December 25th, 2017

Dr. Stefano Luigi Gariano

Handling Editor, Natural Hazards and Earth System Sciences (NHESS)

Email: gariano@irpi.cnr.it

Dear Dr. Gariano:

I write to you concerning a manuscript, "Learning in an Interactive Simulation Tool against Landslide Risks: The Role of Strength and Availability of Experiential Feedback," that I co-authored with my Ph.D. advisor, Dr. Varun Dutt. Please note that the manuscript's title has changed from the last submission to account for one of the reviewer's comments.

We want to thank you and the reviewers for considering our work to NHESS. As per your suggestions and those of reviewers', we have now modified and improved the exposition of our research in the manuscript. We are now re-submitting an improved version of our manuscript to NHESS. We are also submitting point-to-point answers against different comments and suggestions given by you and reviewers. We hope that you now find our revised paper fit for publication in NHESS and we look forward to hearing from you on this draft.

Sincerely,

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Point- by-point replies to the anonymous referee 1

General comments:

The paper deals with a very relevant topic, the involvement of stakeholders in landslide risk management and the adoption of "gamification" type approaches to promote it. The ILS software results a promising tool for capturing the interest of attendees and it could be applied with reduced effort to other test cases. The sections 3 and 4 show in effective ways procedures and results.

Authors: Thank you for appreciating our research. We agree with you that the ILS tool is a promising tool for capturing the decisions of participants against landslide risks and it could be applied with reduced effort to other natural disasters involving human decisions.

We have now added these suggestions as part of our discussion section in the manuscript (pg. 20-22).

However, several elements would require further examination. First, the test case is not adequately introduced: geology, past and recent events, rainfall patterns recognized as main triggers. In this regard, also in ILS, dynamics inducing the events (physical or anthropic) are not adequately taken into account. For example, it is not clear how the spatial distribution of landslide events is accounted for in ILS or if the information about occurrence probability are used in simulation.

Authors: Thank you for your kind comments.

We have now extended our methodological exposition by showing how spatial probabilities (susceptibility of an area to landslides) along with environmental probabilities (triggers due to rainfall patterns) influence the total landslide risk excluding the human factor (pgs. 5-7). Specifically, we have now shown how we used the spatial area and the total estimated hazard (THED) scale of study area in ILS to compute the spatial probability distribution (P(S); pg. 7). In addition, we have now explained how a value of spatial probability was sampled from the P(S) distribution for each participant in ILS (pg. 10). Next, we have also shown how the environmental probability distribution was calculated in ILS from the seasonal rainfall in the area (pg. 5-6). Finally, we have now also shown how the human decisions cause a change in the anthropic probability of landslides and how the anthropic probability interacts with the spatial and environmental probabilities (pg. 5-6).

The role of "anthropic activities" on slopes could often be detrimental and the reduction in earnings due to reducing these one for preserving stability should be taken into account. Moreover, the main stakeholders for ILS are probably not citizens but policy makers and administrators and then financial management (daily income) should be revised accordingly.

Authors: Thank you for your kind comments.

In agreement with you, we have now explained how the anthropic activities may be detrimental to landslide risks (footnote 1 on pg. 4). Also, we have discussed both these ideas as part of our manuscript's discussion section. Specifically, we now discuss both the positive and negative (detrimental) effects of human actions in influencing the anthropic probability of landslides (e.g., afforestation may not help deep-seated landslides). Also, we have now discussed that the use of the ILS tool goes beyond school education and it applies to administrative and policy research as well (pg. 20-22). Here, we have mentioned that for pursuing this research in future, the financial components would have to be revised in ILS to include the population at the risk (rather than a single individual's savings) (pg. 20-22).

The timescales also for simulations does not appear adequate. Several decisions and protection measures need substantial longer times. Timing for measure implementation could be crucial for deciding the more effective strategies.

Authors: Thank you for your comment. We have now stated as part of our methods section that the ILS tool can run for different time periods, which could be from days to months to years.

This feature can be customized in the ILS tool (pg. 8). However, to showcase the potential of using ILS in the real-world, the experiment used the daily setting in the ILS tool. By using the daily setting, we were also able to use the logistic-regression equation to derive the daily probability of landslides due to rainfall (pg. 7). However, as part of our future research, we plan to extend this daily assumption by considering people to make decisions on longer time-scales ranging from months to years. We have added this discussion on pgs. 20-22.

Finally, the references in first part should be extended and updated. Under such constraints, a substantial revision (major revision) of the text should be performed in order to address the issues arisen above (and below) on specific items; on the other side, the text could be rearranged only to promote the general approach and followed procedures and main results stressing the role that it could cover for landslide risk management after proper characterizations of areas of interest.

Authors: Thank you for your comment.

We have now cited latest research concerning landslide risk in the paper, including more research about Early Warning Systems (EWSs) for landslide risk reduction (pg. 1-3). In addition, we have now broadened the discussion section of the paper by including the points suggested by you and other referees (pg. 20-22). Furthermore, we have now also clarified the exposition of different probabilities concerning the anthropic, spatial, and environmental factors in influencing landslide susceptibility in the manuscript (pg. 5-7). In agreement with your kind suggestion, this exposition allowed us to promote the general capabilities of the ILS tool and the procedures we followed for generating outcomes and probabilities.

Specific issues:

Abstract:

rephrase the first sentence; the verb appears missing

Authors: Thank you for the comment.

We have now improved the first sentence of the abstract (Pg. 1).

Introduction

L25-27: please give further details; in my view, "Knowledge about causes-and consequences of landslides and awareness about landslide disaster mitigation" act in different ways; the first one supporting structural protection measurements could reduce the occurrence/magnitude of landslides. The other one tends reducing people and assets vulnerability not varying the physical processes inducing them.

Authors: Thank you for your kind comments.

In agreement with you, we have now clarified on lines 25-27 that imparting knowledge about causes-and-consequences as well as spreading awareness about landslide disaster mitigation are two different ways of managing landslide risks. The former supports structural protection measures that reduce the probability of landslides. In contrast, the latter likely reduces people's and assets' perceived vulnerability and it does not influence the physical processes. We believe that the ILS tool engages people in both ways (pg. 1).

L31-33: please add further details about Early Warning System tools; e.g. you could refer to reviews available in literature.

Authors: Thank you for your kind suggestions. We have now cited more research about Risk Communication Systems.

Specifically, we have now added on pg. 2 of the revised manuscript that Several satellite-based and sensor-based landslide monitoring systems are being used in landslide RCSs (Hong et al., 2006; Quanshah et al., 2010; Rogers et al., 2011). To be effective, however, landslide RCSs need not only be based upon sound scientific models, but, they also need to consider human factors, i.e., the knowledge and understanding of people residing in landslide-prone areas (Meissen and Voisard, 2008).

L71: "Chaturvedi et al. (2016)" reference is missing in the list

Authors: The reference's year should have been 2017 and not 2016. We have fixed this typo everywhere in the revised manuscript.

We have also rectified the referencing problems in the reference section in the revised manuscript (Pg. 24-26).

L82-83: please consider, I'm not sure that "increasing the amount of damage feedback" and "increasing the probabilities of landslide damages" could be assumed equivalent

Authors: Thank you for the comment. In agreement with you, we have now revised the wording as the following:

"…increasing the strength of damage feedback by increasing the probabilities of landslide damages in simulation tools." (pg. 3).

2 Computational model of landslide risk

L106-108 (Figure 1): for landslides, the issue could be quite more challenging; indeed, you should consider "human interventions" detrimental for slope stability. For example, land *use/cover changes (e.g. deforestation, conversion to agricultural practices). In this regard, rainfall required to induce the phenomena (e.g. duration, intensity) could be affected by "human interventions". Furthermore, researchers monitor data for landslide occurrence but not determine them as for "user" with investments. Finally, both influence not only the hazard ("total probability of landslide") but the risk.*

Authors: Thank you for your kind comments. We agree with your observations.

Now, as part of our revised manuscript, we have mentioned that although our model assumes human mitigation actions in the ILS tool, there may also be other model assumptions possible where certain human detrimental actions (footnote 1 on pg. 4). For example, deforestation may increase the probability of landslides or the risk (probability * consequence) of landslides. We plan to consider these model assumptions as improvements to our model as part of our future research (pg. 20-22).

Furthermore, in this manuscript, we restricted our analyses to only people's investments influencing landslides. However, we agree with you that there may be contributions made by the national, regional, and local governments for providing protection measures against landslides in addition to the investments made by people residing in the area We plan to consider the role of governments as part of our future research (pg. 4). We have also discussed these issues in the discussion section of our revised manuscript and we will take them up as a part of the future work to make the ILS model more realistic (pg. 20-22).

L109: please specify if you consider weather(rainfall)-induced landslides

Authors: Thank you. In the current work, we are only dealing with weather (rainfall)-induced landslides.

We have now mentioned this point as footnote 2 on pg. 4.

L128: the main part of investments for protection measurements as structural (e.g. drainages, retention walls) as soft (e.g. EWS) are funded by Administrations (National, Regional and Local); in which ways it is accounted for?

Authors: Thank you. The theme of our research in the manuscript was focused upon common people's contribution for mitigating landslide risks and the effectiveness of the ILS tool in improving people's understanding about landslide processes.

We agree with your comments and as part of our revision we have now added this point on page 4 as a foot note as well as in the discussion section (pg. 20-22).

Section 2.1.2:

further clarifications are needed. Firstly, brief information about the landslides in the area of interest are required; indeed, the relevance of antecedent precipitations is strictly linked to several geomorphological factors (e.g. soil depth, bottom boundary conditions, hydraulic and mechanical properties); without them, it is not possible to evaluate if considered durations (1d, 3d, 30d) are proper. Moreover, it is not clear the role of "Landslide Susceptibility Zonation";

indeed, "susceptibility" does not provide details about frequency of phenomena but attempts defining the area more "vulnerable" to the events while in this case it is intended providing also Hazard. Moreover, please add details about the rating (0-11). Finally, all the slopes in the area are recognized to be affected by the same rainfall patterns (similar properties, similar soil depths and so on)?

Authors: Thank you for your kind comments.

We have now extended our methodological exposition by showing how spatial probabilities (susceptibility of an area to landslides) along with environmental probabilities (triggers due to rainfall patterns) influence the total landslide risk (test case) excluding the human factor (pg. 5-7). Specifically, we have now shown how we used the spatial area and the total estimated hazard (THED) scale of the study area in ILS to compute the spatial probability (P(S)) distribution (pg. 7). In addition, we have explained how a value of spatial probability was sampled from the P(S) distribution for each participant.

Next, we have now also shown the environmental probability distribution and how it was calculated in ILS from the seasonal rainfall in the area (pg. 5-7). Finally, we have now shown how the human decisions causes a change in the anthropic probability of landslides and these decisions interact with the spatial and environmental probabilities (pg. 5-7).

L170: what do you intend for landslide "benign"?
Authors: When the landslide is benign, then there is no injury, fatality, or damage to property.

We have now added this definition to the manuscript (pg. 8, 10).

Section 2.1.3:

please, what do you intend for "random numbers"? which ways are the three damage probabilities computed in?

Authors: Thank you for your kind comments. If a uniformly distributed random number in [0, 1] (U (0, 1)) is less than a probability value, then it simulates this probability value. For example, if U (0, 1) < 30%, then U(0, 1) will be less than the 30% value exactly 30% of the total number of times it is simulated. Thus, this process will simulate a 30% probability value. A landslide occurs on a certain day when a independent random number (~ U(0, 1)) become less than or equal to the corresponding net probability of occurrence of landslide. Similarly, we have used three independent random numbers (uniformly distributed, values ranging from 0 to 1) for each of the three damage probabilities. Whenever, the random number corresponding to the probability value, become less than the probability, then that kind of damage will occur.

We have now included these details on pgs. 5-7 of the revised manuscript.

Section 2.2:

why do you consider a daily time step? Several decisions and protection measures need substantial longer times. Timing for measure implementation could be crucial for deciding the more effective strategies.

Authors: Thank you for your kind comments.

We have now stated as part of our methods section that the ILS tool can run for different time periods, which could be from days to months to years (pg. 7). Furthermore, the length of the time-period in the ILS can also be customized (pg. 7). For this manuscript, we have used the daily setting in the ILS tool to showcase the potential of using this tool for improving understanding of landslide risks among people. As part of our future research, however, we plan to extend our findings by considering people to make decisions on a longer time scales ranging from months to years. Please see this discussion in the discussion section of the revised manuscript (pg. 20-22).

L205: who is the reference stakeholder of interest? Citizens, administrators, policy makers.

Authors: Thank you for your kind comment.

We have now clarified that "decision maker" refers to participants, i.e., common people residing in the study area (pg. 10).

L212-213: in ILS, how is it decided if, for a certain day, landslide could occur or not?

Authors: A landslide occurs on a certain day when an independent random number (~ U(0, 1)) become less than or equal to the corresponding net probability of occurrence of landslide, which is a weighted sum of landslide probability due to environment (spatial and triggering factors) and human factors.

We have now mentioned this point on line 145 (pg. 5).

