Referee(s)' Comments to Author:
Referee: 2

Comments to the Author

The article "Probabilistic seismic landslide hazard assessment considering different scenarios of earthquake and rainfalls in Bomi, China" suggests the use of a new approach for the estimation of landslide hazard over large areas. This approach is a combination of a probabilistic seismic landslide hazard (PSLH) assessment with a rainfall infiltration model which accounts for the variation of soil slope saturation conditions through the calculation of the wetting front depth. In this way, it should be possible to obtain several indications about the proneness to slope failure in response to a combined action of earthquakes and rainfalls.

Although the concept of the manuscript is promising, I believe that it cannot be considered for publication, at least at this stage. To be honest, I have serious concerns about the validity of the methodological approach the authors propose. In particular, even if I may agree with the PSLH analysis (which, however, is not a novelty for your study area, as testified by the articles the authors cited, e.g. Du et al. 2022), I believe that the infiltration model has various critical aspects. These issues mainly concern the excessive simplification of the input parameters.

Response: We thank sincerely the reviewer for the valuable time on the reviewing and the professional expertise in landslide study. We have thoroughly examined, modified and revised the manuscript according to your comments and suggestions. Responses are listed as below.

Comment 1:

- Line 122: "Previous studies suggested that the distribution of landslides is highly related to monthly rainfalls (Mathew et al., 2014; Tang et al., 2017). Therefore, we selected the monthly cumulative rainfall intensity in this study as the input of the Green-Ampt model". Fine, but the parameter the authors use in their model is soil saturation (as parameter m): which is the link between rainfall amount/duration and soil saturation? If the authors want to use rainfall as primary input parameter, it is fundamental to investigate the hydraulic response of the soil to different types of expected rainfalls. For substantiating their strong choice of monthly rainfall, the authors cannot simply rely on the above-mentioned three lines…. Otherwise, it makes more sense to carry out a parametric analysis of soil saturation.

Response: Thanks. In this study, soil saturation is defined as the percent of the saturated portion of a potential landslide, i.e., the ratio of the depth of saturated soil (z_w) to the potential landslide thickness (z). To quantify the depth of saturated soil, we introduced a classical hydrological model (i.e., Green-Ampt model) to simulate approximately the rainfall infiltration processes under different rainfall conditions. The rainfall condition and the hydraulic response of soil to different rainfalls are fundamental to accurately simulate rainfall infiltration. However, such information is difficult to obtain, especially at a regional scale. Although the the hydraulic response of soil to different rainfalls is critical in the hydrological model, which will affect notably the depth of saturated soil, the impact of the hydraulic response of soil to rainfall was not considered in this study since the chief purpose of this manuscript focused on the impact of different rainfall conditions on the calculation of saturated soil depth. Besides, the rainfall data used in this study were derived from a reanalyzed product with a temporal resolution of one month, which is insufficient to support a parametric analysis to explore the impact of different rainfall durations on the probabilistic seismic landslide hazard assessment. Therefore, we selected the monthly cumulative rainfall as the rainfall duration in the Green-Ampt model in this study. Once the rainfall data with higher temporal resolution are available, the effects of different rainfall durations on probabilistic seismic landslide hazard assessment will be further investigated in the future.

Comment 2:

- Line 169: "Physical properties, such as the saturated water content, the initial water content, and the saturated hydraulic conductivity are also important in landslide hazard assessment. Since these parameters are not yet available at a regional scale, we assume that all the Groups in Bomi have the same saturated water content, the initial water content, and the saturated hydraulic conductivity. According to the previous studies in Bomi, the saturated water content of the slopes is usually in the range of 30-50%, and the initial water content is in the range of 10-30%(Liu et al., 2020; SU and LI, 2020). We adopt the average values in previous studies as the saturated water content and initial content of the slopes, being 40% and 20%, respectively." This is another huge simplification, especially in relation to the (extremely) large scale of the study area. Different lithologies imply different hydraulic properties, and the authors should put strong efforts in order to attribute reasonable values to each material. Otherwise, the obtained results could be scarcely significant.

