Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2020-75-AC2, 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.

Vipin Kumar et al.

v.chauhan777@gmail.com

Received and published: 31 December 2020

Response to Anonymous Referee #2

Comment 1: Paper leaves the dual impression. Authors present a lot of data, numerous characteristics and parameters. At the same time it is difficult to understand if landslides at the studied sites had occurred already or they are just expected.

Response: We appreciate the critical, yet constructive, evaluation by the reviewer. The size of the data that we have included in our work reflects our comprehensive method-

ology. We would like to clarify that the landslides have already occurred but many of these are still active and result into frequent failures throughout the year. Stability evaluation is performed in the study to determine the existing stability regime of the landslide slopes through Factor of safety and displacement (Griffiths and lane, 1999). Later, these landslide slopes were categorized into unstable and meta-stable category based on their existing factor of safety.

Comment 2: How one can confirm that the parameters of the assumed landslide dams are estimated correctly or not?

Response: We are thankful for such perceptive query. We have used following parameters to evaluate the possibility of landslide damming; Landslide volume, Dam volume, Width of valley, Upstream catchment area and Local slope gradient of river channel. As stated in the MS, though the resultant (post failure) dam volume could be higher or lower than the landslide volume owing to the slope entrainment, rockmass fragmentation, retaining of material at the slope, and washout by the river (Hungr and Evans 2004; Dong et al. 2011). Exact influence of all these controlling factors on the volume difference can't be ascertained due to following reasons;

Slope entrainment, rock mass fragmentation and retaining of material at the slope will depend on the surface runoff, random joints/fractures on the slope surface, friction of slope the surface, turbulence of the moving mass on slope material and pore water pressure regime (Hungr and Evans 2004; Dong et al. 2011; Cui et al. 2019; Scott and Wohl, 2019). Since surface runoff, turbulence of moving mass and pore water regime are bound to change spatio-temporally, exact estimation seems difficult with available techniques/theories.

Washout of the failed material by the river will depend upon the river discharge. It is to mention that the Satluj River discharge is highly affected by the Western Disturbance and Indian Summer Monsoon induced precipitations, which have shown spatio-temporal variation (Gadgil et al. 2007; Wulf et al. 2012). Since the river is also subjected to many artificial dams (for hydroelectric power) in the upstream direction, river discharge might also get affected by these mega barriers (Kumar and Katoch, 2016). Thus, exact estimation of washout quantity is also difficult to ascertain.

Therefore, dam volume is assumed to be equal to landslide volume for worst case scenario. Similar assumption has also been made in other studies (Canuti et al., 1998) since the existing understanding of such landslide damming studies lack any exact relation between landslide volume and dam volume. Further, the main idea of the study is to predict potential landslide damming sites where damming is yet to takes place, except Urni landslide where it already occurred partially in year 2013 (Kumar et al. 2019a).

For the estimation of width of the valley, upstream catchment area and slope gradient, we used CartoSat-1 panchromatic imagery (spatial resolution 2.5m) and the DEM (spatial resolution 10m) constructed using stereo pairs. These Cartosat-1 imageries have also been evaluated for the morphometric measurement to determine their accuracy (Kandrika and Dwivedi, 2013).

Thus, though exact estimation of all these parameters can't be made due to the aforementioned limitations, we utilized available resources/theory. We are hopeful that the reviewer will perceive our justification rational enough for the query.

Comment 3: Large parts of the text with numerous quantitative parameters can be replaced by tables that will be much easier to follow. I would suggest reworking the paper.

Response: As per the suggestion, we shall be adding a table in the revised MS incorporating all details like landslides dimension, factor of safety, geomorphic indices output for each landslide. However, we are of understanding that the data mentioned in the text is required to justify the proposed approach and interlinked nature.

Comment 4: Clearly indicate what landslide that you mentioned had really occurred

and what is just an unstable slope that might fail. It is especially important for rock avalanches - before such type of landslide occur we cannot be sure that it will not move just as a rockslide.