3 Experiment

L289-295: I am not sure that the sample composition is consistent with those of communities living in the area affected by landslides as in terms of background as in terms of age. It could deeply affect the findings and the generalization of the results also taking into account the very interesting issues arisen in L44-47

Authors: Thank you for your kind comments. The sample was representative of the study area's population because, like in our sample, the literacy rate is quite high (81.5%) in the study area. In addition, before the experiment, participants were also asked about their self-rated knowledge level for landslide risks.

We have now mentioned these points in the revised manuscript on pg. 15. Furthermore, we have also observed that the use of the optimal invest-all strategy was maximized when the experiential feedback was highly damaging in the ILS tool. One likely reason for this observation could be the high educational levels of participants residing in the study area, where the literacy rate was more than 80%. Thus, it seems that participants' education levels helped them make the best use of damaging feedback. We have discussed these points on pg. 20 in the revised manuscript.

L302: It is quite equal to what reported in L287; in my view, it could be removed

Authors: Thank you for your comment.

As per your kind suggestions, we have now removed this repeated line from the paper.

L313: please, provide further details about the symbols reported in brackets

Authors: We performed analysis of variance statistical tests for evaluating our expectations. The F-statistics is the ratio of between-group variance and the within-group variance. The numbers in brackets after the F-statistics are the degrees of freedom (K-1, N - K), where K are the total number of groups compared and N is the overall sample size. The p-value indicates the evidence in favour of the null-hypothesis when it is true. We reject the null-hypothesis when p-value is less than the alpha-level (0.05). The η^2 is the proportion of variance associated with one or more main effects. It is a number between 0 and 1 and a value of 0.02, 0.13, and 0.26 measures a small, medium, or large correlation between the dependent and independent variables given a population size.

We have now mentioned these points as a footnote on pg. 15.

L374: what do you intend for "K-12"?

Authors: By K-12 we meant kindergarten to standard 12^{th}.

We have now clarified this definition on pg. 20.

L457: Mathew et al. reference should be moved in proper alphabetical order

Authors: Thank you for the comment.

As per your kind suggestions, we have now moved the reference Mathew et al. to the proper place as per alphabetic order in the manuscript.

Appendix A

It reports information quite similar to those in Figure 4; for these reason, it could be removed

Authors: We agree with your kind assessment.

As per your kind suggestions, we are now removing Appendix A from the paper.

<u>**Point-by-point replies to the anonymous referee 2**</u>

The manuscript presents an interesting tool for testing the people's propensity to invest money for protecting goods and life from landslides. The tool has been applied for analyzing the effect of feedbacks availably in influencing the people's decision-making process when asked to invest resources for landslide protection. The topic of the manuscript fit into the scopes of the NHESS Journal since it deals with the design and implementation of mitigation and adaptation strategies to reduce the impact of hazardous natural events on human-made structures, infrastructure, and life.

Authors: Thank you for appreciating our research. We agree with you that the ILS tool is a promising tool for capturing the decisions of participants against landslide risks and it could be applied with reduced effort to other natural disasters involving human decisions.

We have added these points as part of our discussion section in the manuscript (pgs. 20-22).

General comments:

The structure of the paper is fair and, even if I'm not a native English speaker, I found the paper understandable. However, I think that some improvements can be made simplifying the sentences and re-phrasing some frequent constructs as "Although . .... ; however . .... .", where the semicolon do not help to understand the sentence.

Authors: Thank you for appreciating our research.

We have now modified the language of the manuscript according to your suggestions and removed the use of semicolons.

I suggest to promote the section "Interactive landslide Simulator (ILS) tool" from the level of a subsection to the level of a section. Currently it is, erroneously, inside the "Computational model of landslide risk" section. More in general I would also suggest to the author to use the common scientific structure which includes "Introduction", "Material and Methods", "Results", "Discussion" (currently discussion and results are in the same section).

Authors: Thank you for the comment.

We have now made ILS tool as a separate section (pg. 8). Also, we have modified the headings in the manuscript as per your kind suggestions.

I think that the ILS tool is very interesting but I see a major problem in the paper: there is not the possibility to test the ILS tool. My opinion is that, according to the open science, open data, open knowledge concepts, researchers should be put in condition of evaluating the ILS tool. From the paper it is not clear if the tool is a web application or a standalone program and there is not a description of the technology adopted for implementing it, nor of the intention of the authors of releasing the code and, if this is the case, adopting which license.

Authors: Thank you for your kind comments. ILS is a web-based tool that one can access on the following URL: www.pratik.acslab.org.

We have now provided a link to the tool on pg. 8 and can provide the tool's code upon request.

Another issue is about the significance of the results of the experiment. Evidences are that people using the ILS tool with feedbacks, rapidly understand that the best strategy to "win the game" is to invest the entire daily income in landslides mitigation measures. Even if this is interesting, the authors do not comment or discuss the fact that the population of the participants is made of people having high to very high educational levels. This can have a strong effect on their capacity to rapidly find the best strategy. This is particularly true where one considers that, as far as I know, the educational levels of people living in the Himalaya region is mostly low and very low. I think that representativeness of the participants to the experiment should be discussed more in detail.

Authors: Thank you for your kind comments. The sample was representative of the study area's population because, like in our sample, the literacy rate is quite high (81.5%) in the study area. In addition, before the experiment, participants were also asked about their self-rated knowledge level for landslide risks.

We have now mentioned these points in the revised manuscript on pg. 15. Furthermore, we have also observed that the use of the optimal invest-all strategy was maximized when the experiential feedback was highly damaging in the ILS tool. One likely reason for this observation could be the high educational levels of participants residing in the study area, where the literacy rate was more than 80%. Thus, it seems that participants' education levels helped them make the best use of damaging feedback. We have discussed these points on pg. 20 in the revised manuscript.

Lastly: figures are enough rough and should be improved and better described in the captions.

Authors: Thank you for your kind suggestions.

We have now improved the quality of figures and their captions in the modified manuscript. All other formatting errors and references are corrected in the revised version. Now, the manuscript has also been proofed for English grammar.

Specific comments:

L138: I think you need to add that $0<M<1$

Authors: Thank you for this comment.

We have now added $0 \leq M \leq 1$ as per your kind suggestion in the revised manuscript on pg. 6.

L162: It is not clear to me what the Total Estimated Hazard is. Please define it.
L162: Landslide Hazard Map: what is this? Not clear how this is related to the LSZ and to the THED. It is even not clear how the spatial probability is included in the tool. It is a single value or there is a map?

Authors: Thank you for your kind comments.

We have now defined the Total Estimated Hazard (THED) as a rating of different locations on a Landslide Hazard Map and their surface area of coverage on pg. 7 of the revised manuscript.

Also, as part of our revision, we have now provided the THED scale in Table 1 (see pg. 7). From this table, the critical THED values (e.g., 3.5, 5.0, 6.5, and 8.0) were converted into a probability value by dividing with the highest THED value (= 11.0). Next, we used the LSZ map of the study area to find the surface area that was under a specific THED value and used this area to determine the cumulative probability density function for P(S). For example, if a THED of 3.5 has a 20% coverage area on LSZ, then the spatial probability is less than equal to 0.32 (=3.5/11.0) with a 20% chance. Similarly, if a THED of 5.0 has a 30% coverage area on LSZ, then the then the spatial probability is less than equal to 0.45 (=5.0/11.0) with a 50% chance (30% + 20%). Such calculations enabled us to develop a cumulative density function for P(S). In the ILS tool, a participant was assumed to belong to a location in the study area and this study area determined the P(S) value. This P(S) value stayed the same for this participant across her performance in the ILS tool (see pg. 7).

L172: Is "become less than" correct? I suppose should be "become greater than". If not please try to explain why must be "less".

Authors: Thank you for your kind comments.

Yes, becomes less than is correct and we have clarified this reasoning as a footnote on pg. 5 in the manuscript.

L182: please change "their total wealth" with "the total wealth of the participants"

Authors: Thank you for the comment.

To keep the grammar consistent, we have changed the sentence to the following, "The goal in ILS tool is to maximize one's total wealth, where this wealth is influenced by one's income, property wealth, and losses experienced due to landslides." (pg. 8)

L207: "decision-maker". Are you meaning "participant"? If yes please change the text accordingly.

Authors: Thank you.

We have replaced the term decision-maker with participant everywhere in the revised manuscript as per your suggestion.

L241-243: the sentence is not clear. Please rephrase.

Authors: Thank you for the comment.

We have rephrased the sentence to make it clearer in its meaning.

L243: "see Figure 2": please explain how the figure helps in understanding the text.

Authors: Thank you for the comment. Figure 2 (now Figure 3) in the revised manuscript shows the investment screen that were shown to participants in the feedback-present conditions.

We have now mentioned this explanation on pg. 12 in the manuscript.

L262: "(W)": it is not immediate to understand that "W" is the parameter of the equation at page 4. Please number the equations and use those numbers in the text.

Authors: Thank you for the comment.

We have addressed this comment in the revised manuscript (pg. 13) by stating the line with the equation number. Now, we state that, "the weight (W) parameter in the equation 1 of the ILS model was fixed at 0.7 across all conditions."

L263: "was fixed to 0.8": in figure 2, W is 0.7.

Authors: Thank you. We made a typo in the manuscript.

We have now fixed this typo and made W equal 0.7 in the manuscript (pg. 13).

L302: the first sentence was already stated at the start of the 3.2 subsection.

Authors: Thank you.

We have now removed this sentence to avoid repeated use.

L313: please describe the meaning of the statistical parameters (derived from statistic tests) inside the brackets.

Authors: Thank you for your kind comment. We performed analysis of variance statistical tests for evaluating our expectations. The F-statistics is the ratio of between-group variance and the within-group variance. The numbers in brackets after the F-statistics are the degrees of freedom (K-1, N - K), where K are the total number of groups compared and N is the overall sample size. The p-value indicates the evidence in favour of the null-hypothesis when it is true. We reject the null-hypothesis when p-value is less than the alpha-level (0.05). The η^2 is the proportion of variance associated with one or more main effects. It is a number between 0 and 1 and a value of 0.02, 0.13, and 0.26 measures a small, medium, or large correlation between the dependent and independent variables given a population size.

We have now mentioned these details as a footnote on pg. 15 in the manuscript.

L330: what "CI" means?

Authors: Thank you for the comment. CI stands for confidence interval value.

We have now added this full form on pg. 16 in the manuscript.

L385-386: unclear. Please rephrase.

Authors: Thank you for the comment.

We have rephrased these sentences to make their meaning clearer in the manuscript (pg. 21).

Point- by-point replies to the anonymous referee 3

General Comments:

The study described in the paper addresses an important and very relevant issue in natural disaster risk management – to explore potential ways to improve risk awareness and knowledge. The authors reported how they used feedback in an Interactive Landslide Simulator to influence people's risk reduction investment behavior. The manuscript was written generally in good English that can be relatively easily understood, but the ILS model still needs to be better elaborated and explained. While the study represent a good initiative, it also suffers from a number of design problems.

Authors: Thank you for summarizing our contribution and providing encouragement to our work. We have now made several improvements to the manuscript based upon review comments from you and other reviewers. In agreement with different reviewers, we have now also extended this paper in both the design choices as well as system constraints. Now the elaboration of the ILS model has been improved and we have also explained the experiment design in detail. In the revised manuscript, we have also addressed several design problems related to participant demographics and details concerning assumptions in the ILS tool.

Specific issues:

The ILS model and simulator structure Significant information about the ILS model was from the authors' published conference paper in 2016. The authors need clearly state this. Much of the information needs not to be repeated. Even so, the current description of the model is still not clear enough. More details are needed to help understand how the rather sophisticated landslide probability calculation relates to damage estimation. For example, the total P is an additive results of the two constituting components, P(I) and P(E), however P(E) is the multiplicative results of its two constituting components. The authors did not give full information to justify this choice. The authors mentioned "study area" only in 2.1.1, while very limited information was provided. The authors also did not give any explanation on how W is determined.

Authors: Thank you for your kind comments.

In the revised manuscript, we have now given proper citation to our 2016 conference paper at different places in the manuscript (actually the year of publication of this conference paper is 2017 and not 2016 and the year has been corrected in the manuscript). Furthermore, we have now clarified the contribution in the manuscript and how this work builds upon prior work (pg. 3). In addition, we have now extended the paper to include a better description of relevant theory (pg. 2-3) and a better description of the probability calculation for P(S), P(R), and P(E) (pg. 5-7). As part of our revision, we have also suggested the rationale for different design and system choices made. In the revised version, we have explained study area by giving more details about its geographic location, climate, and demographic profile (pg. 3, 12-14).

The W is a free parameter. We have fixed the W parameter in this experiment such that human action play a significant role in the reduction of landslide risk (pg. 13). However, as a part of our future research work with ILS tool, we will also vary the M and W parameters to see the effect of this variation on participants' investment decisions against landslides (pg. 20-22).

The assumptions of the ILS model: The ILS was designed with the assumption that people susceptible to landslide hazard aims to maximize their total wealth and the authors started that "a high probability of landslide damages will make people suffer monetary losses and people would tend to minimize these losses by increasing their mitigation actions". This assumption neglects much of the social science research on people's risk perception, attitude and behavior, that people do not behave as an economic rationale individual in the face of extreme events.