Response: Thanks a lot. Different lithologies indeed imply different hydraulic properties. However, obtaining detailed and accurate hydraulic properties parameters at a regional scale is challenging, especially in this plateau area rarely investigated due to inconvenient transportation. Existing studies usually assign empirical hydraulic properties parameters to different lithologies for regional scale analysis. Since the Green-Ampt model selected in this manuscript is applicable to the soil slopes, only the soil slopes (i.e., the area covered by vegetation) were conducted for rainfall infiltration studies. These soil slopes typically have similar lithologic and hydraulic properties. We, therefore, adopted the same hydraulic property parameters without considering the different hydraulic properties of different lithologies. It is worth noting that detailed and accurate hydraulic property parameters will help to further improve the reliability of the rainfall infiltration simulation, and in the absence of such data, appropriate parameter simplifications are still acceptable. Once detailed and reliable data information is available, we will conduct a finer-scale probabilistic seismic landslide hazard assessment in the future.

Comment 3:

- Line 262: "To simplify the operation and reduce the input parameters, we assumed that the saturated hydraulic conductivity is greater than the rainfall in Bomi, and thus the wetting front depth can be calculated with the Green-Ampt model." I think that this sentence summarizes and confirms what I said in the preceding two points….

Response: Thanks very much for mentioning this. Although we have conducted two field investigations in Bomi in 2020 and 2021, respectively, the detailed hydrogeological information about this study area is still insufficient. To this end, according to the information collected from the field investigations, the necessary simplifications and assumptions were made on the hydrological parameters at the regional scale, including ignoring the differences in the hydraulic properties of the different lithologies and assuming that all rainfall infiltrates into the soil, i.e., the saturated hydraulic conductivity is greater than the rainfall intensity. Although such assumptions and simplifications will further affect the reliability of the regional seismic landslide hazard assessment to a certain extent, it is acceptable as compared to that ignoring the rainfall effect on regional seismic landslide hazard assessment.

Comment 4:

- Beyond the infiltration model, it is possible to notice a certain vagueness and uncertainty also in relation to other types of data. For instance, in line 223 the authors assert that: "Since the global empirical depth parameter of the potential landslide was usually used for the CRMSH-PD model in previous studies (Shinoda and Miyata, 2017; Zang et al., 2020), we set the depth of potential landslides as 3 m referring to the depth of landslides from the historic landslide inventory in Bomi". Actually, in the cited papers the investigated landslides have a depth "less than 3 m", which is not "an average value of 3 m".

Response: Thanks for mentioning this point. For the information on the depth of the potential landslide, we assumed that the depth of the landslide is constant at the regional scale, and adopted an empirical parameter (with a maximum of 3m) referring to the relevant literature information. In the revised manuscript, we have added the references for the depth of the potential landslide: "Since the global empirical depth parameter of the potential landslide was usually used for the CRMSH-PD model in previous studies (Shinoda and Miyata, 2017; Zang et al., 2020), we set a maximal and constant depth of potential landslides as 3 m referring to the previous study (Du et al., 2017)".

Comment 5:

- Furthermore, there is no information about these historical landslides in Bomi. The authors mention different times this inventory throughout the manuscript, but they do not provide any detail in this sense (e.g., how many landslides are included? Is it a multi-temporal or an event-based inventory? Which types of landslides are included? Rainfall-induced? Earthquake-induced? Both?). Again, all these approximations and lack of information do not help in substantiating the reliability of your results. A possible solution could come from a strong validation process. But, unfortunately, the manuscript is quite poor also from this point of view. For instance, in line 225 the authors assert that: "According to the yield acceleration calculated with the CRMSH-PD model, the study area is divided into five susceptibility levels. Higher susceptibility levels correspond to lower slope stability, and more historical landslides developed. The results show that the history landslides are distributed mainly in areas with high and extremely high susceptibility levels, accounting for 76.3% of the total landslides, and the number of landslides increases significantly with the landslide susceptibility level." In the light of the lack of information that I mentioned before, it is impossible for the reader to verify what the authors are saying. Are the obtained results reasonable? Maybe, but in the absence of a real validation, Figure 9 and the following ones just represent a useless exercise

