Review of NHESS-2017-461 McAdoo *et al.* Roads and Landslides in Nepal V2

Overview:

This paper presents interesting analysis of the interaction between informal road building and landslide occurrence in Nepal from a statistical perspective. There is little in the literature using methods like this, and I believe there is merit in the approach, so there would be real value in bringing this into the literature in a scientifically evidenced way. The paper has changed considerably since the first submission, with addition of figures and longer text. Because of the considerable difference between the first and second submissions, I have reviewed the paper thoroughly as if it were a first submission. I am keen to see the paper published, and understand the authors' wish to contribute to the debate on this timely topic. However, this cannot come at the cost of scientific rigour and use of evidence, which needs further work. I support the authors' comment that this is a collaborative piece of work with Nepali colleagues where issues of capacity and incentive to publish are a challenge. However, I believe this makes it all the more pertinent to publish a scientifically rigorous and evidenced piece of research that becomes widely cited.

The paper has three key areas for improvement which I outline below, followed by a list of minor revisions which link into these key points. In the previous response to reviewers, each comment was not addressed individually, which made it hard to follow the link between each comment and the action taken. I would appreciate it if each of my comments could be responded to individually, including my original comment in text. To aid this, I have numbered my comments. In the next revised version, I would appreciate it if the authors could use line numbering, as it has made it difficult to indicate precisely where I am commenting.

General comments:

AR1: Being specific and evidencing. The style of writing is somewhat informal and conversational. Rather than saying 'thousands of landslides', stating that your results are 'compelling' or saying a concept is 'well known', be specific, give exact numbers and let the results speak for themselves. There are numerous statements made with no reference to the literature, and only 11 peer-review pieces of research in the reference list. There are several places in the text where the implication is that the reader should go away and read another paper to understand what has been done here. Particularly for a readership from the Global South, it may not be possible to access these papers, and more generally makes it difficult to replicate the results. The authors must demonstrate that their research builds upon a body of evidence by citing existing literature and making closer links to this literature.

AR2: The landslide inventory used. The authors state a preference to use an inventory of landslides created by Nepali colleagues that is within the peer review literature, which is understandable. However, publication of an inventory is not the only criteria to ensure an inventory is suitable for the type of analysis performed on it. See Guzzetti *et al.* (2012) for a review of issues around landslide inventory production. The authors must give more detail on the inventory production methods to indicate that this is statistically robust for the type of analysis they are doing. Other highly cited papers performing statistical analysis of landslide inventories (e.g., Stark and Hovius, 2001; Malamud *et al.*, 2004) describe in considerable detail the previously published inventories they use. The item that concerns me most about the inventory you use is that there is no indication of time scale given for the landslides mapped pre-earthquake. Smaller area landslides tend to be erased from the landscape more quickly than larger area landslides, so it is difficult to make interpretations about the area and spatial distribution of these landslides without assurance that this is a substantially complete inventory.

AR3: Replicability of methods. The Monte Carlo simulation method is interesting, but not all of the NHESS readership will be familiar with this methodology. Indeed, I am familiar with Monte Carlo methods but could not replicate your analysis without further information about how you generated the random landslides. Neither am I convinced that a completely random distribution of landslides is appropriate for comparison, as real-world landslide locations are conditioned by many factors. There appears to have been no consideration of the number of Monte Carlo simulations required to be statistically robust. Overall, it remains difficult for me to fully comment on the methodology as it is still somewhat vague.

Specific comments:

AR4: Road data. Throughout the paper, it is not entirely clear how you make the distinction between formal and informal roads in a systematic way. At times, it is implicit that informal roads are funded by foreign investment. I suggest in the introduction to more explicitly explain what these informal roads are and how you distinguish them. I also see that in

the response to reviewers, you have stated that you are confident that the OpenStreetMap data for this region is robust and you performed some testing of this. If this is the case, state it in the paper and give more detail.

AR5: Figure 1

- Are these images all the authors' own?
- "Deeper seated landslides that are accommodates by" typo.
- Each figure should be labelled 'A', 'B', 'C', 'D' and then the top right figure relabelled I, II, III or something similar. This makes it easier to refer to the figure in text and easier for the reader to quickly distinguish between descriptions.
- Top left figure. This is an interesting diagram. This should be made into a separate figure and enlarged. It also needs to be clearer what the basis for this figure is in terms of evidence. Give some indication why this is a complete set of possible landslide types near informal roads.