Authors: Thank you for providing valuable comments that helped to further improve our research.

First, we have now revised our expectations to be over time (pg. 3). Second, at a first glance, the expectations may seem to assume people to be economically rationale individuals while facing landslide disasters (Bossaerts and Murawski, 2015; Neumann and Morgenstern, 1947), where one disregards people's bounded rationality, risk perceptions, attitudes, and behaviours (De Martino, Kumaran, Seymour, and Dolan; 2005; Gigerenzer and Selten, 2002; Kahneman and Tversky, 1979; Simon, 1959; Slovic, Peters, Finucane, and MacGregor, 2005; Thaler and Sunstein, 2008; Tversky and Kahneman, 1992). However, in this paper, we consider people to be bounded rational agents (Gigerenzer and Selten, 2002; Simon, 1959), who tend to minimize their losses against landslides slowly over time via a trial-and-error learning process driven by personal experience in an uncertain environment (Dutt and Gonzalez, 2010; Slovic et al., 2005). We have now added these explanations on pg. 3 of the manuscript.

Furthermore, we now also discuss how the repeated experiential feedback likely enables learning by repeated trial-and-error procedures, where bounded-rational individuals (Simon, 1959) try different investment values in ILS and observe their effects on occurrence of landslides and their associated consequences. Also, we now mention that according to Slovic et al. (2005), loss-averse individuals tend to increase their contribution against a risk over time. In our case, similar to Slovic et al. (2005), participants started contributing slowly against landslides and, with the experience of landslide losses over time, they started contributing larger amounts to reduce landslide risks. These explanations have been discussed on pg. 20 of the manuscript.

The authors assumed that "damages concerning injury and fatality affect one's income levels". This is rather naïve. While reduced income level is going to be a consequence, but it would be much less a concern for most people than the injury and fatality itself. In reality people can also choose to migrate when mitigation cost is too high and adaptation becomes impossible. The nature of landslide hazard, including its notorious fame of being extremely hard, if not impossible, to predict, makes it quite different from other hazards such as flood and drought, and general climate risk.

Authors: Thank you for sharing this thought provoking comment. In agreement with you, we have now stated as part of our discussion section that currently, in the ILS model, we have assumed that damages from fatality and injury influence participants' daily-income levels. The reduced income levels do create adverse consequences, but one could also argue that they would be much less of a concern for most people compared to the injury and fatality itself. Furthermore, people could also choose to migrate from an area when the landslide mitigation cost is too high and adaptation becomes impossible, especially due to the differences between the landslide hazard and other hazards such as flood, drought, and general climate risks. As part of our future research, we plan to investigate the influence of feedback that causes only injuries or fatalities compared to feedback that causes economic losses due to injuries and fatalities. Also, as part of our future research in the ILS tool, we plan to investigate people's migration decisions when the landslide mitigation costs are too high and adaptation to landslides is not possible.

These explanations have been provided as part of the discussion section in the manuscript (see pg. 21).

The authors' choice of P(I) formula from Hasson et al. 2010 does not seem to be appropriate. It may seem to be obviously useful by applying specific parameters from the Mandi area in India as the participants seem to be mostly from the area (the authors did not clearly elaborate this), however, since the algorithms was not disclosed to the participants and a random number generator was used in producing damages, using the seemingly sophisticated algorithms is in fact not much related to the authors' main objective, instead, a more generic algorithm would serve the same purpose and potential be more useful for testing with participants from other areas.

Authors: Thank you for your kind comments. In agreement with your suggestions, we have now stated as part of our discussion section that in the ILS model, we used a linear model to compute the probability of landslides due to human factors (i.e., Hasson et al. 2010's model). Also, the probabilistic equations governing the physical factors in the ILS model were not disclosed to participants, who seemed to possess high education levels. One could argue that there are several other linear and non-linear models that could help compute the probability of landslides due to human factors. Some of these models could not only influence the probability of landslides, but also the severity of consequences (damages) caused by landslides. Also, other generic models could account for the physical factors in the ILS tool. We plan to try these possibilities as part of our future work in the ILS tool. Specifically, we plan to assume different models of investments in the ILS tool and we plan to test them against participants with different education levels.

These explanations have been added to the discussion section (pg. 21).

Also, we have now clearly elaborated in the revised manuscript that the sample used in the experiment was representative of the study area's population because the literacy rate in the town and surrounding areas is quite high (81.5%) (Pg. 15).

Day was used as the time unit for simulation and people make daily choice in landslide mitigation investment. This is not relevant for real world situation either.

Authors: Thank you for your observation.

We have now stated as part of our methods section that the ILS tool can run for different time periods, which could be from days to months to years. This feature can be customized in the ILS tool (pg. 8). However, to showcase the potential of using ILS, the experiment used the daily setting in the ILS tool. As part of our future research, we plan to extend this limitation by considering people to make decisions on a longer time scale ranging from months to years. Please see this discussion in the discussion section of the manuscript (pg. 20-22).

In most cases, especially in developing countries, households and communities themselves almost never have resources substantial enough to mitigate landslide risk, which is often financed by government and/or international donors. The huge disparity between the average asset (calculated as per capital GDP) and the salary (with the former being 2000 times of a person's annual income) also supported my above statement.

Authors: Thank you for your kind comments. In agreement with you, we have now added to our discussion section that we assumed a large disparity between a participant's property wealth and her daily income. In addition, as part of the ILS model, we did not consider any support from government or international agencies against damages from landslides. As suggested by you, in certain cases, especially in developing countries, mitigation of landslide risks may be often financed by government or international agencies. As part of our future work, we plan to extend the ILS model to include assumptions of contributions from government or international agencies. Such assumptions will help us determine the willingness of common people to contribute against landslide disasters, which is important as the developing world becomes developed over time.

These comments have been reported on pg. 22.

The authors chose a value of 0.8 for W, indicating that the landslide risk can largely be mitigated by human. This is in general not the case, especially for the type of mitigation measures mentioned by the authors – tree plantation. There has been studies showing that afforestation does not help with landslides in similar areas to Mandi in the Sivalik Hills.

Authors: Thank you.

Now, as part of our discussion section (see pg. 22), we have mentioned that these W and M values indicated that landslide risks could largely be mitigated by human actions. However, in agreement with your suggestions, this assumption may not be the case always, especially for mitigation measures like tree plantations. For example, afforestation alone may not help in reducing deep-seated landslides in hilly areas (Forbes, 2011). Thus, it would be worthwhile investigating as part of future research on how people's decision-making evolves in conditions where investments likely influence the landslide probability (higher values of W and M parameters) compared to conditions where investments unlikely influence the landslide probability (lower values of W and M parameters).

3. The study design

The high damage scenario is simply not realistic at all. With such a high risk of mortality and 90% change of injury, no one would still choose to stay in the landslide area, even in least developed countries. The low damage scenario would already be a very high risk area in reality, in any countries.

Authors: Thank you.

In agreement with your suggestions, we have now mentioned as part of our discussion section (see pg. 22) that to test our hypotheses, we presented participants with a high damage scenario and a low damage scenario, where the probability of property damage, injury, and fatality were high and low, respectively. However, such scenarios may not be realistic, where people may want migrate from both low and damage areas in even the least developed countries. In future research with ILS, we plan to calibrate the probability of damages, injury, and fatality to realistic values and test the effectiveness of ILS in improving the participants' investment decision making.

In Fig. 3b, the authors give a smiling face followed by "Landslide did not Occur". This gives a false feeling that the fact that landslide did not occur because of mitigation investment, while in reality much of it should be due to stochastic in the nature of landslide.

Authors: Thank you for your kind comments. In our experiment, when landslide did not occur and experiential feedback was present, people were presented with a smiling face followed by a message. The message and emoticon were provided to connect the cause-and-effect relationships for participants in the ILS tool. However, it could also be that the landslide did not occur on a certain trial due to the stochasticity in the simulation rather than participants' investment actions. Although such situations are possible over shorter time-periods, however, over longer time-periods increased investments from people will only reduce the probability of landslides.

In agreement with your comments, we have now added these explanations as part of the discussion section (pg. 22).

4. The results

First, part of the results were already included in the 2016 paper (apparently including 43 of the 83 participants reported in this study) and this should be fully disclosed.

Authors: Thank you.

In the revised manuscript, we have now given proper citation to our 2016 conference paper (actually 2017 conference paper, where the year has been corrected). We have now clarified the contribution in the manuscript and how this work builds upon the prior 2017 work (pg. 3, 12).

Also, via a footnote on pg. 12, we have mentioned that data reported in Chaturvedi et al. (2017) has been included in this paper with two more conditions, the high-damage feedback-absent (N = 20) and the low-damage feedback-absent (N = 20). Data in all four conditions was collected simultaneously.

Second, the part of the results on people's increasing investment in mitigation seems to be largely an artifact of the choice of M being 0.8. It'd be more interesting to study, with a much larger sample, how how changing M will affect people's behavior, given that the authors choose more realistic scenarios.

Authors: Thank you for your kind comment, which helped us get new ideas for our research. In agreement with you, we have now mentioned that in the experiment, we assumed a value of

0.8 for the return to mitigation (M) parameter. This M value indicated that landslide risks could largely be mitigated by human actions. However, this assumption may not be the case always, especially for mitigation measures like tree plantations. For example, afforestation alone may not help in reducing deep-seated landslides in hilly areas (Forbes, 2011). Thus, it would be worthwhile investigating as part of future research on how people's decision-making evolves in conditions where investments likely influence the landslide probability (higher values of M parameter) compared to conditions where investments unlikely influence the landslide probability (lower values of M parameter).

This discussion appears on pg. 22 of the manuscript.

Some detailed comments on texts:

1. *In Abstract, the first sentence is incomplete.*

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Authors: Thank you.

In the revised manuscript, we have now improved the first line of abstract. All other formatting errors and references are corrected in the revised version. Now, the manuscript has also been proofed.

2. "Different amount of feedback" was used, but in fact the difference between the two different levels of feedback may better be described as "intensity" of "strength" of feedback.

Authors: Thank you.

In agreement with your kind suggestion, we have now changed the "amount of feedback" in the paper everywhere to the "strength of feedback."

3. Fig. 2 is similar to the Fig 2 in the authors' 2016 conference paper and needs to be disclosed.

Authors: Thank you.

In the revised manuscript, we have now given proper citation to our 2017 conference paper as part of this figure.

4. Fig. 5b, it should be high/low damage instead of more/less damage.

Authors: Thank you.

In the revised manuscript, we have now rectified this error.

5. Reference – Mathew et al. was published in 2014 and should be rearranged in alphabetic order.

Authors: Thank you.

In the revised manuscript, all the formatting errors and references are corrected.

While the study represents an interesting attempt, it suffers from seriously false model assumptions and weakness in study design in relation to reality. I personally even think that the simulator may falsely influence participants in terms of how they should make decisions in the face of landslide risk. But I strongly recommend the authors to continue developing the simulator with stronger social science understanding and better design.

Authors: We are thankful for your kind comments as they helped us provide an improved exposition of our methods and results. These comments have also given a lot of new ideas which we will use in our future experimentation with ILS tool. We, hereby want to clarify that current experimental study with ILS was a preliminary but important work to test the effectiveness of simulation models on people's understanding of landslide risks. But, in future we will use several of the manipulations in the model parameters and probabilities to make the simulation exercise more realistic.

In agreement with you, we have now added several ideas suggested by you as part of our discussion section in the manuscript (pg. 20-22).

Learning in an Interactive Simulation Tool against Landslide Risks: The Role of Strength and Availability of Experiential Feedback

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Abstract. Feedback via simulation tools is likely to help people improve their decision-making against natural disasters, however, currently little is known on how differing strengths of experiential feedback and feedback's availability in simulation tools influences people's decisions against landslides. In an experiment involving participants, we tested the influence of differing strengths of experiential feedback and feedback's availability on people's decisions against landslide risks in an Interactive Landslide Simulation (ILS) tool. Experiential feedback (high or low) and feedback's availability (present or absent) were varied across four between-subject conditions: high-damage feedback-present, high-damage feedback-absent, low-damage feedback-present, and low-damage feedback-absent. In high-damage conditions, the probabilities of damages to life and property due to landslides were 10-times higher than those in the low-damage conditions. In feedback-present conditions, experiential feedback was provided in numeric, text, and graphical formats in ILS. In feedback-absent conditions, the probabilities of damages were described, however, there was no experiential feedback present. Investments were greater in conditions where experiential feedback was present and damages were high compared to conditions where experiential feedback was absent and damages were low. Furthermore, only high-damage feedback produced learning in ILS. Simulation tools like ILS seem appropriate for landslide risk communication and for performing what-if analyses.

1 Introduction

Landslides cause massive damages to life and property worldwide (Chaturvedi and Dutt, 2015; Margottini et al., 2011). Imparting knowledge about landslide causes-and-consequences as well as spreading awareness about landslide disaster mitigation are likely to be effective ways of managing landslide risks. The former approach supports structural protection measures that are likely to help people take mitigation actions and reduce the probability of landslides (Becker et al., 2013; Osuret et al., 2016; Webb and Ronan, 2014). In contrast, the latter approach likely reduces people's and assets' perceived vulnerability to risk. However, it does not influence the physical processes. One needs effective landslide risk communication systems (RCSs) to educate people about cause-and-effect relationships concerning landslides (Glade et al., 2005). To be effective, these RCSs should possess five main components (Rogers and Tsirkunov, 2011): monitoring; analysing, risk communication, warning dissemination, and capacity building.