Response: Thanks for your kind comments. In the revised manuscript, we add more information about the inventory as: "*In addition, the history hazard inventory was also used in this study. The inventory data was provided by the China Geological Survey (CGS), which contains all geologic hazards that occurred in Bomi County during the period 2000-2019. The inventory recorded a total of 140 geologic hazard sites, including 28 landslides and 112 debris flows*". In this study, to verify the validity of the results, verification was also performed for the critical input parameter (critical acceleration) in the CRMSH-PD model. In the revised manuscript, we have added detailed descriptions as: "*The yield acceleration is crucial for subsequent PSLH assessment. Studies have shown that the yield acceleration can effectively reflect the slope stability in non-seismic scenarios. Therefore, the distribution of historical hazards can be used to verify the effectiveness of the calculated yield acceleration. This study divided Bomi County into four susceptibility levels based on the calculated yield acceleration, and the effectiveness of the susceptibility zoning was verified using historical hazard inventories. The results show that most of the hazards are distributed in high-susceptibility areas, and the number of hazards increases as the susceptibility level increases. As a result, the critical acceleration calculated with the CRMSH-PD model can reflect slope stability in non-seismic scenarios to a certain extent, which is suitable for the subsequent PSLH assessment.*" For the probabilistic seismic landslide hazard assessment under future earthquake scenarios, the validity of the results is to be evaluated through real scenarios in the future. Whether the results are consistent with existing empirical knowledge is a possible way to evaluate the validity of the assessment results. In the revised manuscript, we added more description about the assessment results as: "*This paper considers the probabilistic seismic landslide hazard assessment under the combined influence of earthquake and rainfall. The assessment results reflect not only the influence of different rainfall on the distribution of seismic landslide hazards but also the influence of different seismic scenarios on the distribution of seismic landslide hazards. Compared to the assessment results from independent consideration of the triggering factors such as rainfall or earthquakes, these results from combined consideration could be more in line with the landslide hazard under real scenarios, especially for the earthquake-prone mountainous areas suffering from heavy rainfalls*."

Comments 6:

- "Introduction": this section should be improved with more international references, mentioning alternative approaches for landslide hazard assessment due to the combined action of earthquakes and rainfalls. This is a research topic that various authors have already dealt with.

Response: Thanks for your kind suggestion. In the revised manuscript, we have cited more international references relevant to the field. Besides, the research questions and objectives have been reformulated in the revised introduction.

Comment 7:

- Figure 2 is very chaotic and does not clarify the different steps of the proposed approach. Please modify it in order to be coherent with the text.

Response: Thank you very much. In the revised manuscript, we have redrawn the Fig.2 as in the following:

