Review of

On the nexus between landslide susceptibility and transport infrastructure – agent-based vulnerability assessment of rural road networks in the Eastern European Alps

by Matthias SCHLÖGL, Michael AVIAN, Gerald RICHTER, Thomas THALER, Gerhard HEISS, Sven FUCHS and Gernot LENZ

Dear Authors,
Dear Editor,

I have reviewed the aforementioned manuscript (nhess-2018-93). The paper presents an agent-based vulnerability assessment of rural road networks in the Federal State of Vorarlberg, Austria. Therefore, approaches for the generation of landslide susceptibility are combined with transport network analysis.

In my opinion, the authors provided a very interesting study, with a largely novel approach to assess the impact of landslides on transport infrastructure in Vorarlberg. However, the paper owes in some parts of methodological details and awakes some ambiguities to the reader.

Based on the aspects I found when evaluating the manuscript, I suggest to consider the manuscript for publication after revision by the authors.

With kind regards

Elmar M. SCHMALTZ

Scope

The topic of the study is within the scope of the journal '*Natural Hazards and Earth System Sciences*'.

General structure

The authors structured the manuscript very well. I believe the study area should be explained more in detail, either in the Introduction or in the Methods.

Content

Title

The title summarises the content of the research in a good way.

Abstract

In my opinion, the introductory part of the abstract (P1 L1-5) is too long and could be shortened to a concise sentence that directs to the research gap and the aim of the paper (P1 L6-8).
Furthermore, I believe that the results should be presented already in the abstract in a more quantitative and discussable way (P1 L17-19), leading to a closing sentence that states the key findings of the paper.

P1 L8: '*[...] landslide events*', not '*[...] landslides events*'.

P1 L12: '*derivates*' is the verb. '*Derivatives*' would be the noun.

Introduction

The introduction embeds the research into a very broad methodological and ethical context about impacts of hazards on transport systems. I do not disagree with this, however, I suggest that the authors sharpen their scientific purposes on landslide hazards and do not divagate too much into rather remotely related hazard fields (hurricanes, terrorist attacks). A connection to these fields, e.g. as application of the presented techniques and methods on those different hazards, could be given in the outlook of the study. I believe the introduction would benefit from the following structure:

(1) Introduction to transport network systems and transport network vulnerability

(2) Introduction to all kind of landslide hazards that can affect transport networks and how they can affects them in terms of topological and system-based vulnerability

(3) Introduction to the situation in Austria with focus on Vorarlberg (why was particularly Vorarlberg chosen as a study site?)

(4) Statement of the research gap, the hypothesis and related (methodological) research questions

It is up to the authors, where to present the geomorphic and infrastructural peculiarities of Vorarlberg (either in the Introduction or the Methods part). Although this paper can be considered as a methodological one, at its present form it lacks of information about the specific situations in Vorarlberg, regarding landslide dynamics and transport networks.

P2 L2: If '*Transport networks*' is plural, then '*its*' should be '*their*'.

P2 L7: The authors mention '*a growing amount of studies*' that deal with the impact of natural hazards on roads, however, only three studies are referenced, albeit there are certainly many more. I would suggest to provide more references, at least for landslide studies that underline the purposes of this paper.

P2 L11: From a geomorphological point of view, a '*complex landscape*' does not necessarily have to be steep – just a minor comment...

P2 L14-15: What are '*reliable networks*' in this context? In general, this sentence is relatively hard to understand from my point of view.

P2 L14-20: This can be shortened to a single, concise sentence.

P2 L21-30: The aim of the paper is '*[...] to present how road infrastructure is vulnerable towards landslides [...]*'. In this paragraph, however, the authors somehow begin to embed their research into prior assessments of transport network systems that were affected either by terrorist attacks or supra-regional or national effective natural hazards like hurricanes. Even though I see the slight connection here, I am strongly suggesting to focus on what was already proposed in the abstract, which is an assessment of the impact of landslide on transport networks in Vorarlberg.

P3 L13-15: Which means it is related to (1) topological vulnerability analysis? If yes, it should be clarified explicitly.