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Among these components, prior research has focused on monitoring and analysing the occurrence of landslide events (Dai et al., 2002; Montrasio et al., 2011). For example, there exist various statistical and process-based models for predicting landslides (Dai et al., 2002; Montrasio et al., 2011). Several satellite-based and sensor-based landslide monitoring systems are being used in landslide RCSs (Hong et al., 2006; Quanshah et al., 2010; Rogers et al., 2011). To be effective, however, landslide RCSs need not only be based upon sound scientific models, but, they also need to consider human factors, i.e., the knowledge and understanding of people residing in landslide-prone areas (Meissen and Voisard, 2008). Thus, there is an urgent need to focus on the development, evaluation, and improvement of risk communication, warning dissemination, and capacity building measures in RCSs.

Improvements in risk communication strategies are likely to help people understand the cause-and-effect processes concerning landslides and help them improve their decision-making against these natural disasters (Grasso and Singh, 2009). However, surveys conducted among communities in landslide-prone areas (including those in northern India) have shown a lack of awareness and understanding among people about landslide risks (Chaturvedi and Dutt, 2015; Oven, 2009; Wanasolo, 2012). In a survey conducted in Mandi, India, Chaturvedi and Dutt (2015) found that 60% of people surveyed were not able to answer questions on landslide susceptibilities maps, which were prepared by experts. Also, Chaturvedi and Dutt (2015) found that a sizeable population reported landslides to be "acts of God" (39%) and attributed activities like "shifting of temple" as causing landslides (17%). These results are surprising as the literacy-rate in Mandi and surrounding areas is quite high (81.5%) (Census, 2011) and these results show numerous misconceptions about landslides among people in landslide-prone areas. Overall, urgent measures need to be taken that improve public understanding and awareness about landslides in affected areas.

Promising recent research has shown that experiential feedback in simulation tools likely helps improve public understanding about dynamics of physical systems (Chaturvedi et al., 2017; Dutt and Gonzalez, 2010; 2011; 2012; Fischer, 2008). Dutt and Gonzalez (2012) developed a Dynamic Climate Change Simulator (DCCS) tool, which was based upon a more generic stock-and-flow task (Gonzalez and Dutt, 2011a). The authors provided frequent feedback on cause-and-effect relationships concerning Earth's climate in DCCS and this experiential feedback helped people reduce their climate misconceptions compared to a no-DCCS intervention. Although the prior literature has investigated the role of frequency of feedback about inputs and outputs in physical systems, yet little is known on how differing strengths of experiential feedback (i.e., differing probabilities of damages due to landslides) influences people's decisions over time. Also, little is known on how experiential feedback's availability (presence or absence) in simulation tools influences people's decisions.

The main goal of this paper is to evaluate how differing strengths of experiential feedback and feedback's availability influences people's mitigation decisions. It is important to understand how differing experiential feedback in terms of differing probabilities of landslide damages influences people's mitigation decisions. That is because the experience of landslide consequences could range from no damages to large damages involving several injuries, infrastructure damages, and deaths. Thus, some people may experience severe damages and consider landslides to be a serious problem requiring immediate actions, whereas, other people may experience no damages and consider landslides to be a trivial problem requiring very little attention.

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In addition, the availability of feedback in simulation tools is also likely to influence people's decisions against landslides. When feedback is absent, people are likely only to acquire descriptive knowledge about the cause-and-effect relationships governing the landslide dynamics (Dutt and Gonzalez, 2010). However, when feedback is present, people get to repeatedly experience the positive or negative consequences of their decisions against landslide risks (Dutt and Gonzalez, 2010; 2011). This repeated experience will likely help people understand the cause-and-effect relationships governing the landslide dynamics.

Chaturvedi et al. (2017) proposed a computer-simulation tool, called the Interactive Landslide Simulator (ILS). The ILS tool is based upon a landslide model that considers the influence of both human factors and physical factors on landslide dynamics. Thus, in ILS, both physical factors (e.g., spatial geology and rainfall) and human factors (e.g., monetary contributions to mitigate landslides) influence the probability of catastrophic landslides. In a preliminary investigation involving the ILS tool, Chaturvedi et al. (2017) varied the probability of damages due to landslides at two levels: low probability and high probability. The high probability was set about 10-times higher compared to the low probability. People were asked to make monetary investment decisions, where the monetary payment would be used for mitigating landslides (e.g., by building a retaining wall or by planting crops with long roots in landslide-prone areas). People's investments were significantly greater when the damage probability was high compared to when this probability was low. However, Chaturvedi et al. (2017) did not fully evaluate the effectiveness of experiential feedback of damages in ILS tool against control conditions where this experiential feedback was not present. Also, Chaturvedi et al. (2017) did not investigate people's investment decisions over time and certain strategies in ILS, where these decisions and strategies would be indicative of learning of landslide dynamics in the tool.

Prior literature on learning from experiential feedback (Baumeister et al., 2007; Dutt and Gonzalez, 2012; Finucane et al., 2000; Knutty, 2005; Reis and Judd, 2013; Wagner, 2007) suggests that increasing the strength of damage feedback by increasing the probabilities of landslide damages in simulation tools would likely increase people's mitigation decisions. That is because a high probability of landslide damages will make people suffer monetary losses and people would tend to minimize these losses by increasing their mitigation actions over time. It is also expected that the presence of experiential feedback about damages in simulation tools is likely to increase people's landslide-mitigation actions over time (Dutt and Gonzalez, 2010; 2011; 2012). That is because the experiential feedback about damages will likely enable people to make decisions and see the consequences of their decisions, however, the absence of this feedback will not allow people to observe the consequences of their decisions once these decisions have been made (Dutt and Gonzalez, 2012). At first glance, these explanations may seem to assume people to be economically rationale individuals while facing landslide disasters (Bossaerts and Murawski, 2015; Neumann and Morgenstern, 1947), where one disregards people's bounded rationality, risk perceptions, attitudes, and behaviours (De Martino, Kumaran, Seymour, and Dolan; 2005; Gigerenzer and Selten, 2002; Kahneman and Tversky, 1979; Simon, 1959; Slovic, Peters, Finucane, and MacGregor, 2005; Thaler and Sunstein, 2008; Tversky and Kahneman, 1992). However, in this paper, we consider people to be bounded rational agents (Gigerenzer and Selten, 2002; Simon, 1959), who tend to minimize their losses against landslides slowly over

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time via a trial-and-error learning process driven by personal experience in an uncertain environment (Dutt and Gonzalez, 2010; Slovic et al., 2005).

In this paper, we evaluate the influence of differing strengths of experiential feedback about landslide-related damages and the experiential feedback's availability in the ILS tool. More specifically, we test whether people increase their mitigation actions in the presence of experiential damage feedback compared to in the absence of this feedback. In addition, we evaluate how different probabilities of damages influence people's mitigation actions in the ILS tool. Furthermore, we also analyse people's mitigation actions over time across different conditions.

In what follows, first, we detail a computational model on landslide risks that considers the role of both human factors and physical factors. Next, we detail the working of the ILS tool, i.e., based on the landslide model. Furthermore, we use the ILS tool in an experiment to evaluate the influence of differing strengths of experiential feedback and feedback's availability on people's decisions. Finally, we close this paper by discussing our results and detailing the benefits of using tools like ILS for communicating landslide risks in the real world.

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2 Computational model of landslide risk

Chaturvedi et al. (2017) had proposed a computational model for simulating landslide risks that was based upon the integration of human and physical factors (see Figure 1). Here, we briefly detail this model and use it in the ILS tool for our experiment (reported ahead). As seen in Figure 1, the probability of landslides due to human factors in the ILS tool is adapted from a model suggested by Hasson et al. (2010) (see box 1.1 in Figure 1). In Hasson et al. (2010)'s model, the probability of a disaster (e.g., landslide) due to human factors (e.g., investment) was a function of the cumulative monetary contributions made by participants to avert the disaster from the total endowment available to participants. Thus, investing against the disaster in mitigation measures reduces the probability of the disaster and not investing in mitigation measures increases the probability of the disaster.[1]

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Furthermore, in the landslide model, the probability of landslides due to physical (natural) factors (see box 1.2) is a function of the prevailing rainfall conditions and the nature of geology in the area (Mathew et al., 2013).[2] As shown in Figure 1, the ILS model focuses on calculation of total probability of landslide (due to physical and human factors) (box 1.3). This total probability of landslide is calculated as a weighted sum of probability of landslide due to physical factors and probability of landslide due to human factors. Furthermore, the model simulates different types of damages caused by landslides and their effects on people's earnings (box 1.4).

[1] Although we assume this model to incorporate human mitigation actions in the ILS tool, there may also be other model assumptions possible where certain detrimental human actions (e.g., deforestation) may increase the probability of landslides or the risk (probability * consequence) of landslides. We plan to consider these model assumptions as part of our future research. In addition, there may be contributions made the national, regional, and local governments for providing protection measures against landslides in addition to the investments made by people residing in the area. In this paper, however, we restrict our analyses to only people's investments influencing landslides. We plan to consider the role of governments as part of our future research.

[2] We restrict our focus to considering only weather (rainfall)-induced landslides.

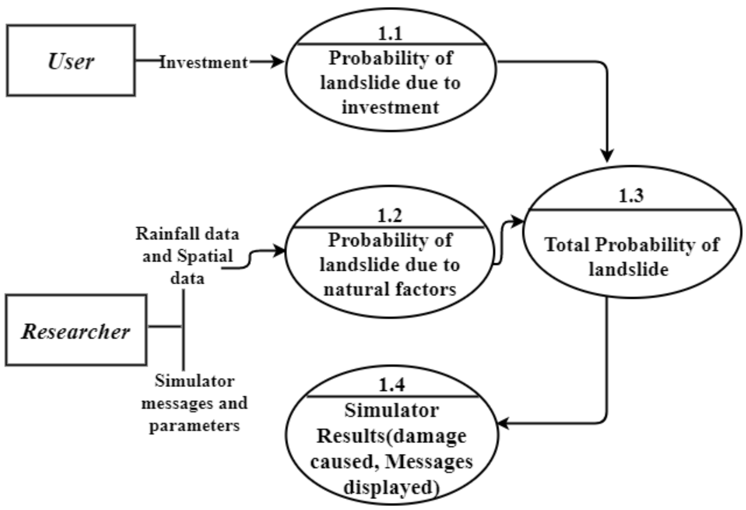

Figure 1. Probabilistic model of the Interactive Landslide Simulator tool. Figure adapted from Chaturvedi et al. (2017).

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2.1 Total probability of landslides

As described by Chaturvedi et al. (2017), the total probability of landslides is a function of landslide probabilities due to human factors and physical factors. This total probability of landslides can be represented as the following:

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$$P(T) = \big(W * P\,(I) + \,(1 - W) * P\,(E)\big) \quad (1)$$

Where W is a free weight parameter in [0, 1]. The total probability formula involves calculation of two probabilities, probability of landslide due to human investments (*P(I)*) and probability of landslide due to physical factors (*P(E)*). These probabilities have been defined below. According to Equation 1, the total probability of landslides will change based upon both human decisions and environmental factors over time. A landslide occurs when a uniformly distributed random number (~ *U(0, 1)*) became less than or equal to *P(T)* on a certain day in the ILS tool. [3]

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2.1.1 Probability of landslide due to human investments (*P(I)*)

As suggested by Chaturvedi et al. (2017), this probability is calculated using the probability model suggested by Hasson et al. (2010). In this model, P(I) is directly proportional to the amount of money invested by participants for landslide mitigation. The probability of landslide due to human investments is:

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$$P(I) = 1 - \frac{M * \sum_{i=1}^{n} x_i}{n * B} \qquad (2)$$

Where,

[3] If a uniformly distributed random number in [0, 1] (*U (0, 1)*) is less than a probability value, then it simulates this probability value. For example, if *U (0, 1)* < 30%, then *U(0, 1)* will be less than the 30% value exactly 30% of the total number of times it is simulated and thus this process will simulate a 30% probability value.

B = Budget available towards addressing landslides for a day (if a person earns an income or salary, then B is the same as this income or salary earned in a day).

n = Number of days.

x_i = Investments made by a person for each day i to mitigate landslides; $x_i \leq B$.

M = Return to Mitigation, which is a free parameter and captures the lower bound probability of $P(I)$, i.e., $P(I) = 1-M$ when a person puts her entire budget B into landslide mitigation ($\sum_{i=1}^{n} x_i = n * B$); $0 \leq M \leq 1$.

People's monetary investments (x_i) are for mitigation measures like building retaining walls or planting long root crops.