AR6: Paragraph starting 'Many villages in the Middle Hills region'. First sentence needs some supporting evidence.

AR7: DesInventar. Although DesInventar is a useful source of data, it has methodological biases which are key when interpreting results. I would suggest briefly describing that DesInventar records primarily come from media sources, so may be biased towards particular locations. I would also suggest giving slightly more detail for the in-text citation, e.g., DesInventar Nepal Database.

AR8 Method paragraph 1

- Without some indication of timescale and the inventory used, it is not convincing to state that landslides mapped pre the Ghorka earthquake are all triggered by the Monsoon. The region was seismically active before 2015, and there are other drivers of landslides aside from over-steepened roads. I suggest introducing the inventory and then discussing what is implicit about it. It may be useful to draw out additional key points from Petley (2007) rather than simply to direct the reader here.
- State why "Landslides generated by the earthquake…respond more to the geomorphology of the landscape" – the mechanism for this is not clear.

AR9: Methods paragraph 2:

- Not entirely clear what you mean by 'discrete' landslides, and how this differs to the landslides triggered by the earthquake
- "The landslide inventories we used was created" – typo – were created?
- Generally more needs to be said about this inventory. Creating an inventory of triggered landslides is not a trivial task. How do we know this is substantially complete? This is important for looking at spatial patterns. One option would be to look at the frequency size statistics of landslide areas and compare to already established distributions.
- Be more specific – how many is 'many landslides'? What percentage is the 'vast majority'
- For mapping landslides pre-earthquake, did you use just one image? If so, what is the date of this image? Can you estimate how many of these were relatively fresh (i.e., seasonal) versus older landslides?
- Landslides (particularly smaller ones) tend to be erased from the landscape over time so I am not convinced about using this 'pre-earthquake' inventory to look at the spatial distribution of landslides, as this may be incomplete. If it is a case that the pre-earthquake inventory is primarily from one season, this might be more reasonable, but needs to be explained.

AR10: Methods paragraph 3:

- The distribution of landslides – state whether you mean spatial, statistical or other type of distribution
- State how you compared the distribution of landslides in your inventory to other earthquake triggered inventories.
- It would be useful for this paper to have a specific section or table on data – state what the sources of all the data are that you are using – e.g., soil types, and give more information about the data you have created (the landslide inventory).
- I see the reasoning that there is more agricultural development in the productive soils, but this needs to be backed up by evidence. There are other data products (e.g., croplands.org) you could use to estimate

agricultural or built-up areas to make this statement more robust. Nepal is also rapidly urbanising, which is a different process that may result in road building around small towns and large villages. I believe this should be considered in addition to agricultural areas as an indicator of human impact on the landscape.

AR11: Methods Paragraph 4:

- Be cautious about stating that the correlation between landslide and road occurrence suggests causality.
- I am not convinced about the comparison of landslides in proximity to the road to a random distribution. Landslide location is conditioned by many factors and I do not believe landslides occur randomly across the landscape, even controlling for the location of roads. As a minimum, this needs further explanation and justification in the paper.
- State the method used to measure whether observed landslides match the randomly generated ones. This is not clear, as the location of randomly generated landslides will be different on each Monte Carlo iteration. State what part of the landslide you measure (centroid? Crown? Toe?) in relation to what (distance to nearest road, count within a buffer of a road?).
- Sentence starting 'the pre-earthquake landslides have a normal distribution' – distribution of what? Size, distance?
- State the resolution of the Google Earth imagery (which is typically sub-metre). I would be surprised if you are missing all but a small portion of the smallest earthquake triggered landslides due to issues of resolution, and believe this may be a result of removal of smaller landslides from the landscape by erosion, revegetation, ploughing etc.
- State how you have performed the curve-fitting of these distributions and tested the goodness of fit.
- Why only 10 runs of the Monte Carlo simulation? See e.g., http://kb.palisade.com/index.php?pg=kb.page&id=125 for a discussion of number of iterations versus confidence intervals.

AR12: Results paragraph 1:

- You did not mention the fieldwork in the methods section, it seems slightly odd to start the results by discussing field observations.
- The second (long) sentence of this paragraph needs splitting and expanding upon. It was not clear from the methods that you focus the analysis on agricultural areas and why this is done.
- What is a 'genetic' relationship?