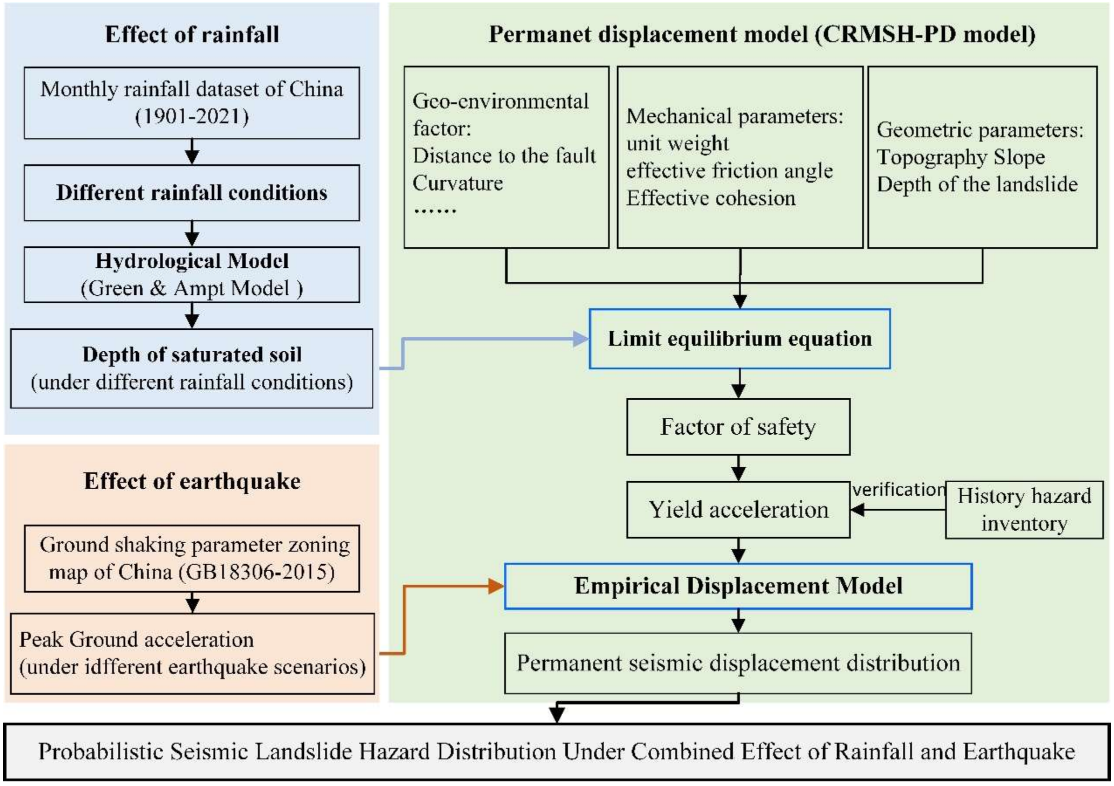

Fig.3 Flowchart of the novel method for PSLH assessment considering both earthquakes and rainfalls.

Comment 8:

- Line 147-148: "As a result, the scale and frequency of geological hazards in Bomi increased significantly compared to that before the great earthquake". Please clarify this sentence. Are you talking about post-seismic landslides? (sensu Fan et al., 2019)?.

Response: Yes, and thanks. In response to the suggestions of the other reviewer, we have reorganized the section in the revised manuscript as: *"Bomi County, located in the southeast of the Tibetan, is a region with the characteristics of fragmented geological structure and complicated topography and geomorphology. The region is a geo-hazards-prone region of high seismic activity, and several strong earthquakes have occurred frequently because of the regional strong tectonic movements(Zhao et al., 2023). According to the earthquake data of the U.S. Geological Survey (USGS), from January 1, 1990, to January 1, 2024, a total of 439 earthquakes have been recorded in Bomi County and its nearby (within a 100km buffer zone), as shown in Fig. 1. For example, the M8.6 Motuo earthquake in 1950 was one of the strongest earthquakes since 1850, which induced a large number of collapses, landslides, and other geologic hazards that caused a large number of casualties(Li et al., 2021). In addition, the rainfall pattern in Bomi County varies significantly in both spatial and temporal domains, with the rainfall mainly concentrated in June, July, and August. Bomi County also plays a pivotal role in the overall economic and social development of southeast Tibet. Several major infrastructures (such as the Sichuan-Tibet Railway) and urbanization engineering have been planned in this region. Threatened by the combined effects of earthquake and rainfall, the settlements, infrastructures, and engineering will be exposed to a huge risk of earthquake and seismic landslide throughout the entire cycle of construction and operation. To effectively avoid, control, and reduce the risk of seismic landslides, assessing the spatial distribution of seismic landslide hazards across various future* *earthquake scenarios and different rainfall conditions is of practical significance."*

Comment 9:

- Figure 5, 6 and 7: please add the monitoring stations. It would be also interesting to understand how authors spatialized the punctual data.