2.1.2 Probability of landslide due to physical factors (*P(E)*)

Some of the physical factors impacting landslides include rainfall, soil type, and slope profile (Chaturvedi et al., 2017; Dai et al., 2002). These factors can be categorized into two parts:

1. Probability of landslide due to rainfall (*P(R)*)
2. Probability of landslide due to soil type and slope profile (spatial probability, *P(S)*)

For the sake of simplicity, we have assumed that spatial probability of landslide is independent of the triggering probability of landslide due to rainfall. Given *P(R)* and *P(S)*, the probability of landslide due to physical factors, *P(E)* is defined as:

$$P(E) = P(R) * P(S) \quad (3)$$

The methodology adopted here comprises of two steps. In the first step, *P(R)* is calculated based upon a logistic-regression model (Mathew et al., 2013) as follows:

$$P(R) = \frac{1}{1+e^{-z}} \quad (4a)$$

And,

$$z = -3.817 + (DR) * 0.077 + (3DCR) * 0.058 + (30DAR) * 0.009$$

$$z: (-\infty, +\infty) \quad (4b)$$

Where, the DR, $3DCR$, and $30DAR$ is the daily rainfall, the 3-day cumulative rainfall, and the 30-day antecedent rainfall. This model in equations 4a and 4b was developed for the study area by Mathew et al. (2013) and we have used the same model in this paper. The rainfall parameters in the model were calculated from the daily rain data from the Indian Metrological Department (IMD). Five years of daily rain data (2010-14) from IMD was averaged to find the average rainfall values on each day out of the 365 days in a year. Next, these averaged rainfall values were put into equations 4a and 4b to generate the landslide probability due to rainfall (P(R)) over an entire year. Figure 4 shows the shape of P(R) as a function of days in the year for the study area. Given the monsoon period in India during July – September, there is a peak in the P(R) distribution curve during these months. Depending upon the start date in the ILS tool, one could read P(R) values from Figure 2, as the probability of landslides due to rainfall on a certain date. This P(R) function was assumed to possess the same shape across all participants in the ILS tool.

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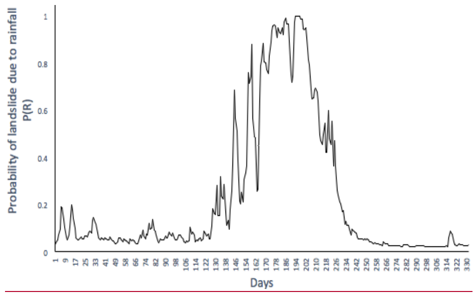

Figure 2: Probability of landslide due to rainfall over days for the study area. The probability was generated by using equations 4a and 4b.

The second step is to evaluate the spatial probability of landslides, *P(S)*. The determination of *P(S)* is done from Landslide Susceptibility Zonation (LSZ) map of the area (Anbalagan, 1992; Chaturvedi et al., 2017; Clerici et al., 2002), which are based on various causative factors for landslides (such as geological, geometry, geomorphological factors) in the study area. The spatial probability is computed based upon the Total Estimated Hazard (THED) rating of different locations on a LSZ map and their surface area of coverage (the maximum possible value of THED is 11.0 and its minimum possible value is 0.0). Table 1 provides the THED scale to report the susceptibility of an area to landslides (Anbalagan, 1992).

Table 1. Total Estimated Hazard (THED) scale for evaluating the susceptibility of an area to landslides

Hazard Zone	Range of corrected THED	Description of zone
I	THED < 3.5	Very low hazard (VLH) zone
II	3.5 ≤ THED < 5.0	Low hazard (LH) zone
III	5.0 ≤ THED ≤ 6.5	Moderate hazard (MH) zone
IV	6.5 < THED ≤ 8.0	High Hazard (HH) zone
V	THED > 8.0	Very high hazard (VHH) zone

First, from Table 1, the critical THED values (e.g., 3.5, 5.0, 6.5, and 8.0) were converted into a probability value by dividing with the highest THED value (= 11.0). Next, we used the LSZ map of the study area to find the surface area that was under a specific THED value and used this area to determine the cumulative probability density function for *P(S)*. For example, if a THED of 3.5 has a 20% coverage area on LSZ, then the spatial probability is less than equal to 0.32 (=3.5/11.0) with a 20% chance. Similarly, if a THED of 5.0 has a 30% coverage area on LSZ, then the then the spatial probability is less than equal to 0.45 (=5.0/11.0) with a 50% chance (30% + 20%). Such calculations enabled us to develop a cumulative density function for *P(S)*. In the ILS tool, a participant was assumed to belong to a location in the study area and this study area determined the *P(S)* value. This *P(S)* value stayed the same for this participant across her performance in the ILS tool.

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2.1.3 Damages due to landslides

As suggested by Chaturvedi et al. (2017), the damages caused by landslides were classified into three independent categories: property loss, injury, and fatality. These categories have their own damage probabilities. When a landslide occurs, it could be benign or catastrophic. A landslide becomes catastrophic when any of the three independent random numbers (~ *U(0, 1)*) become less than or equal to the corresponding damage probability of property loss, injury, and fatality. Once the random number is less than the probability of the corresponding damage, the damage occurs. Landslide damages have different effects on the player's wealth and income, where damage to property affects one's property wealth and damages concerning injury and fatality affect one's income level. When the landslide is benign, then there is no injury, fatality, or damage to property. The exact assumptions about damages are detailed ahead in this manuscript.

3 Interactive Landslide Simulator (ILS) tool

The ILS tool[4] (Chaturvedi et al., 2017) is a web-based tool and it is based upon the ILS model described above. The ILS tool allows participants to make repeated monetary investment decisions for landslide risk-mitigation, observe the consequences of their decisions via feedback, and try new investment decisions. This way, ILS helps improve people's understanding about the causes and consequences of landslides. The ILS tool can run for different time periods, which could be from days to months to years. This feature can be customized in the ILS tool. In this paper, we have assumed a daily time-scale to make it match the daily probability of landslides computed in equations 4a and 4b.

The goal in ILS tool is to maximize one's total wealth, where this wealth is influenced by one's income, property wealth, and losses experienced due to landslides. Landslides and corresponding losses are influenced by physical factors (spatial and temporal probabilities of landslides) and human factors (i.e., the past contributions made by a participant for landslide mitigation). The total wealth may decrease (by damages caused by landslides, like injury, death, and property damage) or increase (due to daily income). While interacting with the tool, the repeated feedback on the positive or negative consequences of their decisions on their income and property wealth enables participants to revise their decisions and learn landslide risks and dynamics over time.

Figure 3 represents graphical user interface of ILS tool's investment screen. On this screen, participants are asked to make monetary mitigation decisions up to their daily income upper bound (see Box A). The total wealth is a sum of income not invested for landslide mitigation, property wealth, and total damages due to landslides (see Box B). As shown in Box B, participants are also shown the different probabilities of landslide due to human and physical factors as well as the probability weight used to combine these probabilities into the total probability. Furthermore, as shown in Box C, participants are graphically shown the history of total probability of landslide, total income not invested in landslides, and their remaining property wealth across different days.

[4] The ILS tool was coded in open-source programming languages PHP and MySQL and it is freely available for use at the following URL: www.pratik.acslab.org

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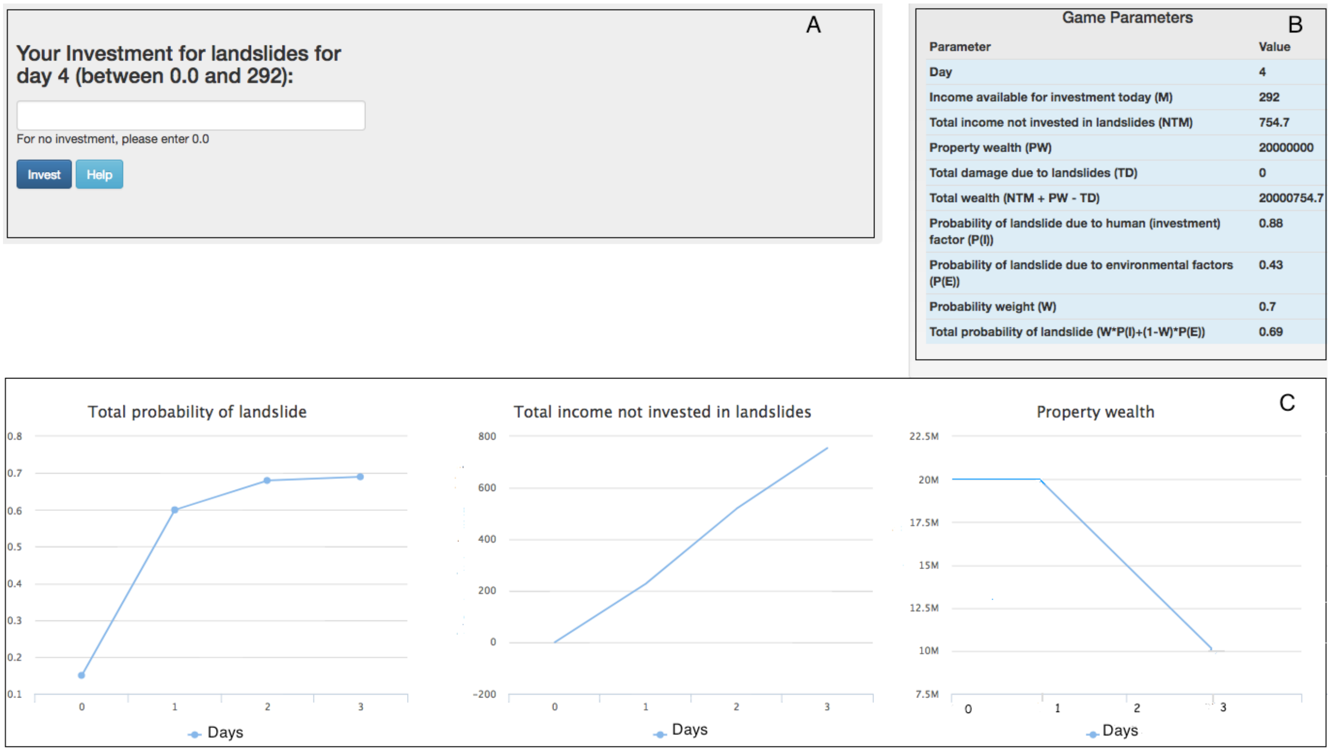

Figure 3. ILS tool's Investment Screen. Box **(A):** The text box where participants made investments against landslides. Box **(B):** The tool's different parameters and their values. Box **(C):** Line graphs showing the total probability of landslide, the total income not invested in landslides, and the property wealth over days. Horizontal axes in these graphs represents number of days. The goal was to maximize Total Wealth across a number of days of performance in the ILS tool. This figure is adapted from Chaturvedi et al. (2017).

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As described above, participants, i.e., common people residing in the study area, could invest between zero (minimum) and player's current daily income (maximum). Once the investment is made, participants need to click the "Invest" button. Upon clicking the Invest button, participants enter the experiential feedback screen where they can observe whether a landslide occurred or not and whether there were changes in the daily income, property wealth, and damages due to the landslide (see Figure 4). As discussed above, the landslide occurrence was determined by the comparison of a uniformly distributed random number in [0, 1] with *P(T)*. If a uniformly distributed random number in [0, 1] was less than or equal to *P(T)*, then a landslide occurred; otherwise, the landslide did not occur. Furthermore, if the landslide occurred, then three uniformly distributed random numbers in [0, 1] were compared with the probability of injury, fatality, and property damage, respectively. If the values of any of these random numbers were less than or equal to the corresponding injury, fatality, or property-damage probabilities, then the landslide was catastrophic (i.e., causing injury, fatality, or property damage; all three events could occur simultaneously). In contrast, if the random numbers were more than the corresponding injury, fatality, and property-damage probabilities, then the landslide was benign (i.e., it did not cause injury, fatality, and property damage). As shown in Figure 4 (A), feedback information is presented in three formats: monetary information about total wealth (box I), messages about different losses (box I), and imagery corresponding to losses (box II). Injury and fatality due to landslides causes a decrease in the daily income and damage to property causes a loss of property wealth (the exact loss proportions are detailed ahead). If a landslide does not occur in a certain trial, a positive feedback screen is shown to the decision maker (see Figure 4 B). The user can get back to investment decision screen by clicking on "Return to Game" button on the feedback screen.