Data and methods

The first subsection of section 2 (2.1 Modeling landslide susceptibility) should be restructured in a way that it follows a more logical order. The description of landslide inventories and the necessities of their compilation should be explained at first. The computation of susceptibility maps that emanate from the inventories, including the incorporation of DTM-derivatives as predictor variables within the modelling procedure, should then subsequently follow. Generally, some paragraphs appear to belong rather in the introduction part than in the methods part (e.g. P5 L4 - P7 L16). The description of the derivatives may be read like a textbook. I suggest to specifically state why these derivatives were chosen as predictors to generate the susceptibility map, with a clear focus on their geomorphic reasonability for landslide initiation. Furthermore, please explain in detail which methods were applied to compute the landslide susceptibility and provide a short description of these methods. If solely the 'Gefahrenhinweiskarte' of the Federal State Vorarlberg was used, then the authors should explicitly state that in the methods part, otherwise it is not clear to the reader if a susceptibility map was generated or an existing one was used.

P5 L2: '*of of*'

P5 L26: Since the authors refer here to regional landslide inventories and landslide susceptibility analysis, I suggest to replace '*Schmaltz et al., 2016*' with

Schmaltz, E. M., Steger, S., Glade, T. The influence of forest cover on landslide occurrence explored with spatio-temporal information, Geomorphology, 290, 250-264, https://doi.org/10.1016/j.geomorph.2017.04.024, 2017.

since a more complete landslide inventory was used.

P6 L8: It is mentioned that the landslide inventory differentiates several process groups. Which are they? Are all kinds of landslides considered (soil creep, debris flows, rockfalls) or only those of the slide-type movement? The landslide process, which is considered in the inventory should be specified in order to understand the susceptibility map.

P6 L9: '*1178 landslide were available*': Are they equally distributed? Are there any (systematic) biases that the authors detected or expected within the dataset?

P6 L11-12: Please specify the classification of the different geological units. Which of the units were considered as similar according to their lithological and geotechnical characteristics? Did the authors also distinguish between the landslide process that can be induced by different lithologies in Vorarlberg (e.g. rather steep walls in sand- or limestones in the Montafon, Rätikon, Walgau and Großwalsertal (etc.), prone to rockfalls; claystones, marls (Walgau, Bregenzer Wald, Pfänderstock) and Molasse (Doren), prone to slides; etc...)?

P6 L17: Which ALS-DTM was used? 2004? If yes, why did the authors not consider the ALS-DTM of 2011, since there were remarkable changes of both landslide dynamics (e.g. triggering event of 2005) and infrastructural development on landslide-prone hillslopes.

P6 L18: The grid sizes are confusing me. Which one was used, 5 m or 10 m? If latter, then please correct on P6 L1, or further explain why the resampling procedure was performed as mentioned in the manuscript.

Results

In parts, the results section reads like a mix of methods and discussion part (e.g. P9 L30 - P11 L19), I believe the authors should be much more quantitative in presenting their results and shift any interpretation into the discussion part.

P11 L5: Syntax ('*[...] and landslide areas and are [...]*')

P11 L10-11: How did the authors deal with the detected inventory incompleteness mentioned in the manuscript?

P11 L12: Syntax ('*[...] used needs [...]*')

P11 L12: A 50 m buffer around points that mark locations of landslide initiation introduces a large systematic error (that obviously already exists in the inventory) to the modelling procedure. The authors should justify i) why they chose such a large radius and ii) how they believe that they can still ensure geomorphic plausibility of their approach.

P11 L26: What landslide susceptibility value did the authors expect?

P11 L29-31: I believe this statement should be justified quantitatively, since no quantitative measures or values were provided by the authors that indicate a reasonable accuracy.

Discussion

P16 L3-5: These are two crucial points for assessing the reliability of the susceptibility maps. Although the authors identified these drawbacks, I suggest to add information on how they cope with the resulting susceptibility maps and in which way their results have to be evaluated by the reader.

P16 L6-8: Even though the geological map might be too coarse for a reliable susceptibility analysis, the authors mentioned that they were able to detect incident points along the traffic network. If geology is believed to be of central importance for landslide susceptibility*, then incident points could be detected with the rough geological map and susceptibility could be re-computed using the more detailed maps for areas where they are available.