Response: Sorry for making the confusion. The regional rainfall data used in this study were not derived from the monitoring stations, but rather from the reanalyzed rainfall data products publicly released. In the revised manuscript, we add more information about the resource of the rainfall data as: "*The rainfall data are derived from the 1-km resolution month-by-month precipitation dataset of China (1901-2021) (Peng, 2020). The dataset was generated with the Delta spatial downscaling scheme based on the global 0.5° climate dataset released by CRU and the global high-resolution climate dataset released by WorldClim. The rainfall data was validated using data from 496 independent meteorological observation stations, including the Bomi station, and the results were verified to be credible.*"

Comment 10:

- Figure 8-11: in my opinion, these figures are far from explanatory, since it is very difficult to distinguish different susceptibility levels. Please modify them.

Response: Thanks a lot. In the revised manuscript, we have used different colormaps to distinguish different landslide susceptibility levels. The modified figures are as follows:

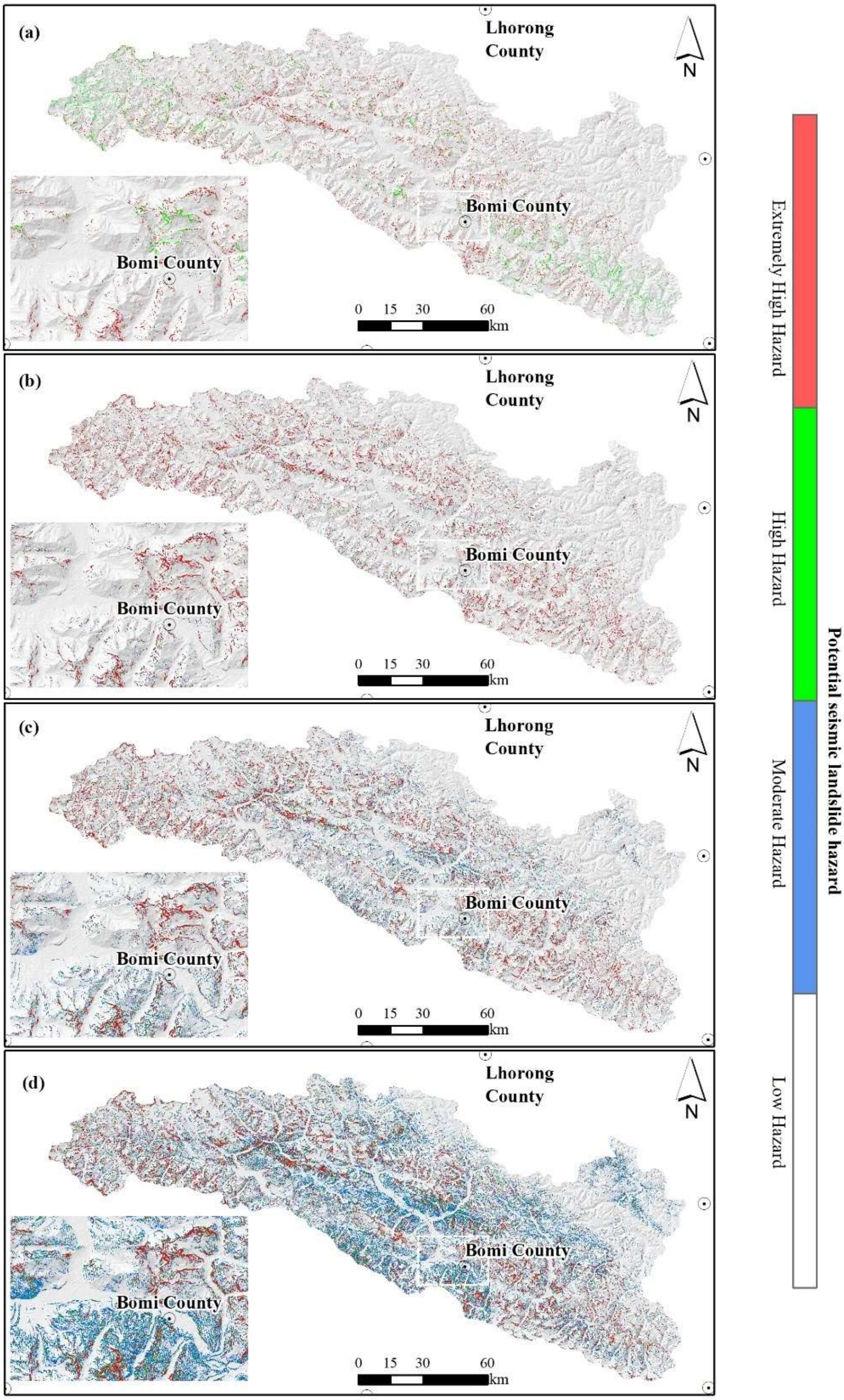

Figure 8 Maps of seismic landslide hazard levels in conditions of frequent (a), occasional (b), rare (c), and extremely rare (d) earthquake occurrence scenarios.

