Response to Reviewers on, “Brief communication: Roads and landslides in Nepal: How development affects risk” by Brian G. McAdoo et al.

Dear Faith,

Thank you for your comments on the paper now entitled, “**Roads and landslides in Nepal: How development affects environmental risk**”. Based on your request, we have expanded it to a full research paper, going into more detail with the methodology and analysis of the data. I will leave the previous responses to the reviewers below, with any new information appended in red.

Anonymous Referee #1

Reviewer #1 (RC1) makes some very good comments, and points out some extremely helpful papers that we were not aware of. RC2 suggests that the paper should be expanded past a Brief Communication- while I certainly agree, we feel that the timeliness of this paper with the coincidence of the special issue and the rapid expansion of roads with the ~~One Belt One Road~~ Belt and Road Initiative (BRI) make it quite topical right now, and should get out sooner rather than later with a more thorough treatment (which is indeed underway).

We have agreed to expand it to a full research paper.

RC1 points out that there have been links between roads and landslides have been addressed in the past- while this is indeed true, this paper seeks to point out the heightened need to pay attention to this well-documented phenomenon as the development increases a notch following the end of the civil war and the pressing forward of the BRI. As far as I am aware, this is the first study to compare landslides generated by an earthquake to landslides generated by monsoon rains through a lens of development.

RC1 points out a recent paper by Roback et al. (2018) that mapped coseismic landslides in this region. There are at least 4 different landslide catalogues that I am aware of, and we chose to use the one generated by our Nepali colleagues (Gynawali and Adhikari, 2017) that we have been partnering with since before the earthquake. We find it important to not only include our local colleagues in the paper writing process, but also use the data they collected as a way of building the necessary local capacity. Without entrusting our colleagues to do this critical work and see their work represented in the literature, and having only the work from large, well-funded researchers from overseas recognised, local scientists are actively disincentivised from doing their own research. ~~The methodology is indeed described in their paper, and as this is a Brief Communication, while I hope we can trust the reference.~~ While I would hope we could trust a published reference, we have described the methodology for identifying failures in the text.

On lines 57-59, RC1 asks about the correlation between landslide location and soil type, and specifically mentions the possibility of bedrock failures. We expanded this in the text, noting that the vast majority of slides that we groundtruthed in the field involved only the regolith, we were not able to assess all slides, and our sampling would have been biased as we were traveling along roads. It is exceedingly difficult to identify bedrock failures from satellite data alone. Furthermore, while RC1 is correct that this is a strong correlation, being critical of that fact does not rule out causation. As there will be more landslides (shallow) where there are soils in steep terrain, the soil is weaker than bedrock (which because of climate hasn’t developed soils…), therefore is more likely to fail under the same stressors. This is an observation based on the data as shown in ~~figure 1~~ (now Fig. 2). The distinction of soil type and land use is significant, since nearly all economic activity in this region is agriculture-based, therefore that is where most of the risk is located. Because the sample size of the earthquake (EQ) landslides is large compared to the pre-EQ slides, there are quite a few EQ slides in unpopulated areas, and those might skew the results. As those are not pertinent to the question of development and risk, we cut them out based on the fact that development occurs where there are resources available to support it.

RC1 states that there may be a problem if the landslide areas don’t match the size of the hillslope where they have been randomly placed. I think that they are referring to the possibility that a landslide could be large enough to exceed the size of the hillslope it occurs on (but I am not entirely clear about that). Most slides are quite small as compared to the scale of the topography of the region- we have sought to clarify this by adding an inset to Figure 2 that shows the histogram of the slide areas. We also noted that we did ~~20~~ 10 Monte Carlo simulations for each class of slides (EQ vs. monsoon triggered- thanks for catching that).

RC2 questions if the buffers are cumulative. The buffers are indeed cumulative. For us, this makes it clear that, for example, almost 50% of all random/EQ generated slides are within 450 meters of a road. This also shows that there are a LOT of slides that are not near a road in both datasets (~30% in the case of pre-EQ slides and ~50% of the others). RC1 is right to point out that this wasn’t clear, so we clarified this in the text. However, RC2 makes an excellent point- we added the incremental distribution to the graph in new Fig. 3, and it clearly shows the reason for the overall higher cumulative distribution of slides lies entirely in that there are twice as many monsoon generated slides within 50 m of the road, strongly supporting our hypothesis.

