenges". Including this kind of background will bring this work on volcanic risk to the Earth and social science audience as well.*

  Suggested references:
  Melcher, G. (2004). El Norte de Chile: su gente, desiertos y volcanes. Editorial Universitaria.

  Romero, H., & Albornoz, C. (2013). Erupciones volcánicas, en Chile-La educación de los jóvenes en Putre. Retratos da Escola, 7(13), 513-527.

  Petit-Breuilh Sepúlveda, M. E. (2016). Volcanes fronterizos en América Latina y la importancia de los comités de frontera en casos de desastre: Chile y Argentina en el siglo XX. Clima, desastres y convulsiones sociales en España e Hispanoamérica, siglos XVII-XX.

  Ramos, S., & Tironi, M. (2022). An Inside Sun: Lickanantay Volcanology in the Salar de Atacama. Frontiers in Earth Science, 10, 909967.

  Response: Thank you very much, we have incorporated your suggestion and references (lines 59-63).

- **Comment 3:** *Lines 59-60: The objective is missing in the introduction. I suggest stating the main objective of this work, what VRR's most relevant findings were, and why it is considered necessary to use it as an approach or method for the CVZA. This will give the reader an idea of how this new ranking differs from others.*

Response: Thank you for this suggestion, we modified the last paragraph to make the objective clearer and included our most relevant findings (lines 101-106).

- **Comment 4:** *Line 112-113: The choice of parameters would need to be justified, and whether it implies the presence of all 3 types of signals simultaneously or at least one of the three.*

  Response: It implies records of all three types of unrest signals, it is clarified now thank you (lines 242-244). The choice of this criteria is discussed in section 5.2 (lines 367-379).

- **Comment 5:** *Lines 121-122: While the reader is asked to refer to the supplementary material for information on these concepts, the definition of Hazard and Resilience must be mentioned at least once in this part of the Methodology. They are the central elements of this new approach to risk ranking that the authors are trying to promote and should be present.*

  Response: For clarification, we have included the definitions of hazard, exposure, vulnerability and resilience in the Introduction (lines 80-82 and 92-94).

- **Comment 6:** *Lines 260-261: Could the authors explain the relevance of assessing each factor for each volcano? For example, it is not very clear that Misti tops the ranking of Normalized Exposure and Resilience simultaneously. On the other hand, it also needs to be clarified to determine a value (of H, V, E, R) for a volcano as a unit because depending on the distribution of the population in different flanks or sectors, it will vary. Finally, the authors need to mention how resilience is associated with a specific volcano, as resilience is the human or social characteristic within the formula, so there would be more or less resilient groups or villages around volcanoes. Moreover, resilience alone does not reduce risk; it must be associated with vulnerability reduction.*

  Response: Each risk factor has different implications in terms of ranking, and therefore, an independent analysis provides an overview of the weight of each factor. The maximum hazard score represents the highest intensity of each volcanic process; the maximum exposure score is the largest quantity of elements prone to be affected; and the maximum vulnerability score, represents the highest level of susceptibility to damage or loss. In contrast, the maximum resilience score represents the maximum level of capacity to face or overcome a disaster (lines 261-264). In the case of Misti volcano, for example, it stands in the tops of the rankings of Normalized Exposure and Resilience simultaneously since its exposure parameters have (relatively) the largest quantity of elements prone to be affected, and at the same time its resilience parameters (relatively) sum up the maximum level of capacity to face or overcome a disaster. Unlike previous rankings that assess only hazard and exposure parameters, this new strategy integrates hazard, exposure, vulnerability, and resilience for each volcano as a "whole system" without disregarding the contribution of each risk component. Indeed, one of the major outcomes of this VRR lies in the identification of tipping points linked to each of the 41 parameters to reduce future risk.

  Whilst the reviewer is correct in stating that the distribution of elements in the flanks of the volcano may not be homogeneous; and that resilience can strongly change from one community to another one; this VRR strategy accounts for the first appearance within a specific

radius around the volcano and hence, assuming a homogeneous distribution. The analysis of the spatial distribution of the different groups or communities around volcanoes and their vulnerability and resilience are aspects that can be explored when carrying on a very detailed analysis at local scale.

- **Comment 7:** *Line 282: This whole paragraph corresponds rather to a theoretical or conceptual framework and should therefore be placed in the Introduction, for example as subheading 1.1 "Definitions of active and potentially active volcanoes".*

  Response: Thank you for this suggestion, this entire section has been removed from the discussion and moved to the introduction (lines 65-78) and methods (lines 152-161).

- **Comment 8:** *Lines 301-302: This is a good sentence to start the discussion, taking up the problem addressed in the paper.*

  Response: Following the suggestions from reviewer 1 and 2, the original section 5.1 has been deleted and we moved this sentence to methods (lines 152-154).

- **Comment 9:** *Line 345: Here, it is mentioned that the regional mapping carried out can contribute to further risk analysis. Do the authors consider that they are already providing a risk analysis with these results and the method applied? If yes, it should be mentioned. On the other hand, "the VRR method provides an in-depth risk analysis", but some interpretations by the authors on the combination of the 4 factors are missing, apart from those done individually. I recommend then to improve this part of the discussion to mention "What is the risk for the different segments of the central volcanic zone?" or "Why does the identification of active or potentially active volcanoes not considered in other classifications contribute to a better understanding of CVZA risks?"..*

  Response: We have rephrased the sentence to make it clearer (lines 341-343). We also incorporated some interpretations on the VRR implications (345-356).
  Regarding the second part of this comment: "Why does the identification of active or potentially active volcanoes not considered in other classifications contribute to a better understanding of CVZA risks?". We have incorporated some aspects in the conclusions (lines 540-550).

- **Comment 10:** *Line 378: (Fig. 6a-b)?.*

  Response: Modified thank you (line 397).

- **Comment 11:** *Lines 393-394: This idea is central to the paper. The authors should emphasise that they are interested in demonstrating the value of assessing risk on a regional scale and that, in the event of an eruption of CVZA volcanoes in a border zone, this type of "regional" risk analysis can significantly aid collaboration between countries in managing a volcanic emergency that may affect their populations (in different ways probably, e.g., tephra fall or PDCs)..*

Response: Thank you we incorporated your suggestion in the conclusions.

- **Comment 12:** *Lines 486-487: What are the riskiest volcanoes in the CVZA? The authors could mention the 5 or 10 most risky volcanoes (or a number they consider appropriate) in the conclusion without breaking them down again by factor or element.*

  Response: As explained in the comment 6, we believe that each risk component contributes in different ways to the VRR. For this reason, we still prefer to mention the top 5 risky volcanoes specifying whether they come from the VRR-1 or VRR-2 because they highlight different aspects, and the choice of the approach depends on the scope of the user. The discretized analysis of each approach highlights the relevance of resilience (VRR-2) aiming to identifying volcanoes which might require the implementation of mitigation and response measures or its increase.

- **Comment 13:** *Finally, it would be ideal to conclude why it is important to rethink volcanic risk classifications (in this case, at the regional level), and how this could reflect DRR and mitigation measures tailored to the regional reality of the area: an area with very explosive volcanoes, with volcanoes whose history is partially unknown and may be potentially active, and with diverse populations around them that indeed share some socio-cultural and economic characteristics because they have been there since before the division of borders. Finally, because some of these volcanoes are located on the border, it is necessary to rethink the volcanic risk of the Central Andes at a regional level.*

  Response: Thank you very much, we have incorporated your suggestion (lines 552-560).