RC1: 'Comment on nhess-2021-336', Anonymous Referee #1, 03 Dec 2021 reply

Reply to Referee # 1

This study explored the impact of forest cover dynamics, roads and mining activities on the occurrence of landslides in the study area. The results showed that susceptibility patterns and area distributions are different between old and recent deep-seated landslides, and natural factors contributing to their occurrence were either different or changed over time, additionally, the forest dynamics and the presence of roads play a key role in their regional distribution pattern. I enjoyed reviewing your paper and believe it contributes to assess landslide susceptibility/risk for the local government. I have made comments in the hopes that they will be useful to improve the manuscript.

The authors thank the reviewer for his/her assessment of the study's contribution to understanding landslide susceptibility/risk at the regional scale.

General comments:

1. The abstract should be simplified, and it is the embodiment of the core of the article, so you can delete descriptions that are not very important. In addition, I suggest that research methods of article can be added in the abstract.

We will simplify the abstract and, in the meantime, ponder the fact that adding methodological information is not contradictory to the request for simplification. We believe that the originality of our research lies more in the understanding of the slope processes rather than in the methods used for their investigation.

2. In the introduction, you should be added some contents: (i) background information on the hazards of landslides, (ii) the methods of landside susceptibility, and you can analysis the advantages and disadvantages about different methods, (iii) influence factors of landslide should be listed and analyzed based on the previous achievements, especially in the study area or similar area, (iv) you can simplify some contents, such as lines 60 – 75.

We agree with the comment and will include additional relevant information in this section. (i) With regard to the general background information on the hazards of landslides, we believe that the reviewer refers to the temporal aspects of the landslides. We will improve the content of the introduction that deals with this issue. Note that in that respect, lines 60-75 are relevant (iv). Since this paragraph is also key to support the compilation of the inventory, i.e. one of the key originalities of our research, we will avoid simplifying this section too much. (ii) Numerous susceptibility analysis methods have been used in the recent literature, with, as a common goal, the comparison of these methods. This has been extensively described by authors such as Reichenbach et al. (2018) who focus well on showing the advantages and limitations of each. Our study does not aim at evaluating the performance of one method or another but rather to determine the predictors related to the occurrence of the different types

of landslides studied. We therefore believe that expanding on this in the introduction is not relevant. Nevertheless, we will make sure that the fact that we will rely on a susceptibility assessment is understood before the presentation of the objectives. We will also include additional information on landslide susceptibility assessment to further support our methodological choices in the method section. (iii) The factors of landslide occurrence are described in the methodology and are those used in similar environments but notably in our study area. Nevertheless, the study opted for a selection of variables having a real supposed significance in the occurrence of a particular type of landslide. And it is one of the recommendations of the study to take into account these aspects in the selection of predictive variables supposed to contribute to their occurrence. We will make sure that that background information on this methodological approach is provided in a logical way. (iv) We will consider simplifying this section.

3. In the section 1.1, you can further analyze the relationship between LULC, population and landslides, because the article results showed that the forest dynamics and the presence of roads play a key role in their regional distribution pattern.

The relevance of the remark is well taken in consideration. This aspect will be further developed in the section.

4. Authors have chosen 10 predictor variables use for the landslide susceptibility by applying different method, however, the triggering factor may be very difference for the shallow landslide and deep-seated landslide, and the assessment result will be changed, have you ever thought about that? If you considered, and you should be list evaluation factor for different landslide type.

This study did not investigate the triggering factors in a direct way. For the shallow landslides, Dewitte al . (2021) demonstrate that all the observed hillslope instabilities during the last 2 decades are associated with rainfall. The research having been carried out in a data-scarce environment where timely access to information on the triggering of landslides is very difficult and where rain gauge information is also very scarce, an analysis of the triggering conditions could only be done over a region that is much larger than our study area using rainfall satellite products with a km-scale spatial resolution (Monsieurs et al., 2019a; 2019b). For a much larger area than our study area, Depicker et al. (2021b) also show the role of triggering rainfall in the spatial distribution of shallow landslides through the use, as rainfall data, of a regional climate model providing a resolution of 2.8 km. Considering what has already been done in other published research work and the context of data-scarcity of our study area, further analysis on the rainfall triggering conditions of the landslides would not have been possible at this stage. .

For the deep-seated landslides, a few of them are associated with rainfall events that are at the origin of landslide clusters. However, such information is only available for a limited number of recent landslides. For the very large majority of the deep-seated landslides, the triggering aspects can only be assumed, going from seismo-tectonic aspects to weathering and climatic controls (Dille et al., 2019; Dewitte et al., 2021). This information is already described in section 1.1.

We will make sure to make it clearer that the purpose of this research is to look at the susceptibility of the landslides, not at their triggering directly. Nevertheless, the difference of predictor variables for both shallow and deep-seated landslides highlighted through the susceptibility analysis allows to discuss triggering conditions (see section 4).

5. Fig 7a and 7b presented the shallow landslide susceptibility and old deep-seated landslide susceptibility, author have analyzed the reason of differences, however, the results of fig 7a and 7b were also similar in a certain, you should be further explained.

This is a relevant remark for which we will add the information about the aspects of similarities for both models.

6. The distribution of different landslide was presented in the figure 8, meanwhile, authors should be further analyzed the reason.

Some lines will be added for further explanation.

