



# A Closer Look at Factors Governing Landslide Recovery Time in Post-Seismic Periods

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## Motivation

Near real-time global landslide hazard assessment methods are separately available for both earthquake- (e.g., Jesse Nowicki et al., 2018) and rainfall-triggered (e.g., Kirschbaum and Stanley, 2018) landslides although none of them are capable of accounting for the coupled effect of earthquakes and precipitation. However, characterizing these interactions is critical to advance effective landslide hazard assessment. To capture this coupled effect for a rainfall-triggered landslide hazard assessment, we need to consider the preconditioning effect of seismic shaking. Hence, we first need to understand the legacy effect of previous earthquakes (hillslope memory) (Parker et al., 2015) and its evolution through time under the control of site-specific factors.

## Aim and Scope

Our study aims at better understanding the concept of landslide recovery in post-seismic periods considering the characteristics of both landslide events and landslide sites associated with diverse seismotectonic, morphologic and climatic conditions. To accomplish this, we analyze the recovery time from 11 earthquakes and their association with earthquake and landscape characteristics.

We hypothesize that ***the dominant characteristics of post-seismic landslide*** is the key to understand the recovery time.

## Background

In this study, we will often refer to two terms namely, ***landslide recovery*** and ***landslide recovery time***. The former is equivalent to the common definition of hillslope healing whereas the latter consists of the time span in which the natural landslide susceptibility of a given area is restored after the disturbance of an earthquake.

To better characterize different post-seismic landslide processes we use three key terms:

- 1) ***New landslide*** refers to mass movements that occur in unfailed hillslopes before or during the seismic shaking or on hillslopes where there is no evidence of physical contact with previously occurred landslides.
- 2) ***A reactivated landslide*** refers to a landslide that occurred on a previously failed hillslope and
- 3) ***A remobilized landslide*** refers to a failure initiated from previously deposited landslide materials.