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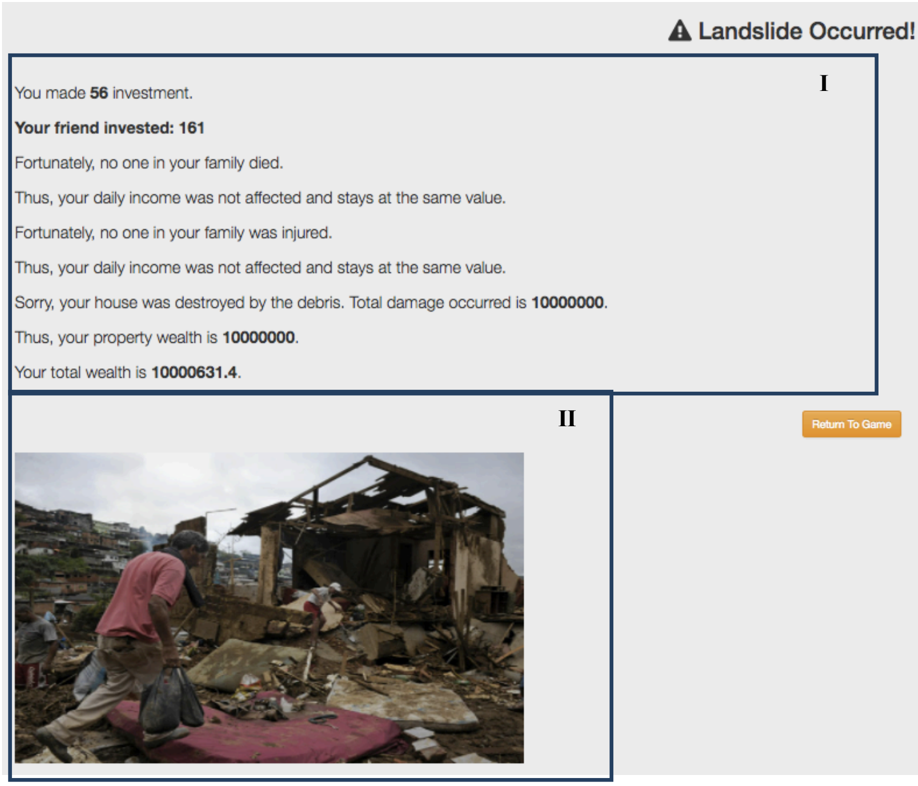
(A) Negative Feedback



(B) Positive Feedback

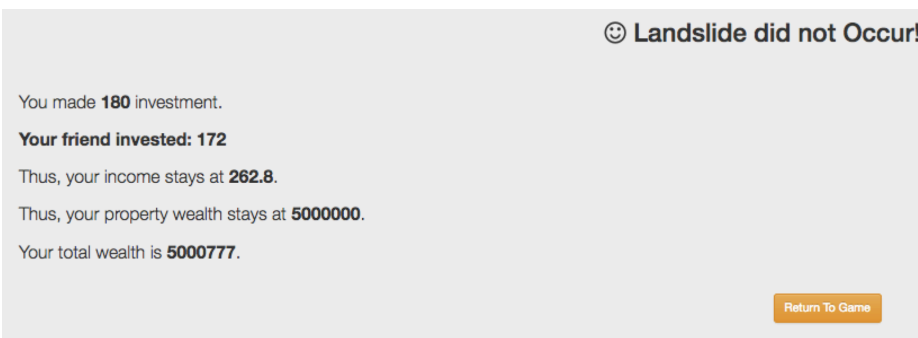


Figure 4. ILS tool's feedback screens. **(A)** Negative feedback when a landslide occurred. Box (I) contains the loss in terms of magnitude and messages and Box (II) contains associated imagery. **(B)** Positive feedback when a landslide did not occur.

4 Methods

To test the effectiveness of strength and availability of feedback, we performed a laboratory experiment involving human participants where we compared performance in the ILS tool in the presence or absence of experiential feedback about different damage probabilities. Based upon prior literature (Baumeister et al., 2007; Dutt and Gonzalez, 2012; Finucane et al., 2000; Knutty, 2005; Reis and Judd, 2013; Wagner, 2007), we expected the proportion of investments to be higher in the presence of experiential feedback compared to those in the absence of experiential feedback. Furthermore, we expected higher investments against landslides when feedback was more damaging in ILS compared to when it was less damaging (Chaturvedi et al., 2017; Dutt and Gonzalez, 2011; Gonzalez and Dutt, 2011a).

4.1 Experimental Design

Eighty-three participants were randomly assigned across four between-subjects conditions in the ILS tool, where the conditions differed in the strength of experiential feedback (high-damage (N= 40) or low-damage (N= 43)) and availability of feedback (feedback-present (N= 43) or feedback-absent (N= 40)) provided after every mitigation decision.[5] They were asked to invest repeatedly against landslides across 30-days. In feedback-present conditions, participants made investment decisions on the investment screen and then they received feedback about the occurrence of landslides or not on the feedback screen. Participants were also provided graphical displays showing the total probability of landslides, the total income not invested in landslides, and the property wealth over days. Figures 3 and 4 show the investment and feedback screen that were shown to participants in the feedback-present conditions. In feedback-absent conditions, participants were given a text description and they made an investment decision, however, neither they were shown the feedback screen nor they were shown the graphical displays on the investment screen. Thus, in the feedback-absent condition, although participants were provided with the probability of damages due to landslides and the results of 0% and 100% investments as a text description, however, they were not shown the feedback screen as well as the graphical displays on the investment screen. Figures 5A and 5B show the text description and investment screen (without graphical displays) shown to participants in the feedback-absent conditions. In high-damage conditions, the probability of property damage, fatality and injury on any trial were set at 30%, 9%, and 90%, respectively, over 30-days. In low-damage conditions, the probability of property damage, fatality and injury on any trial were set at 3%, 1%, and 10%, respectively, over 30-days (i.e., about 1/10th of its values in the high-damage condition). Across all conditions, participants made one investment decision per trial across 30-days (this end-point was unknown to participants). Participants' goal was to maximize their total wealth

[5] An experiment involving the high-damage feed-present condition (N = 20) and the low-damage feedback-present condition (N = 23) in the ILS tool was reported by Chaturvedi et al. (2017). This data has been included in this paper with two more conditions, the high-damage feedback-absent (N = 20) and the low-damage feedback-absent (N = 20). Data in all four conditions was collected simultaneously.

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over 30-days. Across all conditions, only 1-landslide could occur on a particular day. The nature of functional forms used for calculating different probabilities in ILS were unknown to participants.

The proportion of damage (in terms of daily income and property wealth) that occurred in an event of fatality, injury, or property damage was kept constant across 30-days. The property wealth decreased to half of its value every time property damage occurred in an event of a landslide. The daily income was reduced by 10% of its latest value due to a landslide-induced injury and 20% of its latest value due to a landslide-induced fatality. The initial property wealth was fixed to 20 million EC[6], which is the expected property wealth in Mandi area. The initial per-trial income was kept at 292 EC (taking into account the GDP and per-capita income of Himachal state where Mandi is located). Overall, there was a large difference between the initial income earned by a participant and the participant's initial property wealth. In this scenario, the optimal strategy dictates participants to invest their entire income in landslide protection measures, since participants' goal was to maximize total wealth. The weight (W) parameter in the equation 1 of the ILS model was fixed at 0.7 across all conditions. The value of the W parameter ensured that participants' investment decisions played a dominant role in influencing the total landslide probability. Also, the value of the W parameter was shown to participants through the investment screen on the ILS tool's interface (see Figures 3 and 5). Furthermore, the return to mitigation free parameter (M) was set at 0.8. Again the value of the M parameter ensured that probability of landslides reduced to 20% when participants invested their daily income in full. Participants performed in the ILS for 30-days, starting in mid-July and ending in mid-August. This period coincided with the period of heavy monsoon rainfall in Mandi area. Thus, participants performing in ILS experienced an increasing probability of landslides due to environmental factors (due to increasing amount of rainfall overtime). We used the investment ratio as a dependent variable for the purpose of data analyses.

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The investment ratio was defined as the ratio of investment made in a trial to total investment that could have been made up to the same trial. This investment ratio was averaged across all participants in one case and averaged over all participants and days in another case. We expected the average investment ratio to be higher in the feedback-present and high-damage conditions compared to feedback-absent and low-damage conditions. We took an alpha-level (the probability of rejecting the null hypothesis when it is true) to be 0.05 (or 5%).

[6] To avoid the effects of currency units on people's decisions, we converted Indian National Rupees (INR) to a fictitious currency called "Electronic Currency (EC)," where 1 EC = 1 INR.

A

Instructions

Welcome! You are a resident of Mandi district of Himachal Pradesh, India, a township in the lap of Himalayas. You live in an area that is highly prone to landslides due to several environmental factors (e.g., the prevailing geological conditions and rainfall). During the monsoon season, due to high intensity and prolonged period of rainfall, landslides may occur in the Mandi district. These landslides may cause fatalities and injuries to you, your family, and to your friends, who reside in the same area. In addition, landslides may also damage your property and cause loss to your property wealth.

In this task, you will be repeatedly making daily investment decisions to mitigate landslides over a period of several days. We use a fictitious currency called "EC". Every day, you earn 292 EC. This money is your daily income and you may use a part or whole of it for making investments against landslides. Your investments will be used to provide landslide mitigation measures like planting trees and building reinforcements, both of which prevent landslides from occurring. Every day, you may decide to invest a certain monetary amount from your income towards landslide mitigation; however, you may also decide not to invest anything on a day (in which case, you invest 0.0 against landslides).

Your total wealth at any point in the game is the following: sum of the amounts you did not invest against landslides across days + your property wealth - damages to you, your family, your friends, and to your property due to landslides. Your property wealth is assumed to be 20 million EC at the start of the task. **The income invested against landslides is lost and it cannot contribute to the total wealth. Your goal in this task is to maximize your total wealth.**

Generally, landslides are triggered by two main factors: environmental factors (e.g., rainfall; outside one's control) and investment factors (money invested against landslides; within one's own control). The total probability of landslide = 0.2 * probability of landslide due to environment factors + 0.8 * probability of landslide due to investment factors.

Whenever a landslide occurs, if it causes fatality, then your daily earnings will be reduced by 5% of its value. If landslide causes injury to you or your family member, then your daily earnings will be reduced by 2.5% of its value. Furthermore, if a landslide occurs and it causes property damage, then your property wealth will be reduced by 80% of its value; however, the money available to you to invest against landslides due to your daily earnings will remain unaffected.

If the probability of property damage, fatality, and injury due to landslides were 30%, 9%, and 90%, respectively, then the damages due to landslides were 197 million EC with 0 EC per day investment and 114 million EC with 292 EC per day investment.

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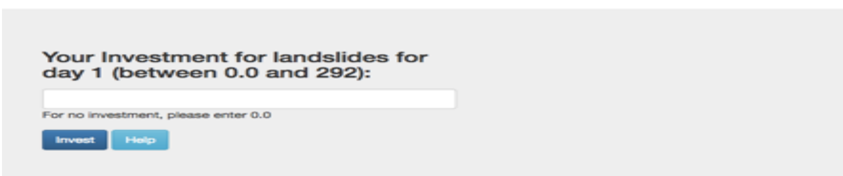

Figure 5. The ILS tool in the feedback-absent condition. Participants were tasked to enter across 30-days how much out of 292 EC they were willing to contribute against landslides. The task was similar in the high-damage feedback-absent condition, however, the damage percentages in the last paragraph were 30%, 9%, and 90%, respectively. **(A)** Instructions given to participants. **(B)** Investment screen (without graphical displays).

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Deleted: The ILS tool in the feedback-absent condition. Participants were tasked to enter across 30-days how much out of 292 EC they were willing to contribute against landslides. The task was similar in the high-damage feedback-absent condition; however, the damage percentages in the last paragraph were 30%, 9%, and 90%, respectively.

4.2 Participants

Participants were recruited from Mandi area via an online advertisement. The research was approved by the Ethics Committee at Indian Institute of Technology Mandi. Informed consent was obtained from each participant and participation was completely voluntary. All participants were from Science, Technology, Engineering, and Mathematics (STEM) backgrounds and their ages ranged in between 21 and 28 years (Mean = 22 years; Standard Deviation = 2.19 years). The following percentage of participants were pursuing or had completed different degrees: 6.0% high-school degrees; 54.3% undergraduate degrees; 33.7% Master's degrees; and, 6.0% Ph.D. degrees. The Mandi area is prone to landslides and most participants self-reported to be knowledgeable or possess basic understanding about landslides. The literacy rate in Mandi and surrounding area is quite high (81.5%) (Census, 2011) and our sample was representative of the population residing in this area. When asked about their previous knowledge about landslides, 2.4% claimed to be highly knowledgeable, 16.8% claimed to be knowledgeable, 57.8% claimed to have basic understanding, 18.2% claimed to have little understanding, and 4.8% claimed to have no idea. All participants received a base payment of INR 50 (~ USD 1). In addition, there was a performance incentive based upon a lucky draw. Top-10 performing participants based upon total wealth remaining at the end of the study were put in a lucky draw and one of the participants was randomly selected and awarded a cash prize of INR 500. Participants were told about this performance incentive before they started their experiment.

4.3 Procedure

Experimental sessions were about 30-minutes long per participant. Participants were given instructions on the computer screen and were encouraged to ask questions before starting their study. Once participants had finished their study, they were asked questions related to what information and decision strategy they used on the investment screen and the feedback screen to make their decisions. Once participants ended their study, they were thanked and paid for their participation.

5 Results

5.1 Investment Ratio Across Conditions

The data were subjected to a 2 × 2 repeated-measures analysis of variance. As shown in Figure 6A, there was a significant main effect of feedback's availability: the average investment ratio was higher in feedback-present conditions (0.53) compared to that in feedback-absent conditions (0.37) (F (1, 79) = 8.86, p < 0.01, η^2 = 0.10)[7]. The bracket values are indicative of the F-value, its significance and effect size. This result is as per our expectation and shows that the presence of experiential feedback in ILS tool helped participants increase their investments against landslides compared to investments in the absence of this feedback.