7. In the section 4.3, authors have said rainfall is the trigger of the shallow landslides that we have identified in this study, and the reason explanation was lacked, however, this part have discussed that anthropogenic factors have an obviously effected on landslide, so you need further analyzed the relationship between shallow landslide and rainfall.

In one of the above replies, we explain why the analysis of the rainfall as triggering factor is not possible in our research due to a lack of information (landslide dates, rainfall data) and the limited size of the study area. This is the reason why the triggering analysis could only be performed over a much large region than ours (Monsieurs et al., 1019a, 2019b). Nevertheless, we will highlight this issue better.

Minor comments:

1. Lines 95-100 or 205: you can draw a figure about the change of LULC in the different years.

This study considers the LULC on the long-term and, as said line 210, completes the study by Depicker et al. (2021b) who analysed the deforestation over the last 20 years and its impacts on landslides. We will explore if adding a figure on known LULC changes is relevant here since this is not the objective of our research.

2. Line 110: you can draw a figure about population density or the change of population.

There is very little information on the spatial distribution of the population characteristic. For example, the information from the spatially explicit Global Human Settlement Layer46, which is provided for four years: 1975, 1990, 2000 and 2015, is relevant for regional analysis. The data are available at: http://ghsl.jrc.ec.europa.eu/. The gridded data are the result of detecting the built-up land in satellite imagery and subsequently calculating the average population density per built-up pixel (at a 30 m resolution) by means of regional/national census data. However,

when looking a specific locations like our region, it shows some discrepancies. We will see to what extent adding a figure on the population is relevant. We may provide extra quantitative information depending on the quality of the available datasets.

3. Lines 155- 160: add the website of different source data.

We will add the references of these different data sources.

4. Line 175: you can read the relevant references about landslide types, sush as Varnes, 1984; Cruden and Varnes, 1996; Hungr et al., 2014, and it may be better for your research.

We are aware of these relevant references on the types of landslides according to the movement and the materials mobilized; in our research we make reference to Hungr et al. (2014).

5. The section 2.2 may be put into section 1.1, you can check it.

Since the reconstruction of the forest cover dynamics is a key element of this study; bringing new results, we believe that it should be included in a separate section of the materials and methods.

6. Lines 300-3015: you can simplify.

We will make these lines clearer.

7. The format of Table 3 should be nice.

We will arrange this table better.

8. Lines 530-545: authors have discussed the difference between Van Den Eeckhaut's achievements and this study, and this is well. If you can add others' achievements that is in similar area or nearby the study area, and it may be better.

We will consider the relevance of the remark with further documentation. However, to our knowledge, there is no other study of this kind in an area similar or nearby to ours.

9. I suggest that the previous achievements (similar results or research) should be added, and they can abundant your research in the section 4.1-4.4.

As best as we can, we have documented our discussions with relevant studies conducted in the tropical and mountainous context. And the previous work of our research teams has been documented in sections 4.1-4.4 as well. We will explore the very recent literature to see to what extend other achievements could help to support our discussion.

References

Depicker, A., Jacobs, L., Mboga, N., Smets, B., Van Rompaey, A., Lennert, M., Wolff, E., Kervyn, F., Michellier, C., Dewitte, O. and Govers, G.: Historical dynamics of landslide risk from population and forest-cover changes in the Kivu Rift, Nat. Sustain., 4(11), 965–974, doi:10.1038/s41893-021-00757-9, 2021a.

Depicker, A., Govers, G., Jacobs, L., Campforts, B., Uwihirwe, J. and Dewitte, O.: Interactions between deforestation, landscape rejuvenation, and shallow landslides in the North Tanganyika–Kivu rift region, Africa, Earth Surf. Dyn., 9(3), 445–462, doi:10.5194/esurf-9-445-2021, 2021b.

Dewitte, O., Dille, A., Depicker, A., Kubwimana, D., Maki Mateso, J.-C., Mugaruka Bibentyo, T., Uwihirwe, J. and Monsieurs, E.: Constraining landslide timing in a data-scarce context: from recent to very old processes in the tropical environment of the North Tanganyika-Kivu Rift region, Landslides, 18(1), 161–177, doi:10.1007/s10346-020-01452-0, 2021.

Dille, A., Kervyn, F., Mugaruka Bibentyo, T., Delvaux, D., Ganza, G. B., Ilombe Mawe, G., Kalikone Buzera, C., Safari Nakito, E., Moeyersons, J., Monsieurs, E., Nzolang, C., Smets, B., Kervyn, M. and Dewitte, O.: Causes and triggers of deep-seated hillslope instability in the tropics – Insights from a 60-year record of Ikoma landslide (DR Congo), Geomorphology, 345, 106835, doi:10.1016/j.geomorph.2019.106835, 2019.

Hungr, O., Leroueil, S. and Picarelli, L.: The Varnes classification of landslide types, an update, Landslides, 11(2), 167–194, doi:10.1007/s10346-013-0436-y, 2014.

Monsieurs, Dewitte, Depicker and Demoulin: Towards a Transferable Antecedent Rainfall—Susceptibility Threshold Approach for Landsliding, Water, 11(11), 2202, doi:10.3390/w11112202, 2019a.

Monsieurs, E., Dewitte, O. and Demoulin, A.: A susceptibility-based rainfall threshold approach for landslide occurrence, Nat. Hazards Earth Syst. Sci., 19(4), 775–789, doi:10.5194/nhess-19-775-2019, 2019b.