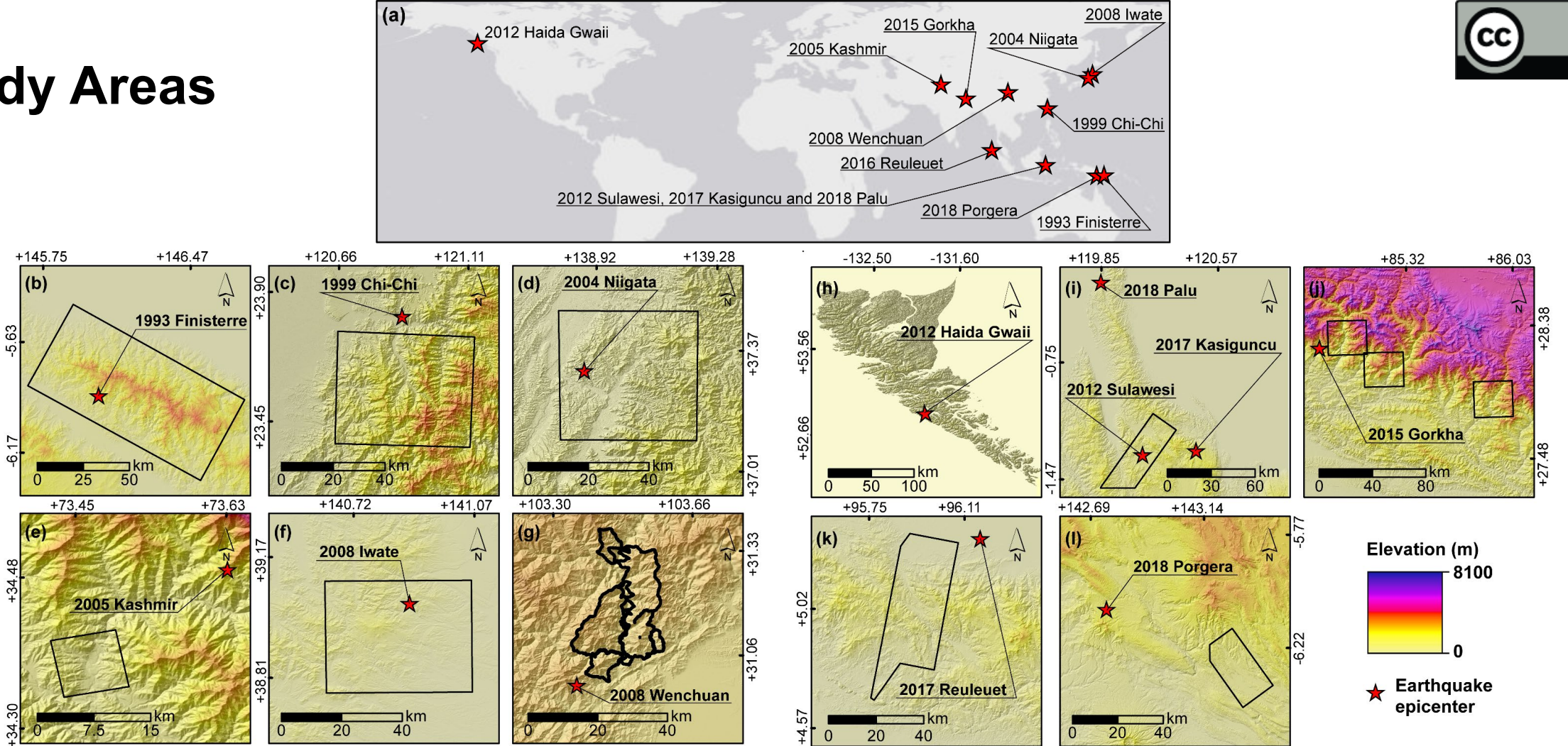
## Method

We extract the landslide recovery times from the literature for eight cases where landslide inventories are not available. If there is more than one article that examined the event, or if there are some uncertainties either indicated by the authors or some that we noticed, we use such findings as uncertainty bounds in our evaluation. For the three cases where we newly compiled the multi-temporal landslide inventories, we calculated the landslide rates as the total landslide area divided by the length of the scanned time-window.

We analyze 11 earthquake-affected areas and examine the characteristics of post-seismic landslides associated with four environmental factors:

- (1) ***the fraction of area affected by co-seismic landslides,***
- (2) ***mean relief,***
- (3) ***average daily accumulated precipitation*** and
- (4) ***rainfall seasonality.***

