Response to comment on nhess-2022-199

Response to general comments

The manuscript deals with the development and evaluation of regional landslide precipitation thresholds in Peru. The Authors used the available high-resolution gridded precipitation and landslide events data to define empirical thresholds which is an important step towards the development of landslide early warning system in Peru (a country with limited landslide studies).

The study seems very important especially in a country with limited landslide studies yet with frequent landslide hazards problems. However, some sections of the manuscripts need to be polished for a better flow of the manuscript. Some points also need to be corrected:

Comment response: Thank you very much for your review and general comments, we have tried to make it not a bit difficult to read and also not seems unorganized, considering all your comments in the new version of the manuscript. Additionally, this document is highly important for the scientific community related to landslides in Peru since this type of work has not been developed in Peru, which, in addition, faces the limited availability of data compared to other countries. Lastly, other investigations also faced similar difficulties (e.g., Kirschbaum et al., 2015; Abraham et al., 2019).

Specific comments

Section 2 This section presents the methodology used. Figure 1 summarises the methodology in 6 steps which is really good. However, from sub_sect. 2.1 to 2.6 one would expect the details from step 1 to step 6. These steps are not outlined clearly in these sections and may break the flow of the manuscript not only in Methodology section but also the Results section.

Comment response: Thanks for the observation. This observation was taken in account in the new manuscript, we reorder and organized the methodology on the sub sec 2.4 as you can see below:

"2.4 Rainfall threshold model

An empirical–statistical approach was used to define rainfall thresholds for landslide-susceptible regions, consisting of the following steps: (1) determination of rainfall events from a historical rainfall series, (2) definition of the variables of rainfall events, (3) define landslides regions from maximum daily rainfall region and GEOGloWS basins for the area studio, (4) threshold estimation for individual rainfall event variables for calibration period based on an objective maximization of predictive performance, (5) threshold estimation for combination of rainfall event variables for calibration period based on an objective maximization of predictive performance, and (6) run thresholds models and get metrics for analysis and discussions 110 (methodology is presented in Figure 2). Below are the details of the method.

The first step was the construction of a historical rainfall series from gridded rainfall data (PISCOpd_Op) for each basin that had a minimum of one landslide event. After obtaining the rainfall series, rainfall events were defined along with a historical series for each selected basin. For this work, we define an independent rainfall event as a series of consecutive rainy days where it has rained above a minimum rainfall threshold (Figure 3). Many authors use minimum thresholds of 1 mm to define rainy days (Dai, 2006; Dai et al., 2007; Han et al., 2016; Leonarduzzi et al., 2017; Shen et al., 2021; Tian et al., 2007;

Yong et al., 2010). However, given the great climatological spatial variability in the study area, it was determined that there was not a single minimum threshold for the entire territory, but a minimum threshold was discretized from the bias of PISCOpd_Op for non-rainy days. The PISCOpd_Op bias was determined when rain gauges did not report rain (0 mm), and the discretized minimum threshold (Umin) of rain was defined according to the following Equation 1:

$$U_{min} = \begin{cases} U_0 & \text{if } s \leq U_0 \\ s & \text{if } s > U_0 \end{cases} \quad (1)$$

where s is the average of simple bias when rainfall stations reported a value of 0 rainfall compared with the estimation in PISCOpd_Op. And U0 is the initial minimum rainfall threshold, and it is established as 1 mm for all regions with exception of coastal Pacific regions which is considered 0.5 mm. Once rainfall events were defined, whether they were triggering or non-triggering events was established. A rainfall event is considered a rainfall trigger event if it is associated with a landslide event, i.e., if during the duration of the rainfall event a shallow landslide has occurred.

The second step was to determine analysis variables for each rainfall event, for which the maximum daily intensity Imax (mm/day), the accumulated rainfall E (mm), the duration D (day), and the mean daily intensity Imean = E/D (mm/day) were calculated. Concerning the triggering rain events, two scenarios were considered. For the first scenario (entire event - EE), the properties of the rainfall event (Figure 3) were defined considering the rainfall rate of the landslide occurrence day. The second scenario (antecedent event - AE) defined the properties up to one day before the occurrence, i.e., it did not consider the rainfall rate of the landslide occurrence day. The reason for analyzing the second scenario was to evaluate the level of incidence that is attributed only to antecedent conditions for landslide occurrence, as this allows us to evaluate if it is possible to forecast or warn landslides based only on the antecedent conditions. The temporal evolution of hydrometeorological variables provides an idea of how the critical conditions of the activation of landslides develop (Prenner et al., 2018; Segoni et al., 2018).

