Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2020-75-AC1, 2020

Interactive comment on "Inferring potential landslide damming using slope stability, geomorphic constraints and run-out analysis; case study from the NW Himalaya" *by* Vipin Kumar et al.

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Received and published: 27 October 2020

Referee #1

Comment:

I find this study is very relevant. The approach is quite good. Unstable landslides (out of 44) were identified through FEM and subsequently five landslides, those found unstable were further analysed for its blockage potential using a debris flow model. MOI and HDSI are used to evaluate the potential of landslide damming. Many geotechnical

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Discussion paper

parameters were estimated from field survey and laboratory analysis. This kind of investigation is quite less in literature although previously attempted by these authors for one landslide. I have some minor comments.

Response: We are grateful for the constructive comments/suggestions by Reviewer 1. We are also pleased that the reviewer perceives it as a valuable contribution. Below are our responses that will be considered in the final manuscript following the completion of the interactive review period.

Comment: line 45 - Rapid Mass Movement Simulation (RAMMS)

Response: We apologize for the typing error. As per the suggestion, it will be updated in the revised MS.

Comment: Line 102 - Do you mean KCF is a splay fault of KF?

Response: In our manuscript, we have stated that the Kaurik-Chago Fault (KCF) is subjected to the Karakoram Fault (KF). However, it does not intend to imply that the KCF is a splay fault of the KF. The KCF is an N-S oriented trans-tensional rift fault across the Himalayan strike that has been observed to extend to the north right up to the strike-slip Karakoram Fault. The Karakoram Fault follows the Himalayan strike in the NW Himalaya. The word “subjected” is used in the manuscript because the Kaurik-Chago Fault has been observed to differentiate between the NW and SE part of the Karakoram Fault that comprises different slip rates (Kundu et al. 2014).

Comment: Line 120 - It is a complex sentence. Pl. modify it.

Response: As per the suggestion, it will be modified in the revised MS for further clarification.

Comment: Line 161 - Pl. discuss briefly the spatial variability of compressional and extensional regime here.

Response: The spatial variability of the compressional and extensional regime has been mentioned on the basis of observations of Vannay et al. (2004). As per the suggestion, it is being described as follows;

The study area in the Tethyan Sequence (TS) region has been observed to possess the NW-SE directed extensional regime based on the slickensides present on the brittle-ductile structures. The Sangla detachment (SD) fault has been observed to comprise two regimes belonging to two different deformation phases. Earlier one corresponds to compression due to foreland thrusting whereas, later one corresponds to extension as evident from normal drag shear bands (Grasemann et al. 2003). The structural features in the Higher Himalaya Crystalline (HHC) reveal spatial variability of compression and extension regime. The structures in the upper part of the HHC are influenced by east directed extension along the SD fault. The lower part, however, comprises signs of SW directed compression along the Main Central Thrust (MCT). The structures in the Main Central Thrust (MCT) region have been observed to consist of a compressional regime, later superimposed by an extensional regime. In contrast to the HHC, structures in the Lesser Himalaya Crystalline (LHC) don't comprise any phase of the extensional regime and are influenced by the compressional regime. Based on the orientation of slickensides, kink bands, and other features, Vannay et al. (2004) observed SSW directed compressional regime in the Munsiari Thrust (MT) region. In the Lesser Himalaya Sequence (LHS) region, SW directed compressional regime has been observed on the basis of SW verging folds, crenulation cleavage, and other features. The same explanation, in brief, will be added in the revised manuscript as per the suggestion.

Comment: Line 203 - whether width of dammed valley is measured at full reservoir level?

Response: We would like to clarify that the phrase "width of dammed valley" corresponds to the actual width of the section of the valley where damming is supposed to occur. For further clarification, the phrase "width of dammed valley" in the manuscript will be revised to "width of the valley".

Comment: Runout analysis - This analysis was performed using RAMMS. The method and parameters are fairly well discussed. I missed your explanation wrt. release area. Pl. describe.