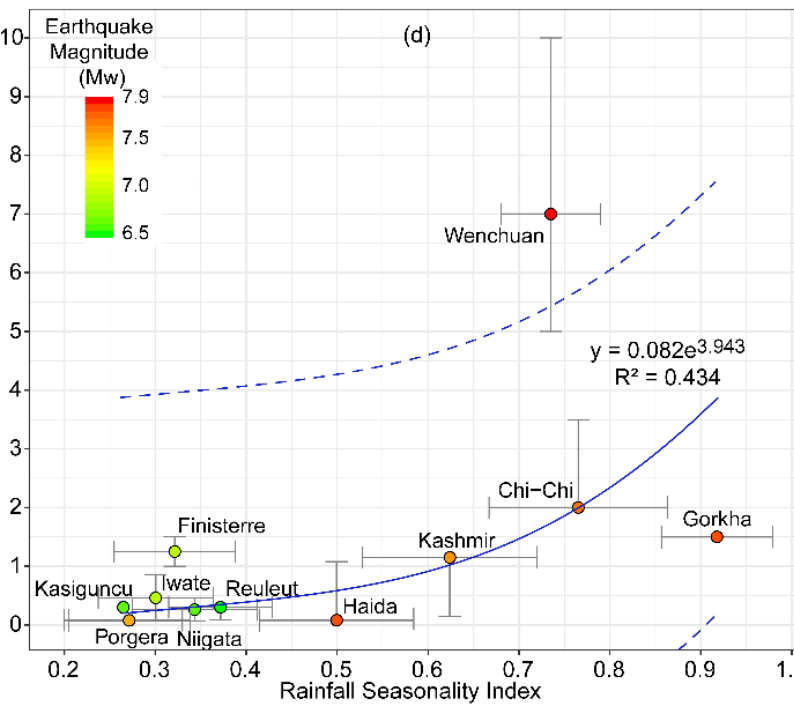
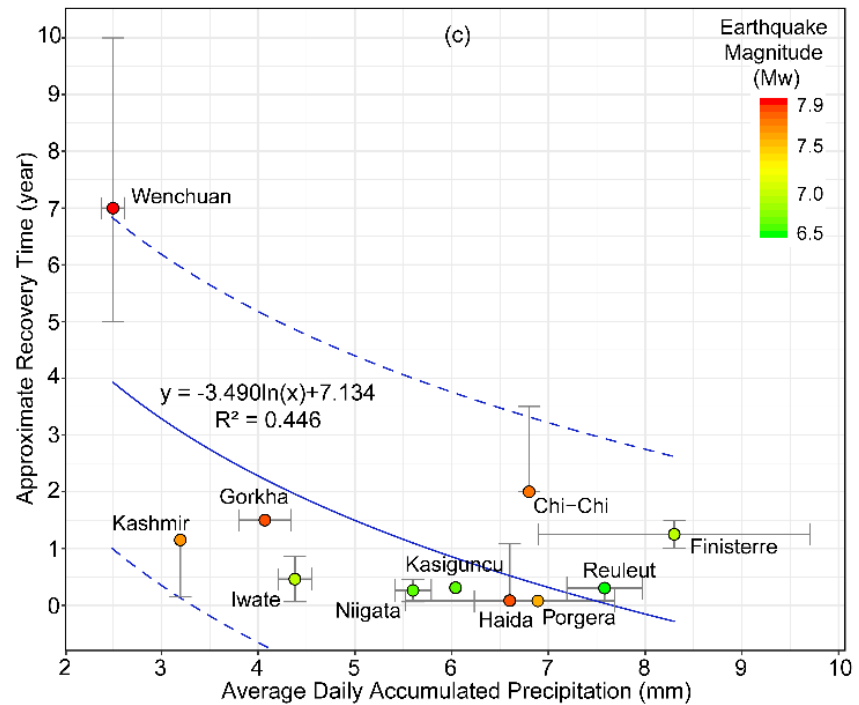
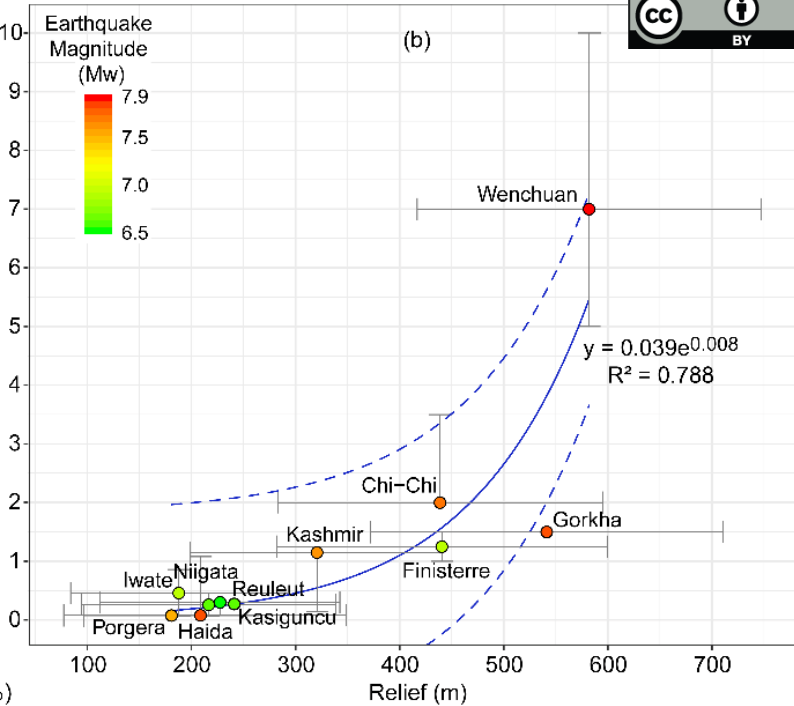
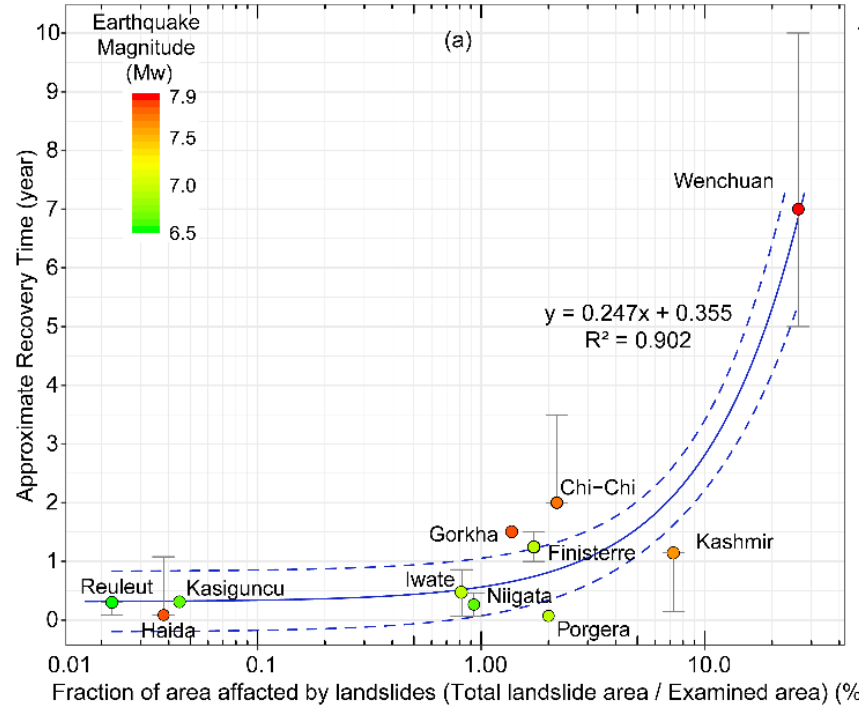
# Study Areas