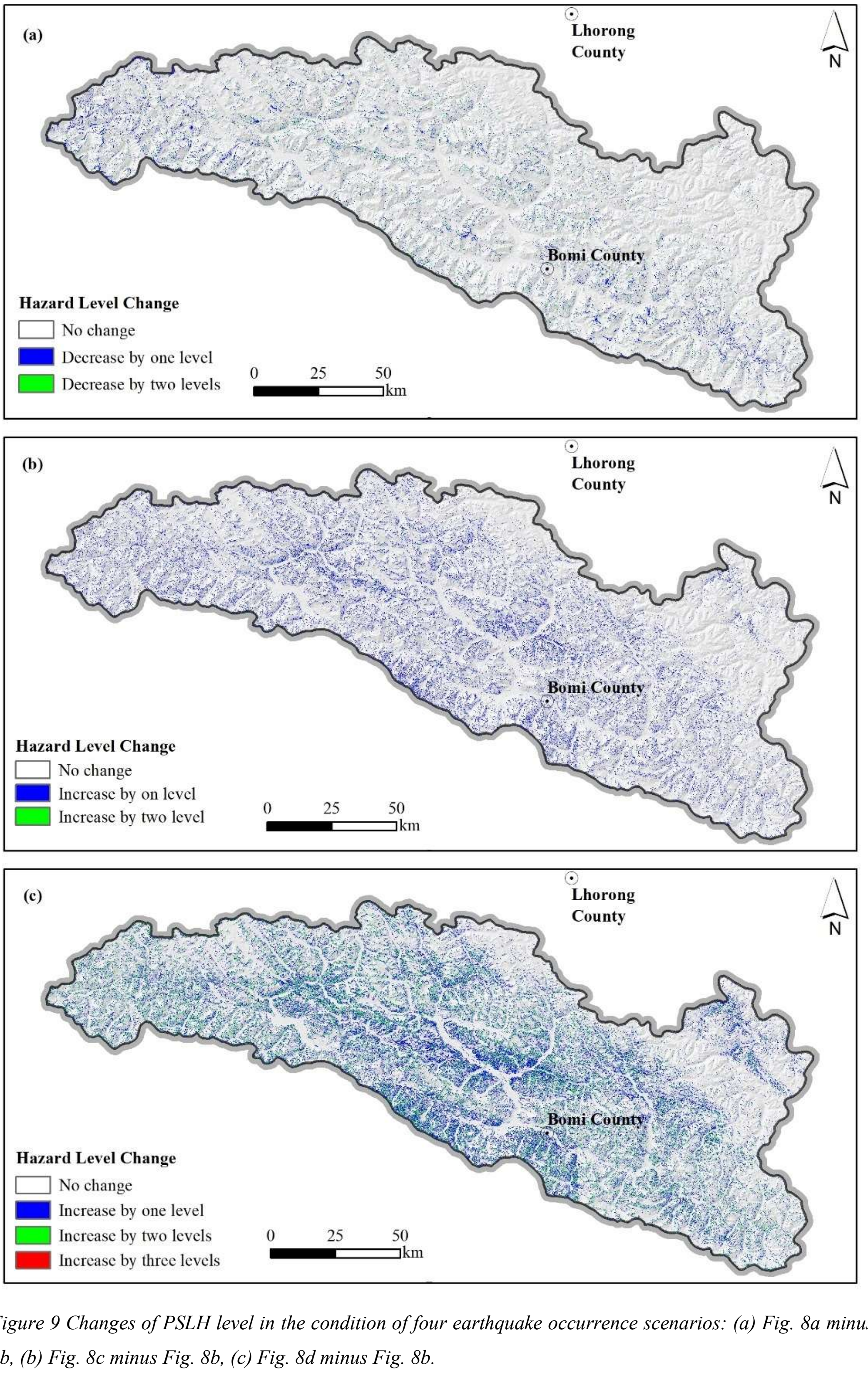

Figure 9 Changes of PSLH level in the condition of four earthquake occurrence scenarios: (a) Fig. 8a minus Fig. 8b, (b) Fig. 8c minus Fig. 8b, (c) Fig. 8d minus Fig. 8b.