Response: We are thankful to the referee for pointing out this crucial aspect of the run-out analysis. There are two possible ways to simulate the run-out event i.e., release area (for unchanneled flow or block release) and hydrograph (for channeled flow) concept. The channelized flow concept, however, requires spatial-temporal information of discharge at these flow channels (Rickenmann et al. 1999; RAMMS v.1.7.0). During the field visits, we did not find specific flow channels (or gullies) on the slope of landslides except few centimeters deep seasonal flow channels for S. N. 5 and S.N. 15 landslides (Table 1). However, the data pertaining to spatial-temporal information of discharge at these two landslides were not available. Therefore, we have chosen the release area concept because it is more appropriate when the flow path (e.g. gully) is uncertain and its possible discharge on the slope is unknown. As per the suggestion, this explanation will be added to the revised manuscript.

Comment: I think you have assumed the flow as block release. Is there any chance of Channelized flow also?

Response: We agree with the referee that we have considered the flow as a block release. As elaborated in the response to the previous comment, most of the landslides don't comprise specific flow channels except S. N. 5 and S.N. 15 landslides (Table 1). Though the possibility of channelized flow at these two landslides can't be denied, the data pertaining to spatial-temporal information of discharge at these two landslides were not available. We are hopeful that in further studies in the future, such data would be attempted to analyze.

Comment: Line 256 - Since you have mentioned that majority of landslides are debris slides, pl. explain how the runout analysis, which is mainly done for debris flow, is valid in your study.

Response: We are of understanding that the debris flow is a stage of debris-laden landslide that under excessive saturation results in the discharge of poorly sorted sediments (or debris) with varying velocity and pressure. Since the majority of the landslides are debris slides, as rightly pointed out by the referee, having unconsolidated poorly sorted overburden, there is a high probability that these debris-laden landslides will transform into debris flow during extreme rainfall events (Embley, 1976; Hungr et al. 2005; Jakob et al. 2005). Further, the study area has been witnessing enhanced rainfall since 2010 and subsequent flash floods (Fig. 11 in the Manuscript), run-out evaluation of the debris slides becomes more crucial. We are hopeful that the referee is convinced with our rational attempt of explanation.

Comment: Line 415 - Your previous publication on Urni landslide gives a different flow height. Can you explain?

Response: We acknowledge that the previous publication involving the Urni landslide had a different flow height than the one mentioned in the present study. The reason for this difference pertains to the following input parameters; friction, turbulence, and depth. The previous study utilized single values of friction and turbulence whereas, in the present study we have used a range (9 sets of values) of these parameters to minimize the possible uncertainty in output (sec. 3.5 in the manuscript). Further, we have been more conservative in the selection of depth in the present study because these landslides are relatively deep in nature and we are of the understanding that during slope failure, irrespective of the type of trigger, entire loose material might not slide down. Therefore, the depth of the landslide is taken as only $\frac{1}{4}$ (thickness) in the run-out calculation.

Comment: Line 469 - What do you mean by strong / weak lithology. I suggest to use a technical term here.

Response: As per the suggestion, it will be replaced in the revised MS with the proper lithology term.

Comment: ’therefore’ is repeated

Response: We apologize for the typing error. It will be removed in the revised manuscript.

Comment: Table 1 - Have you assumed uniform thickness while estimating volume from area?

Response: We would like to clarify that we have not assumed uniform thickness for the volume calculation. These landslides were recently mapped by our team and a detailed procedure has been mentioned in Kumar et al. (2019). We are quoting the same here for clarification.

“The landslide dimension mapping was performed using high resolution GE Imagery, and their locations were verified during field investigation. The uncertainty in the landslide dimension caused by measurement in GE was determined by comparing the known distances in the study area with the measured ones in GE. The known distances were obtained from the Survey of India toposheets (53/I/10, 53/I/6, 53/I/2, 53/E/4, and 53/E/11). A difference of 1.06% was noted between known distances (from toposheets) and measured ones in the GE. Landslide dimension was characterized using the area (total disturbed area), shape (length and width), and volume. Approximate thickness and area of landslides were used to determine the volume. The thickness of individual landslides was ascertained in the field investigation, as also practiced by Larsen and Torres-Sanchez (1998) and Guzzetti et al. (2009).”

Comment: How can you say that area measurement has error of 1.06% due to measurement from Google Earth image?

Response: As mentioned in the response to the previous comment, an error of 1.06% was noted between the known distances (from toposheets) and measured ones in Google Earth (GE) imagery. The known distances were obtained from the Survey of India toposheets (53/I/10, 53/I/6, 53/I/2, 53/E/4, and 53/E/11).

We tried our best to rationally convince the referee with our explanations and we are hopeful that these responses will be received constructively.

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