Both RC1 and RC2 raised questions about the Open Street Map data. In response to RC2, the OSM data is remarkably comprehensive- we ground trothed it using both recent Google Earth imagery as well as field observations. For RC1’s question about are they footpaths or bulldozed roads- this is an excellent question, and all I can state is that they are all roads/path large enough to be seen on satellite, hence we assume will have a more significant effect on the physical landscape than smaller, less well-travelled paths. Our Nepali colleagues have since confirmed that these are the roads that are capable of supporting some kind of vehicle. (Now, anyone who has been to Nepal is right to question this!)

RC2 questions the 100 m distance as being considerably wider than the road plus the likely zone of influence on each side. I think it is a bit beyond the scope of this short ~~communication~~ paper to delve into the details of specific slides, but I can assure RC2 that the zone of landsliding can extend hundreds of meters past the road itself- runout zones of debris mobilized during rainfall failures can be kilometers, and retrogressive failures can extend far upslopes. In fact, we were quite surprised to see how more of the EQ landslides didn’t intersect roads!

We were hoping to see that magical peak of landslide occurrence at a certain distance from a road, however the data were not cooperative. As this paper is an attempt to look at the ***risk*** of landslides to exposed communities, not just understanding the physical ***hazard*** that the landslides represent, we feel it necessary to frame the results in the context of how attempts to make communities less vulnerable (economically, socially and physically) by constructing roads is actually making them more vulnerable as far as exposure to landslides hazard is concerned. We will leave it to the social scientists to sort out if the relative gains achieved by constructing roads (along with the iterant landslides) exceed the losses of property and life that comes every monsoon season. Therefore, I would like to keep the analysis, recognizing a shift from hazard focus to a more nuanced and complex treatment of the associated risk.

We agree with the reviewers and the editor that the conclusions did not match the majority of the paper. We have tried to rectify this with more analysis of the data presented while sticking with our goal to highlight how the hazard and the risk to communities are tied together. Here, communities are affecting the hazard, and vice-versa.

Response to Editor

We have agreed with the editor that this paper should be submitted as a full paper rather than a brief communication. As such, the paper is largely rewritten, and many of the comments are addressed in the expanded version. Below, we will endeavour to address the comments, but perhaps less with specifics (line-by-line) and more with the big picture.

Point 1- Further explanation of data and Monte Carlo. We have added a more detailed description of each. The description of the landslides was done by our Nepali co-author (KRG) using a method that was very similar to that described in detail by Roback et al. As we have not seen the Monte Carlo method that we used in this paper described in the literature, we have tried to describe it in sufficient detail for it to be repeatable, but not so much detail so that it drowns the results.

Point 2- The analysis of the results is complicated by the fact that this is not a pure hazards paper. Instead, we seek to see how the hazards affect people and, critically, vice-versa. In this particular case, it is not possible to divorce the two. The analysis we seek to complete is not so much about understanding the mechanics of the hazard, but rather the effect the increased hazards have on exposed communities. As such, the distribution with topography (did it occur on a steep slope? Was it at the bottom or top of the slope?) is less important than the fact that wherever the communities are that built these roads are located, they still built the roads and are therefore by their sheer existence, tied to the associated hazards. If this were a paper that focused on the distribution of slides, amount of additional sediment delivered to streams, etc., we would agree that the relationship with topography would be key to predictability.

Other, big picture changes. With more space, you will notice that we decided to add a figure at the beginning (Fig. 1) that shows what this actually looks like in the field, along with a schematic that shows the different modes of failure, and a couple examples of two of those modes. As far as we are aware, this simple schematic has not been done previously.

We have cleaned up Fig. 2 with landmarks (towns, river names) based on suggestions by the reviewers, and made the inset (Fig. 2b) slightly less psychedelic looking (purple to grey).

The new Fig. 3 now shows both the cumulative and incremental number of slides at given distances from the road. This has the benefit of clearly showing that the main driver of the discrepancy is the number of monsoon-triggered slides that are within 50 m of a road, clearly demonstrating the genetic relationship.

We have added a Fig. 4 that shows the relationship between road construction, the increase in Foreign Direct Investment following the end of the Maoist insurrection, and associated landslide deaths. This shows how if the trend of increased road construction is magnified by the Belt and Road Initiative, the upward trend of landslide deaths is also likely to increase.