AR13: Results paragraph 2:

- Why state a range (20-25%) for earthquake triggered landslides occurring within 100m of a road, but no range for pre-earthquake triggered landslides? Be specific rather than stating 'nearly 50%'.
- Not clear why you are discussing the total area of landslides, particularly when the sample size is two orders of magnitude different between the monsoon and earthquake triggered landslides.
- As stated previously, I believe the difference in average area may be due to the difference between analysing a triggered versus multi-temporal landslide inventory. For distributions that span multiple orders of magnitude and are skewed, it may be more appropriate to analyse the mode or median landslide area.

AR14: Figure 3

- Add legend indicating difference between bars and lines
- Add description of sub-figure in the figure caption
- Ensure axes are appropriately labelled in sub-figure. Unclear what has been normalised and why.

AR15: Results paragraph 3

- This paragraph is very conversational in style and needs tightening up, e.g., what is a 'kink in the trend'. Why 'borrow from the fractal literature'?
- This discussion about a 'crossover length' is unclear – explain in the text why one would expect to see a decline in number of landslides at a given distance from the road.
- Generally, the concepts in this paragraph are interesting but need further explanation and possible supporting evidence.

AR16: Results paragraph 4. Give evidence to support the statement that the roads follow river valleys and ravines

AR17: Discussion paragraph 1

- In the methods, state how you systematically separated out informal and formal roads from the OSM dataset
- In the results section, I suggest presenting a brief quantitative analysis of kilometres of road length per soil type to support the statement 'with its good agricultural soils and vast network of informal roads')
- As per comment AR10, in addition to agriculture, urbanisation is another form of development. At present, you imply that good soil is the only control over which areas are developing (and where there are more roads). I believe the language needs adjusting (or analysis also performed on small towns and large villages) to reflect that soil quality is not the only indicator of development.

AR18: Discussion paragraph 2. If something 'is well known', then add citations to support it. More broadly, there are very few references in the discussion to frame your results in terms of previous work done on this topic.

AR19: Discussion paragraph 3. As per AR9 and AR11, the size (or area) of landslides is an area where a lot of work has been done (e.g., Stark and Hovius, 2001; Malamud *et al.*, 2004; Stark and Guzzetti, 2009 amongst others). I believe it is possible that your findings in terms of landslide size may be a result of sampling rather than process necessarily.

AR20: Discussion paragraph 4

- This is a little confusing to introduce the Maoist insurgency here without any prior discussion of the insurgency or its implications for road building.
- Generally in this paragraph, the discussion about correlation between deaths from landslides and increase in road length sounds more like results than discussion, and would benefit from evidencing.
- I am concerned about the use of DesInventar here to imply an indirect link between political regime and deaths from landslides. As mentioned previously, much of the data for DesInventar comes from media reports, and thus has biases. The links between politics and journalism are of course too complex to discuss in detail in this paper, but there needs to be some acknowledgement from earlier on in the paper that DesInventar has biases and this uncertainty acknowledged when discussing DesInventar. I suggest that Aryal (2012) should be read and possibly cited to give some context.

AR21: Figure 4

- Give legend entries titles
- In legend, state deaths from landslides (otherwise it implies total deaths from all causes)

AR22: Conclusions

- Without further discussion in previous parts of the paper, I am not convinced that you are comparing datasets of human versus natural triggered landslides
- Some of the conclusions are introducing new ideas and read more like a discussion

I would like to reiterate that I genuinely found the approach of the paper novel and interesting, which is why I have put a lot of effort into a complete review. My comments primarily relate to better communicating the research and demonstrating that this work has not been done in a vacuum. I look forward to seeing the revised paper.

References Cited:

Aryal, K.R., 2012. The history of disaster incidents and impacts in Nepal 1900–2005. *International Journal of Disaster Risk Science*, *3*(3), pp.147-154.

Guzzetti, F., Mondini, A.C., Cardinali, M., Fiorucci, F., Santangelo, M. and Chang, K.T., 2012. Landslide inventory maps: New tools for an old problem. *Earth-Science Reviews*, *112*(1-2), pp.42-66.

Malamud, B.D., Turcotte, D.L., Guzzetti, F. and Reichenbach, P., 2004. Landslide inventories and their statistical properties. *Earth Surface Processes and Landforms*, *29*(6), pp.687-711.

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