The third step consisted in divide the study area into regions based on clustering techniques (this step is explained in more detail in the section 2.5). Next, GEOGloWS basins were merged with regions in order to determine their spatial correspondence. The fourth and fifth step was to objectively select a rainfall threshold that separates triggering rainfall events from Non triggering rainfall events with the best level of predictive performance. Rainfall thresholds were established by maximizing predictive performance in two ways: the first one only included variables independent of rainfall properties (Imax,E,D, Imean), and the second one determined was through curve-like thresholds that related two properties (Imax −D,E −D, Imean −D) in the form of V = a. D−b, where V represents the variables Imax, E, and Imean; a and b are the scale and shape parameters of the curve (while for logarithmic space, a is the intersection parameter and b denotes the slope of the linear curve). Finally, the sixth step consisted in apply the model to the rainfall events and compare with the observed landslides events and get the predictive performance metrics for each region at calibration and validation periods."

Minor comments/technical corrections

Figure 2 caption. "Methodology six steps" is not relevant for the Figure. I would suggest to correct the Caption as: "Study area. Left: Spatial distribution of the Global Landslide Catalog (red) and SENAMHI landslide inventory (yellow). Right: Eleven landslide-susceptibility regions for Peru and distribution of calibration (blue) and validation (yellow) landslides" .

Comment response: Thanks for the suggest. It was added on the new version of the manuscript, as you can see:

"Study area. Left: Spatial distribution of the Global Landslide Catalog (red) and SENAMHI landslide inventory (yellow). Right: Eleven landslide- susceptibility regions for Peru and distribution of calibration (blue) and validation (yellow) landslides."

LL101. …. Is shown in 3. There is something missing. Is it Figure 2? Or sect. 3?
Comment response: Thanks for the observation. It is Map Figure (Fig. 2), and it was edited on the new manuscript.

LL126-127. "If it is possible to forecast or warn of possible landslides". To be corrected as "If it is possible to forecast or warn landslides"

Comment response: Thanks for the observation. It was corrected on the new version of the manuscript, as you can see:

"The reason for analyzing the second scenario was to evaluate the level of incidence that is attributed only to antecedent conditions for landslide occurrence, as this allows us to evaluate if it is possible to forecast or warn landslides based only on the antecedent conditions."

LL 131. " triggering rain evens" to be corrected as "triggering rain events"

Comment response: Thanks for the observation. It was corrected on the new version of the manuscript, as you can see:

"… objectively select a rainfall threshold that separates triggering rainfall events from non-triggering rainfall events with the best level of predictive performance."

Figure 7 caption is a little bit messy. May be this: The first column shows the spatial distribution of Rainfall thresholds for independent variables magnitude for Peru: (a) D (days), (b) total cumulative rainfall E (mm), (c) mean daily intensity I_{mean} (mm/day) and (d) maximum daily intensity Imax (mm/day). The second and third columns show the bivariate maps indicating the spatial distribution of the sensibility (probability of correctly predicting landslide triggering rainfall events) and specificity (probability of correctly predicting non-triggering rain events from landslide) of the thresholds for calibration and Validation.

Comment response: Thanks a lot for the observation and recommendation. It was corrected on the new version of the manuscript, as you can see:

"Figure 7. The first column shows the spatial distribution of Rainfall thresholds for independent variables magnitude for Peru: (a) day D (days), (b) total cumulative rainfall E (mm), (c) mean daily intensity Imean (mm/day) and (d) maximum daily intensity Imax (mm/day). The second and third columns show the bivariate maps indicating the spatial distribution of the sensitivity (probability of correctly predicting landslide triggering rainfall events) and specificity (probability of correctly predicting non-triggering rainfall events from landslide) of the thresholds for calibration and validation."