*From my point of view, the lithological underground is a discussable predictor, since the lithological setting in Vorarlberg largely determines the topographical situation, meaning that for instance sandstone facies are responsible for steep terrains in the flysch zone, marly substrates for shallower slopes. Thus, the inclusion of slope steepness as a predictor variable might be already enough in order to avoid systematic biases in the modelling procedure. In my opinion, soil material plays a more important role and should be rather considered as predictor compared to geology. However, this is only my personal opinion that I thought be worth to mention here.

P17 L9-10: Is this always true for all rural areas throughout the year? I am thinking of locations for winter sports, which are frequent in Vorarlberg (Montafon, Bregenzerwald, etc.). Would not these areas might be also quite frequently accessed via roads and enhance an element at risk, particularly in early spring, where snowmelt occurs but winter sport tourism is still active?

Conclusions

P19 L8-9: The authors should provide information, which of the analysed transport systems or roads (according to their applied classification) are mostly prone to landslides. Additionally, the temporal differences at which time each type of road is mostly vulnerable would be interesting.

Style and formatting

Text

Besides some typing and syntax errors, the text is written in good English and easy to read.

Figures and tables

Fig. 1: A small overview map of Austria with indication where Vorarlberg is located would be helpful for readers that are not familiar with the Alps.

NHESS specific review criteria

1. Does the paper address relevant scientific and/or technical questions within the scope of NHESS?

   Yes.

2. Does the paper present new data and/or novel concepts, ideas, tools, methods or results?

   Yes. The analysis of transport network vulnerability towards landslides by means of agent-based modelling as it is performed in the present study depicts a novum.

3. Are these up to international standards?

   Yes.

4. Are the scientific methods and assumptions valid and outlined clearly?

   The manuscript owes a more detailed description of the landslide susceptibility analysis performed.

5. Are the results sufficient to support the interpretations and the conclusions?

   Partly, the conclusions do not necessarily reflect the findings. This is largely due to lack of quantification of the results.

6. Does the author reach substantial conclusions?

   Although it is announced in the abstract, the authors did not provide hints for decision makers based on their findings.

7. Is the description of the data used, the methods used, the experiments and calculations made, and the results obtained sufficiently complete and accurate to allow their reproduction by fellow scientists (traceability of results)?

   The methods applied partly lack on details and do not make it possible to reproduce similar results in the same way as it is presented in the manuscript.

8. Does the title clearly and unambiguously reflect the contents of the paper?

   On the whole, yes.

9. Does the abstract provide a concise, complete and unambiguous summary of the work done and the results obtained?

   The findings, interpretations and resulting conclusions should be expanded in the abstract.

10. Are the title and the abstract pertinent, and easy to understand to a wide and diversified audience?

    Yes.

11. Are mathematical formulae, symbols, abbreviations and units correctly defined and used? If the formulae, symbols or abbreviations are numerous, are there tables or appendixes listing them?

    No equations can be found in the manuscript.

12. Is the size, quality and readability of each figure adequate to the type and quantity of data presented?

    Yes. However, more concise figures would support and visualise the described results in a better way.

13. Does the author give proper credit to previous and/or related work, and does he/she indicate clearly his/her own contribution?

Yes.

14. Are the number and quality of the references appropriate?

    Yes.

15. Are the references accessible by fellow scientists?

    Yes.

16. Is the overall presentation well structured, clear and easy to understand by a wide and general audience?

    Yes.

17. Is the length of the paper adequate, too long or too short?

    It could be shortened at some parts by replacing text passages that appear to be not very comprehensive (details provided in the review).

18. Is there any part of the paper (title, abstract, main text, formulae, symbols, figures and their captions, tables, list of references, appendixes) that needs to be clarified, reduced, added, combined, or eliminated?

    Explanations are given in the detailed review.

19. Is the technical language precise and understandable by fellow scientists?

    Yes, except of minor syntax and typing errors.

20. Is the English language of good quality, fluent, simple and easy to read and understand by a wide and diversified audience?

    Yes.

21. Is the amount and quality of supplementary material (if any) appropriate?

    There is no supplementary material provided.