Response: As per the suggestion, we shall be clearly mentioning the state of slopes in the "Study Area" and "Results" sections. However, we would like to mention that we have stated in the "Study Area" section that it covers forty-four (44) 'active' landslides (20 debris slides, 13 rock falls, and 11 rock avalanches) along the study area that have been mapped recently by Kumar et al. (2019b). Further, we are of understanding that a clarification is required to be mentioned in the revised MS about the difference between landslide slope and unstable state. When we used the word "active landslide", it refers to the fact that hillslope is still subjected to slope failures caused by various factors. It, of course, doesn't mean that the entire hill slope has moved down. As we understand the word "landslide" can be perceived in following three ways; pre-failure deformations, failure itself, and post-failure displacement (Terzaghi 1950; Skempton and Hutchinson, 1969; Cruden & Varnes, 1996; Hungr et al., 2014). Landslide slopes in our study pertains to the post-failure state that are categorized into "unstable" and "meta-stable" stages based on their existing factor of safety. Furthermore, if an active landslide slope is not categorized as "unstable" in our study, it means that its existing slope geometry provides it a "meta-stable" stage that might transform into unstable stage with time due to stability controlling parameters (explained in the Sec. 4.1 in the MS).

Comment 5: It will be very useful to analyse at least several case studies of past real river-damming landslides that can be used as a ground truth to check the reliability of the proposed approach.

Response: We are thankful to the reviewer for the suggestion. We would like to clarify that our study attempts a predictive approach unlike the post-dam formation studies (detailed review in Fan et al. 2020).

In this predictive approach, at first the stability evaluation of active landslides is performed to determine their existing failure potential. Spatio-temporal regime of the failure triggering factors like earthquakes and rainfall is explored to infer the triggering possibility. Later, widely used geomorphic indices are used to find out those landslides that may result into damming of the river. These landslides are further evaluated using the run-out modelling to understand the response of failed slope material in the river channel and hence in the valley. Thus, the whole approach aims to find those slopes that will contribute to the damming, in case of slope failure.

We acknowledge the necessity of validation of the proposed approach, as suggested by the reviewer. Therefore, we would like to state that we have validated our predictive sites with the field observations (Fig. I, II) in the study area where damming has occurred in the past. Sedimentological analysis by other researchers has also confirmed the landslide damming events in the geological past at the region containing our predictive sites (Sharma et al. 2017). This approach has also been applied recently at an already dammed (partially) site where we predicted complete blockade of the river and consequent damage to the nearby bridge in case of further failure (Kumar et al. 2019a). As predicted, further failure blocked the river and damaged the bridges (https://timesofindia.indiatimes.com/city/shimla/nh-5-remains-blocked-due-to-landslides-in-himachal-pradesh/articleshow/74613645.cms, retrieved on 24th Dec. 2020).

Though we have provided the field examples (Fig. I, II), we can't deny the significance of multiple case studies involving existing damming sites, as suggested by the reviewer. However, it will require the back analysis of the following parameters to apply our proposed approach;

Back analysis of the damming volume to reconstruct the landslide volume. As mentioned in the response of the Comment 2, there are several uncertain spatio-temporal factors that play a crucial role between landslide volume and dam volume. The Exact response of these factors can't be ascertained at present.

Back analysis of the failed slope topography to reconstruct the pre-failure slope stability model. It will require the adjustment of landslide area (not the volume because we have performed 2D analysis). Such readjustment of the landslide area to pre-failure state will also include uncertainty because there might be many episodes of failures (which are not dated/recorded) that resulted in final topography. Regional faults/lineaments also affect the slope topography and thus during slope topography reconstruction, lack of inclusion of this factor will surely affect the reconstruction.

We are hopeful that the reviewer will understand the merits and limitations of the predictive nature of the approach that we tried to present judiciously.

References

Canuti P, Casagli N, Ermini L (1998) Inventory of landslide dams in the Northern Apennine as a model for induced ïňĆood hazard forecasting. In: Andah, K. (Eds.), Managing hydro-geological disasters in a vulnerable environment for sustainable development, National Research Council of Italy, UNESCO (IHP), Porano, pp. 189–202.