[7] We performed analysis of variance statistical tests for evaluating our expectations. The F-statistics is the ratio of between-group variance and the within-group variance. The numbers in brackets after the F-statistics are the degrees of freedom (K-1, N - K), where K are the total number of groups compared and N is the overall sample size. The p-value indicates the evidence in favor of the null-hypothesis when it is true. We reject the null-hypothesis when p-value is less than the alpha-level (0.05). The η^2 is the proportion of variance associated with one or more main effects. It is a number between 0 and 1 and a value of 0.02, 0.13, and 0.26 measures a small, medium, or large correlation between the dependent and independent variables given a population size.

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As shown in Figure 6B, there was a significant main-effect of strength of feedback: the average investment ratio was significantly higher in high-damage conditions (0.51) compared to that in low-damage conditions (0.38) (F (1, 79) = 5.46, p < 0.05, η^2 = 0.07). Again, this result is as per our expectation and shows that high-damaging feedback helped participants increase their investments against landslides compared low-damaging feedback.

Furthermore, as shown in Figure 6C, the interaction between the strength of feedback and feedback's availability was significant (F (1, 79) = 8.98, p < 0.01, η^2 = 0.10). There was no difference in the investment ratio between the high-damage condition (0.35) and low-damage condition (0.38) when experiential feedback in ILS was absent, however, the investment ratio was much higher in the high-damage condition (0.67) compared to the low-damage condition (0.38) when experiential feedback in ILS was present (Chaturvedi et al., 2017). Thus, feedback needed to be damaging in ILS to cause an increase in investments in mitigation measures against landslides.

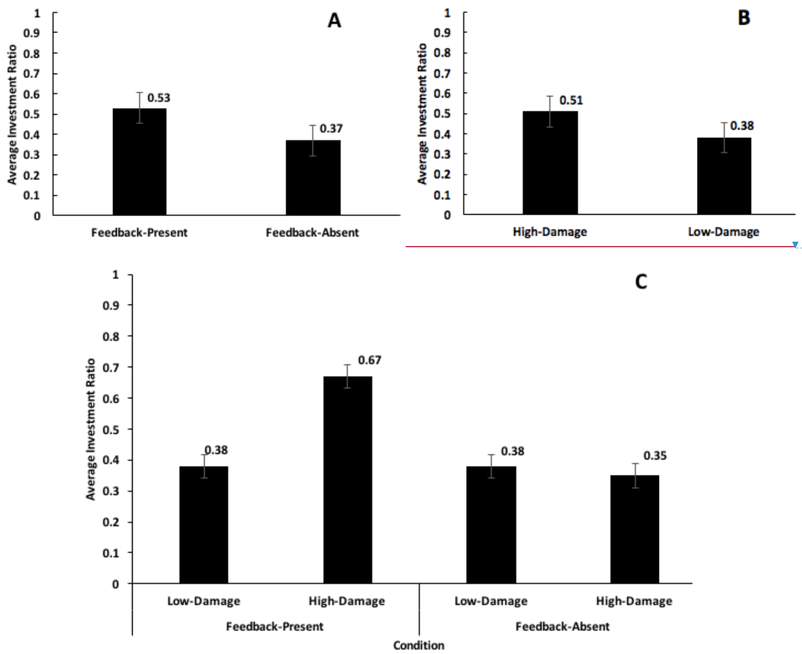

Figure 6. (A) Average investment ratio in Feedback-present and Feedback-absent conditions. **(B)** Average investment ratio in low- and high-damage conditions. **(C)** Average investment ratio in low- and high-damage conditions with Feedback-present and absent. The error bars show 95% Confidence Interval (CI) around the point estimate.

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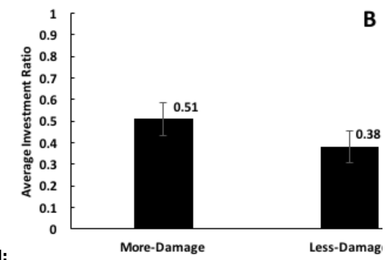

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5.2 Investment Ratio Across Days

The average investment ratio increased significantly over 30-days (see Figure 7A; F (8.18, 646.1) = 8.35, $p < 0.001$, $\eta^2 = 0.10$). As shown in Figure 7B, the average investment ratio increased rapidly over 30-days in feedback-present conditions, however, the increase was marginal in feedback-absent conditions (F (8.18, 646.1) = 3.98, $p < 0.001$, $\eta^2 = 0.05$). Furthermore, in feedback-present conditions, the average investment ratio increased rapidly over 30-days in high-damage conditions, however, the increase was again marginal in the low-damage conditions (see Figure 7C; F (8.18, 646.1) = 6.56, $p < 0.001$, $\eta^2 = 0.08$). Lastly, as seen in Figure 7D, although there were differences in the increase in average investment ratio between low-damage and high-damage conditions when experiential feedback was present, however, such differences were non-existent between the two damage conditions when experiential feedback was absent (F (8.18, 646.1) = 4.16, $p < 0.001$, $\eta^2 = 0.05$). Overall, ILS performance helped participants increase their investments for mitigating landslides when damage feedback was high compared to low in ILS.

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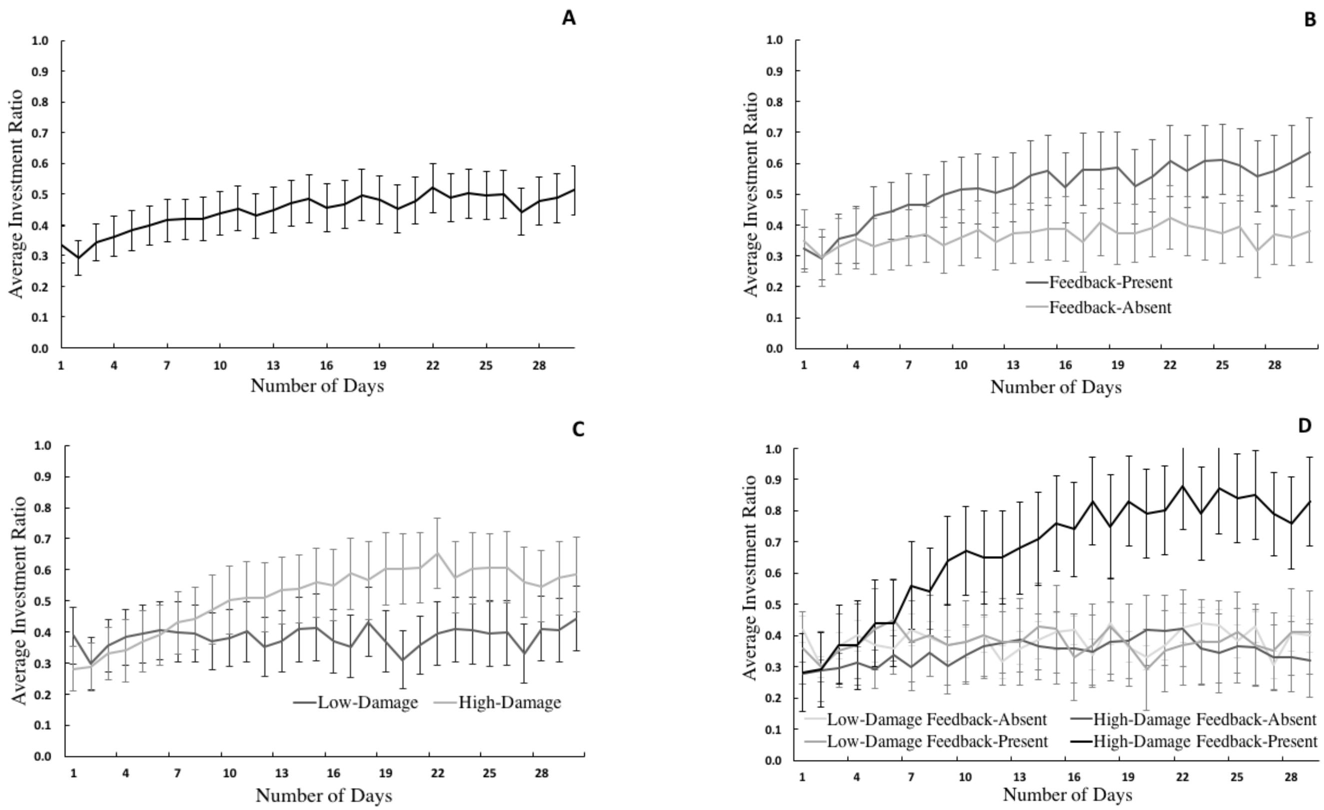

Figure 7. (A) Average investment ratio over days. **(B)** Average investment ratio over days in Feedback-present and Feedback-absent conditions. **(C)** Average investment ratio over days in low- and high-damage conditions. **(D)** Average investment ratio over days in low- and high- damage conditions with Feedback-present or absent. The error bars show 95% CI around the point estimate.

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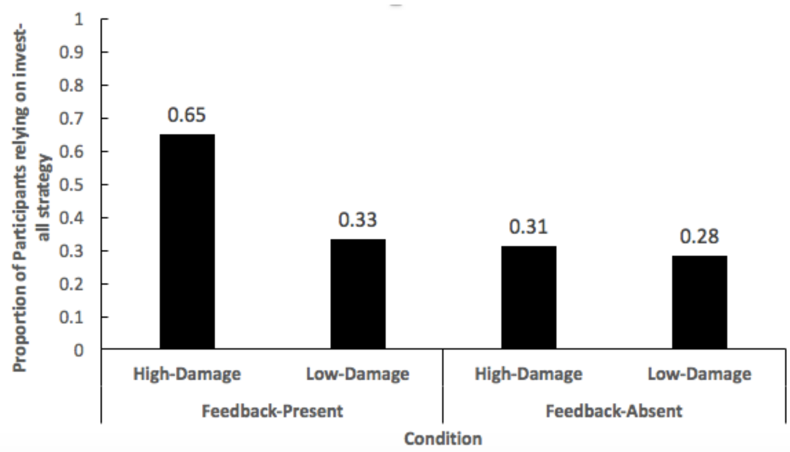

Figure 8. The proportion of reliance on the invest-all strategy across different conditions.

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However, in feedback's absence in ILS, participants were unable to increase their investments for mitigating landslides, even when damages were high compared to low.

5.3 Participant Strategies

We analyzed whether an "invest-all" strategy (i.e., investing the entire daily income in mitigating landslides) was reported by participants across different conditions. As mentioned above, the invest-all strategy was an optimal strategy and this strategy's use indicated learning in the ILS tool. Figure 8 shows the proportion of participants reporting the use of the invest-all strategy. Thus, many participants learnt to follow the invest-all strategy in conditions where experiential feedback was present and it was highly damaging compared to participants in the other conditions.

6 Discussion and Conclusions

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In this paper, we used an existing Interactive Landslide Simulator (ILS) tool for evaluating the effectiveness of feedback in influencing people's decisions against landslide risks. We used the ILS tool in an experiment involving human participants and tested how the strength and availability of experiential feedback in ILS helped increase people's investment decisions against landslides. Our results agree with our expectations: Experience gained in ILS enabled improved understanding of processes governing landslides and helped participants improve their investments against landslides. Given our results, we

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First, the high-damaging feedback helped increase people's investments against landslides over time compared to the low-damaging feedback. Furthermore, the feedback's presence helped participants increase their investments against landslides over time compared to feedback's absence. These results can be explained by the previous lab-based research on use of repeated feedback or experience (Chaturvedi et al., 2017; Dutt and Gonzalez, 2010, 2011; Finucane et al., 2000; Gonzalez and Dutt, 2011a). Repeated experiential feedback likely enables learning by repeated trial-and-error procedures, where bounded-rational individuals (Simon, 1959) try different investment values in ILS and observe their effects on the occurrence of landslides and their associated consequences. The negative consequences due to landslides are higher in conditions where the damages are more compared to conditions where the damages are less. This difference in landslide consequences influences participants' investments against landslides. According to Slovic et al. (2005), loss-averse individuals tend to increase their contribution against a risk over time. In our case, similar to Slovic et al. (2005), participants started contributing slowly against landslides and, with the experience of landslide losses over time, they started contributing larger amounts to reduce landslide risks.

We also found that the reliance on invest-all strategy was higher in the high-damage and feedback-present condition compared to the low-damage and feedback-absent condition. The invest-all strategy was the optimal strategy in the ILS tool. This result shows that participants learned the underlying system dynamics (i.e., how their actions influenced the probability of landslides) in ILS better in the feedback-rich condition compared to the feedback-poor condition. As participants were not provided with exact equations governing the ILS tool and they had to only learn from trial-and-error feedback, the saliency of the feedback due to messages and images likely helped participants' learning in the tool. In fact, we observed that the use of the optimal invest-all strategy was maximized when the experiential feedback was highly damaging. One likely reason for this observation could be the high educational levels of participants residing in the study area, where the literacy rate was more than 80%. Thus, it seems that participants' education levels helped them make the best use of damaging feedback.