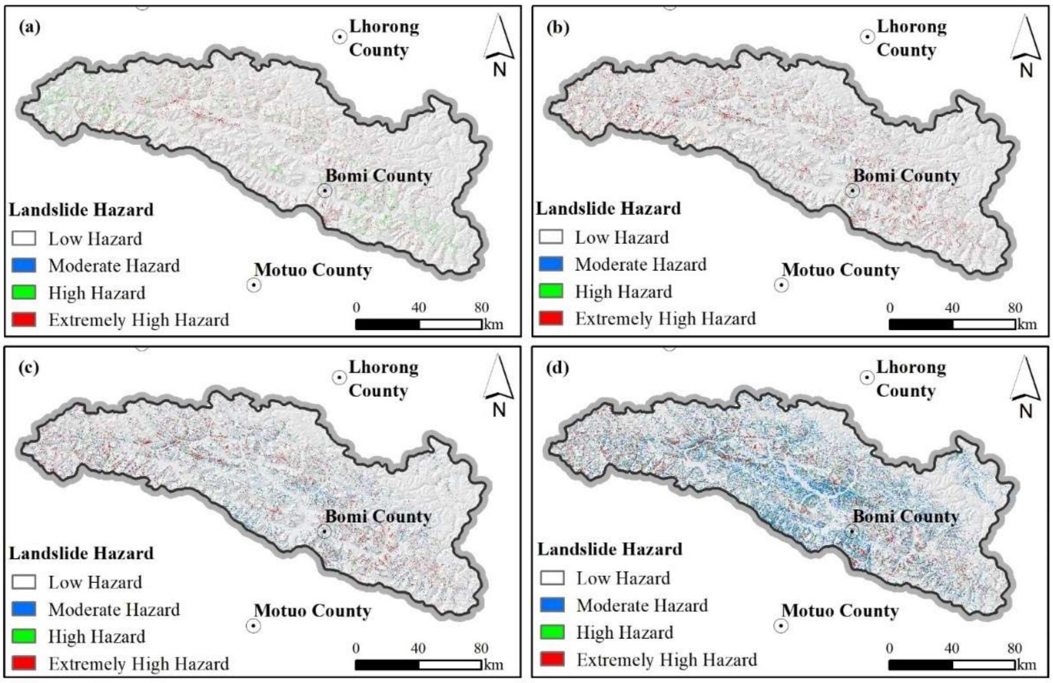

Figure 10 PSLH maps considering the spatial variability of rainfall in conditions of frequent (a), occasional (b), rare (c), and extremely rare (d) earthquake occurrence scenarios.