Cruden DM, Varnes DJ (1996) Landslides: investigation and mitigation. Chapter 3-Landslide types and processes. Transportation research board special report, (247).

Cui Y, Jiang Y, & Guo C (2019) Investigation of the initiation of shallow failure in widely graded loose soil slopes considering interstitial flow and surface runoff. Landslides, 16(4): 815-828.

Dong JJ, Tung YH, Chen CC, Liao JJ and Pan YW (2011) Logistic regression model for predicting the failure probability of a landslide dam. Engineering Geology 117(1): 52-61.

Fan X, Dufresne A, Subramanian SS, Strom, A, Hermanns R, Stefanelli CT., ... & Geertsema M (2020) The formation and impact of landslide dams–State of the art. Earth-Science Reviews, 203, 103116.

Gadgil S, Rajeevan M and Francis PA (2007) Monsoon variability: Links to major oscillations over the equatorial Pacific and Indian oceans. Current Science. 93(2):182-194.

Griffiths DV, Lane PA (1999) Slope stability analysis by finite elements. Geotechnique, 49(3): 387-403.

Hungr O, Leroueil S, Picarelli L (2014) The Varnes classification of landslide types, an update. Landslides 11 (2): 167-194.

Hungr O and Evans SG (2004) Entrainment of debris in rock avalanches: an analysis of a long run-out mechanism. Geological Society of America Bulletin 116(9-10): 1240-1252.

Kandrika S & Dwivedi RS (2013) Reclamative grouping of ravines using Cartosat-1 PAN stereo data. Journal of the Indian Society of Remote Sensing, 41(3): 731-737.

Kumar V, Gupta V, Jamir I, Chattoraj S L (2019a) Evaluation of potential landslide damming: Case study of Urni landslide, Kinnaur, Satluj valley, India. Geosci. Front. 10(2): 753-767.

Kumar V, Gupta V, Sundriyal YP (2019b) Spatial interrelationship of landslides, litho-tectonics, and climate regime, Satluj valley, Northwest Himalaya. Geol. J. 54: 537–551.

Kumar D & Katoch SS (2016) Environmental sustainability of run of the river hydropower projects: A study from western Himalayan region of India. Renewable Energy, 93: 599-607.

Scott DN & Wohl EE (2019) Bedrock fracture influences on geomorphic process and form across process domains and scales. Earth Surface Processes and Landforms, 44(1): 27-45.

Sharma S, Shukla AD, Bartarya SK, Marh BS & Juyal N (2017) The Holocene floods and their affinity to climatic variability in the western Himalaya, India. Geomorphology, 290: 317-334.

Skempton AW, Hutchinson JN (1969) Stability of natural slopes and embankment foun-

dations, state-of-the-art report. Proc. 7th Int. Conf. Soil Mech. Found. Eng. 291-340.

Terzaghi K (1950) Mechanism of Landslides, in: Application of Geology to Engineering Practice.

Wulf H, Bookhagen B and Scherler D (2012) Climatic and geologic controls on suspended sediment flux in the Sutlej River Valley, western Himalaya". Hydrology and Earth System Sciences 16(7): 2193-2217.

Fig. Captions

Fig. I (As Fig. 10 in the Manuscript) Field signatures of the landslide damming near Akpa_III landslide. (a) Upstream view of Akpa landslide with lacustrine deposit at the left bank; (b) enlarged view of lacustrine deposit with arrow indicating lacustrine sequence; (c) alternating fine-coarse sediments. F and C refer to fine (covered by yellow dashed lines) and coarse (covered by green dashed lines) sediments, respectively.

Fig. II (As Fig. 2 in Kumar et al. 2019a) Field photographs. (a) Front face of the Urni landslide; (b) and (c) are upstream and downstream view of the valley from the landslide location; (d) and (e) denote river damming during year 2013 and 2016, respectively; (f) slope in the opposite side. Red circles denote relative size by encircling heavy truck in 2b, 2e and tunnel outlet building (6 m x 4 m) in 2c.