We believe that the ILS tool can be integrated in teaching courses on landslide sustainable practices in schools from kindergarten to standard 12th. These courses could make use of the ILS tool and focus on educating students about causes, consequences, and risks of hazardous landslides. We believe that the use of ILS tool will make teaching more effective as ILS will help incorporate experiential feedback and other factors in teaching in interactive ways. The ILS tool's parameter settings could be customized to a certain geographical area over a certain time period of play. In addition, the ILS tool could be used to show participants the investment actions other participants (e.g., society or neighbours). The presence of investment decisions of opponents in addition to one's own decisions will likely enable social norms to influence people's investments and learning in the tool (Schultz et al., 2007). These features makes ILS tool very attractive for landslide education in communities in the future.

Furthermore, the ILS tool holds a great promise for policy-research against landslides. For example, in future, researchers may vary different system-response parameters in ILS (e.g. weight of one's decisions and return to mitigation

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actions) and feedback (e.g. numbers, text messages and images for damage) in order to study their effects on people's decisions against landslides. Here, researchers could evaluate differences in ILS's ability to increase public contributions in the face of other system-response parameters and feedback. In addition, researchers can use the ILS tool to do "what-if" analyses related to landslides for certain time periods and for certain geographical locations. The ILS tool has the ability to be customized to certain geographical area as well as certain time periods, where spatial parameters (e.g., soil type and geology) as well as temporal parameters (e.g., daily rainfall) can be defined for the study area. Once the environmental factors have been accounted for, the ILS tool enables researchers to account for assumptions on human factors (contribution against landslides) with real-world consequences (injury, fatality, and infrastructure damage). Such assumptions may help researchers model human decisions in computational cognitive models, which are based upon influential theories of how people make decisions from feedback (Dutt and Gonzalez, 2012; Gonzalez and Dutt, 2011b). In summary, these features make ILS tool apt for policy research, especially for areas that are prone to landslides. This research will also help test the ILS tool and its applicability in different real-world settings.

Although the ILS tool causes the use of optimal invest-all strategies among people in conditions where experiential feedback is highly damaging, however, more research is needed on investigating the nature of learning that the tool imparts among people. As people's investments for mitigating landslides in ILS directly influences the risk of landslides due to human and environmental factors, investments indeed have the potential of educating people about landslide risks. Still, it is important to investigate how investing money in the ILS tool truly educates people about landslides.

Currently, in the ILS model, we have assumed that damages from fatality and injury influence participants' daily-income levels. The reduced income levels do create adverse consequences, but one could also argue that they would be much less of concern for most people compared to the injury and fatality itself. Furthermore, people could also choose to migrate from an area when the landslide mitigation cost is too high and adaptation becomes impossible, especially due to the differences between the landslide hazard and other hazards such as flood, drought, and general climate risks. As part of our future research, we plan to investigate the influence of feedback that causes only injuries or fatalities compared to the feedback that causes economic losses due to injuries and fatalities. Also, as part of our future research in the ILS tool, we plan to investigate people's migration decisions when the landslide mitigation costs are too high and adaptation to landslides is not possible.

In the ILS model, we used a linear model to compute the probability of landslides due to human factors. Also, the probabilistic equations governing the physical factors in the ILS model were not disclosed to participants, who seemed to possess high education levels. One could argue that there are several other linear and non-linear models that could help compute the probability of landslides due to human factors. Some of these models could not only influence the probability of landslides, but also the severity of consequences (damages) caused by landslides. Also, other generic models could account for the physical factors in the ILS tool. We plan to try these possibilities as part of our future work in the ILS tool. Specifically, we plan to assume different models of investments in the ILS tool and we plan to test them against participants with different education levels.

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In the current experiment, we assumed a large disparity between a participant's property wealth and her daily income. In addition, as part of the ILS model, we did not consider any support from government or international agencies against damages from landslides. In certain cases, especially in developing countries, mitigation of landslide risks may often be financed by government or international agencies. As part of our future work, we plan to extend the ILS model to include assumptions of contributions from government or international agencies. Such assumptions will help us determine the willingness of common people to contribute against landslide disasters, which is important as the developing world becomes developed over time.

To test our hypotheses, we presented participants with a high damage scenario and a low damage scenario, where the probabilities of property damage, injury, and fatality were high and low, respectively. However, such scenarios may not be realistic, where people may want to migrate from both low and damage areas in even the least developed countries. In future research with ILS, we plan to calibrate the probability of damages, injury, and fatality to realistic values and test the effectiveness of ILS in improving the participants' investment decision making.

Furthermore, in our experiment, when landslide did not occur and experiential feedback was present, people were presented with a smiling face followed by a message. The message and emoticon were provided to connect the cause-and-effect relationships for participants in the ILS tool. However, it could also be that the landslide did not occur on a certain trial due to the stochasticity in the simulation rather than participants' investment actions. Although such situations are possible over shorter time-periods, however, over longer time-periods increased investments from people will only reduce the probability of landslides.

In this paper, the experiment used a daily investment setting in the ILS tool. However, the ILS tool can easily be customized to different time periods ranging from seconds, minutes, hours, days, months, and years. As part of our future research, we plan to extend the daily assumption by considering people making decisions on longer time-scales ranging from months to years. In addition, in the experiment, we assumed a value of 0.7 and 0.8 for the weight (W) and return to mitigation (M) parameters. These W and M values indicated that landslide risks could largely be mitigated by human actions. However, this assumption may not be the case always, especially for mitigation measures like tree plantations. For example, afforestation alone may not help in reducing deep-seated landslides in hilly areas (Forbes, 2013). Thus, it would be worthwhile investigating as part of future research on how people's decision-making evolves in conditions where investments likely influence the landslide probability (higher values of W and M parameters) compared to conditions where investments unlikely influence the landslide probability (lower values of W and M parameters). Some of these ideas form the immediate next steps in our ongoing research program on landslide risk communication.

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Data availability. Data used in this article have not been deposited to respect the privacy of users. The data can be provided to readers upon request.

Author contributions. AA designed the website, administered the account, PC wrote the first draft of website articles and collected data. VD supervised the website contents. AA provided technical support for website maintenance. PC and VD analysed the data and prepared the manuscript. PC and VD revised the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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However, in feedback's absence in ILS, participants were unable to increase their investments for mitigating landslides, even when damages were high compared to low.

4.3 Participant Strategies

We analyzed whether an "invest-all" strategy (i.e., investing the entire daily income in mitigating landslides) was reported by participants across different conditions. As mentioned above, the invest-all strategy was an optimal strategy and this strategy's use indicated learning in the ILS tool. Figure 7 shows the proportion of participants reporting the use of the invest-all strategy. Thus, many participants learnt to follow the invest-all strategy in conditions where experiential feedback was present and it was highly damaging compared to participants in the other conditions.

Discussions and Conclusion

In this paper, we used an existing Interactive Landslide Simulator (ILS) tool for evaluating the effectiveness of feedback in influencing people's decisions against landslide risks. We used the ILS tool in an experiment involving human participants and tested how the amount and availability of experiential feedback in ILS, including the use of ILS tool itself, helped increase people's investment decisions against landslides. Our results agree with our expectations: Experience gained in ILS enabled improved understanding of processes governing landslides and helped participants improve their investments against landslides. Given our results, we believe that ILS could potentially be used as a landslide-education tool for increasing public understanding and awareness about landslides. The ILS tool can also be used by policymakers to do what-if analyses in different scenarios concerning landslides.

First, high-damaging feedback in ILS tool helped increase people's investment against landslides over time compared to low-damaging feedback in the tool. Furthermore, the experiential feedback helped participants increase their investments against landslides compared to conditions where this feedback was absent. These result can be explained by previous lab-based research on use of repeated feedback or experience (Chaturvedi et al., 2016; Dutt & Gonzalez, 2011; Fischoff, 2001; Finucane et al., 2000). Repeated experiential feedback likely enables learning by repeated trial-and-error procedures, where participants try different investment values in ILS and observe their effects on occurrence of landslides. This feedback is higher in the condition when damages are more compared to when damages are less and this difference in feedback influences participant investments against landslides. In fact, we observed that the use of the optimal invest-all strategy was maximized when the experiential feedback was highly damaging.

We also believe that the ILS tool can be integrated in teaching courses on landslide sustainable practices in K-12 schools. This course could make use of the ILS tool and focus on educating students about causes, consequences, and risks of hazardous landslides. We believe that the use of ILS tool will make teaching more effective as ILS will help incorporate experiential feedback and social norms in teaching in interactive ways.

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The ILS tool's parameter settings could be customized to a certain geographical area over a certain time period of play. In addition, the ILS tool could be used to present investment actions of other decision-makers (e.g., society or neighbours) compared to one's own investment actions. The presence of investment of other decision-makers in addition to one's own decisions will likely enable the use of social norms towards learning (Schultz et al., 2007). These features makes ILS tool very attractive for landslide education in communities in the future. Furthermore, the ILS tool holds a great promise for policy-research against landslides. For example, in future, researchers may vary different system-response parameters in ILS (e.g. weight of one's decisions and return to mitigation actions) and feedback (e.g. numbers, text messages and images for damage) in order to study their effects on people's decisions against landslides. Here, researchers could evaluate differences in ILS's ability to increase public contributions in the face of other system-response parameters and feedback. In addition, researchers can use the ILS tool to do "what-if" analyses related to landslides for certain time periods and for certain geographical locations. The ILS tool has the ability to be customized to certain geographical area as well as certain time periods, where spatial parameters (e.g., soil type and geology) as well as temporal parameters (e.g., daily rainfall) can be defined for the area of interest. Once the environmental factors have been accounted for, the ILS tool enables researchers to account for assumptions on human factors (contribution against landslides) with real-world consequences (injury, fatality, and infrastructure damage). Such assumptions may help researchers model human decisions in computational cognitive models, which are based upon influential theories of how people make decisions from feedback (Dutt & Gonzalez, 2012; Gonzalez & Dutt, 2011). In summary, these features make ILS tool apt for policy research, especially for areas that are prone to landslides. This research will also help test the ILS tool and its applicability in different real-world settings.

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we will try to find without causing reduction in income, only due to fatality and injury what effect it have on participants' investment

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Another idea is to test whether people would continue to invest large money or choose to migrate.

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This idea is very interesting to study because The nature of landslide hazard, including its notorious fame of being extremely hard, if not impossible, to predict, makes it quite different from other hazards such as flood and drought, and general climate risk.

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to calculate P(I) to showcase the potential of using ILS in the real-world

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Appendix A

Instructions of the Experiment

Welcome!

You are a resident of Mandi district of Himachal Pradesh, India, a township in the lap of Himalayas. You live in an area that is highly prone to landslides due to a number of environmental factors (e.g., the prevailing geological conditions and rainfall). During the monsoon season, due to high intensity and prolonged period of rainfall, a number of landslides may occur in the Mandi district. These landslides may cause fatalities and injuries to you, your family, and to your friends, who reside in the same area. In addition, landslides may also damage your property and cause loss to your property wealth.

This study consists of a task, where you will be making repetitive decisions to invest money in order to mitigate landslides. Every trial, you'll earn certain money between 0 and 10 points. This money is available to you to invest against landslides. You may invest certain amount from the money available to you; however, if you do not wish to invest anything, you may invest 0.0 against landslides on a particular trial. Based upon your investment against landslides, you'll get feedback on whether a landslide occurred and whether there was an associated loss of life, injury, or property damage (all three events are independent and they can occur at the same time).

Your total wealth at any point in the game is the following: sum of the amounts you did not invest against landslides across days + your property wealth - damages to you, your family, your friends, and to your property due to landslides. Your property wealth is assumed to be 100 points at the start of the game. The amount of money **not invested against landslides** increases your total wealth. **Your goal is to maximize your total wealth in the game**.

Whenever a landslide occurs, if it causes fatality, then your daily earnings will be reduced by 5% of its present value at that time and if landslide causes injury to someone, then the daily earnings willbe reduced by 2.5% of its present value at that time. Thus, the amount available to you to invest against landslides will reduce with each fatality and injury due to landslides. Furthermore, if a landslide occurs and it causes property damage, then your property wealth will be reduced by 80% of its present value at that time; however, the money available to you to invest against landslides due to your daily earnings will remain unaffected.

Generally, landslides are triggered by two main factors: environmental factors (e.g., rainfall; outside one's control) and investment factors (money invested against landslides; within one's own control). The total probability of landslide is a weighted average of probability of landslide due to environment factors and probability of landslide due to investment factors. The money you invest against landslides reduces the probability of landslide due to investment factors and also reduces the total probability of landslides. However, the money invested against landslides is lost and it cannot become a part of your total wealth.

At the end of the game, we'll convert your total wealth into INR and pay you for your effort. For this conversion, a ratio of 100 total wealth points = INR 1 will be followed. In addition, you will be paid INR 30 as base payment for your effort in the task. Please remember that your goal is to maximize your total wealth in the game.

Starting Game Parameters

Your wealth: **20 Million**

When a landslide occurs:

If a death occurs, your daily income will be reduced by **50**% of its current value.

If an injury takes place, your daily income will be reduced by **25**% of its current value.

If a property damage occurs, your wealth will be reduced by **50**% of your property wealth.

Best of Luck!