**Figure 1.** (a) Distribution of examined earthquakes and areal extends of sites affected by: (b) 1993 Finisterre (Papua New Guinea,  $M_w=6.9$ ), (c) 1999 Chi-Chi (Taiwan,  $M_w=7.7$ ), (d) 2004 Niigata (Japan,  $M_w=6.6$ ), (e) 2005 Kashmir (India-Pakistan,  $M_w=7.6$ ), (f) 2008 Iwate (Japan,  $M_w=6.9$ ), (g) 2008 Wenchuan (China,  $M_w=7.9$ ), (h) 2012 Haida Gwaii (Canada,  $M_w=7.8$ ), (i) 2012 Sulawesi (Indonesia,  $M_w=6.3$ ), 2017 Kasiguncu (Indonesia,  $M_w=6.6$ ) and 2018 Palu (Indonesia,  $M_w=7.5$ ), (j) 2015 Gorkha (Nepal,  $M_w=7.8$ ), (k) 2016 Reuleuet (Indonesia,  $M_w=6.5$ ) and (l) 2018 Porgera (Papua New Guinea,  $M_w=7.5$ ) earthquakes. Red stars show the epicenters of earthquakes.

# Results

If there are not enough co-seismic landslide deposits or not enough relief to trigger large deposits on hillslopes, then the recovery processes are mostly controlled by new and reactivated landslides caused by strength reduction of hillslope materials. This mostly results in a relatively quick recovery process in which most post-seismic landslides may happen within a year or less if sufficient intense rainfall events occur soon after the earthquake. If the predisposing factors create large co-seismic landslide deposits on hillslopes, then remobilization of material takes the role of the dominant mechanism and recovery may take years. Overall, our analyses show that the recovery takes relatively longer if a large amount of co-seismic landslide material is deposited within a high-relief mountainous environment where precipitation rates are low and strongly seasonal.



## Results

As a result, we can categorize the available cases in association with the dominant post-seismic landslide processes as:

- (i) Niigata, Iwate, Haida Gwaii, Kasiguncu, Reuleuet, Porgera (new landslides and reactivations),
- (ii) Wenchuan (remobilization) and
- (iii) Finisterre, Chi-Chi, Kashmir and Gorkha (transition between the two categories mentioned above). This category refers to cases where we observe not only new landslides and reactivations but also remobilizations.

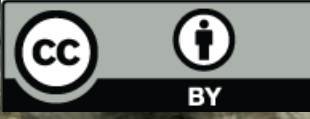


## Conclusion

The cases examined in this work suggest that landslide recovery time in post-seismic periods is mainly controlled by the interactive relationship between characteristics of co-seismic landslide events and site-specific morphologic and climatic factors.

We conclude that the longest landslide recovery times occur if a large amount of co-seismic landslide is deposited in mountainous regions where average daily precipitation is lower and seasonal.

**Thank You!**



***The presented work is currently being revised. Please feel free to contact me if you have any question/comment or need any further information.***

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## References

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