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

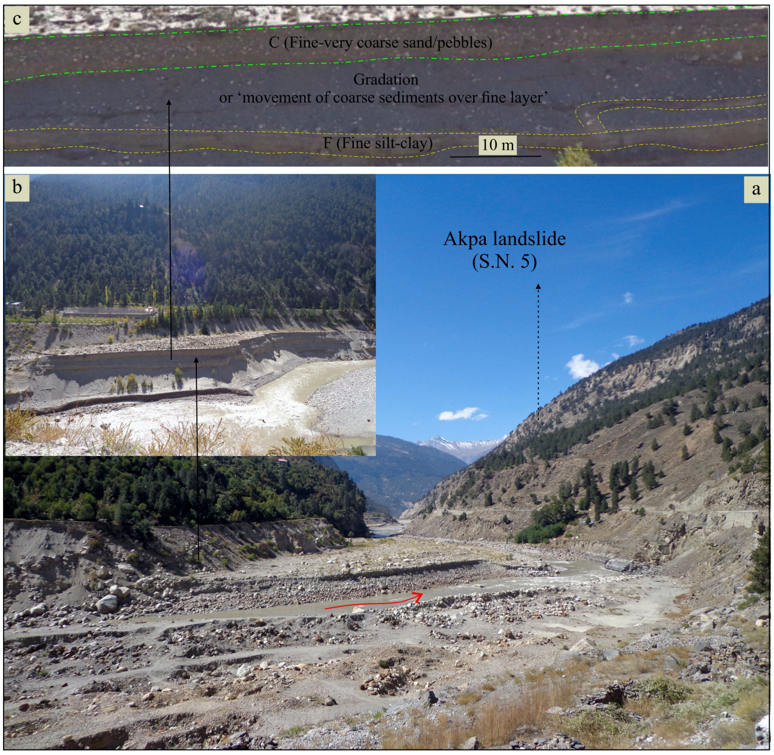

Fig. 1. Fig I (As Fig. 10 in the Manuscript)

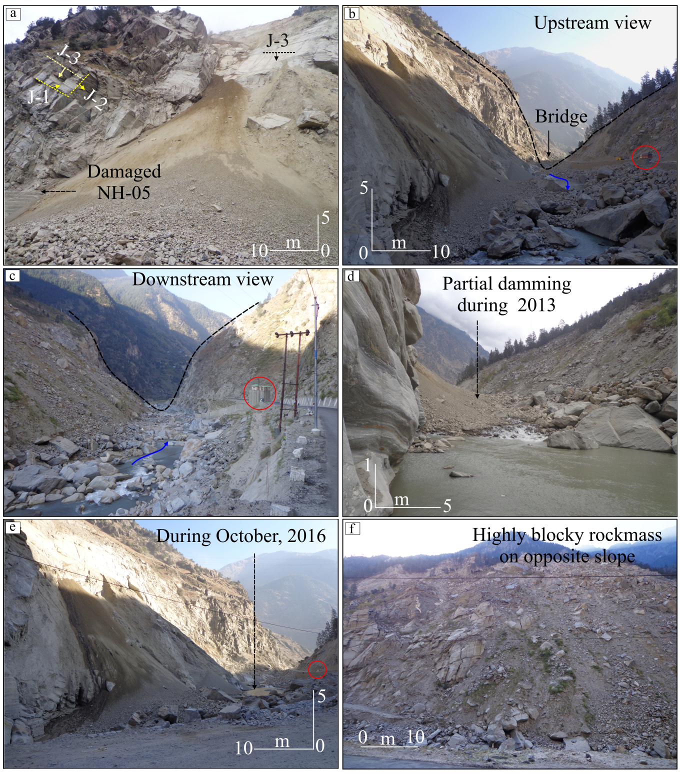

Fig. 2. Fig II (As Fig. 2 in Kumar et al. 2019a)