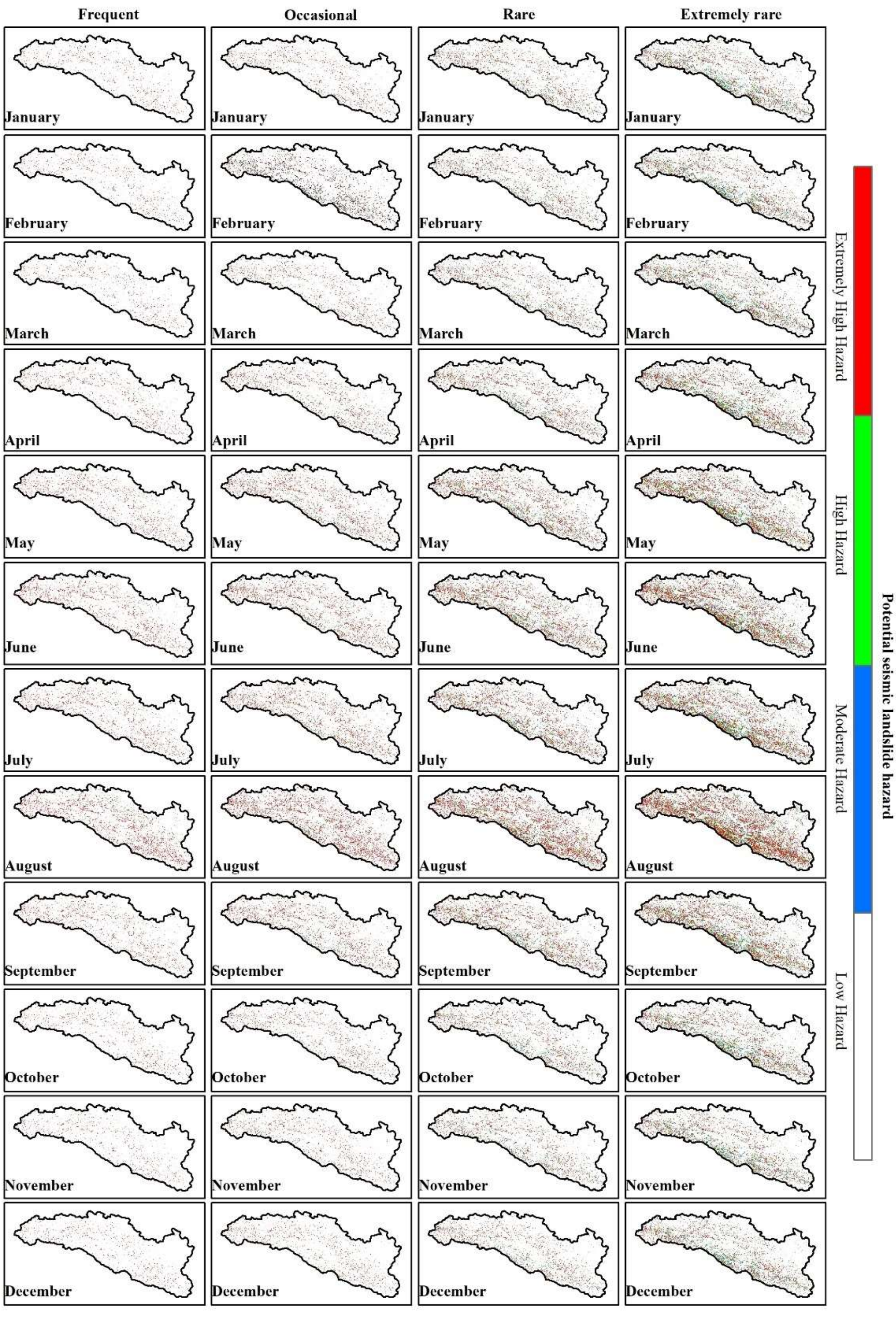

Figure 11　PSLH maps in different months referring to different earthquake occurrence scenarios.

Once again, we appreciate your carefully reading on the manuscript and your kindness on helping improve the quality. The comments and suggestions are very valuable for the revision to improve the quality and readability of the paper.

Best regards,
Lixin and Shuai