Forestry and Forest Products Research Institute

Spatial relationship between extreme rainfall anomalies and density of the triggered landslides

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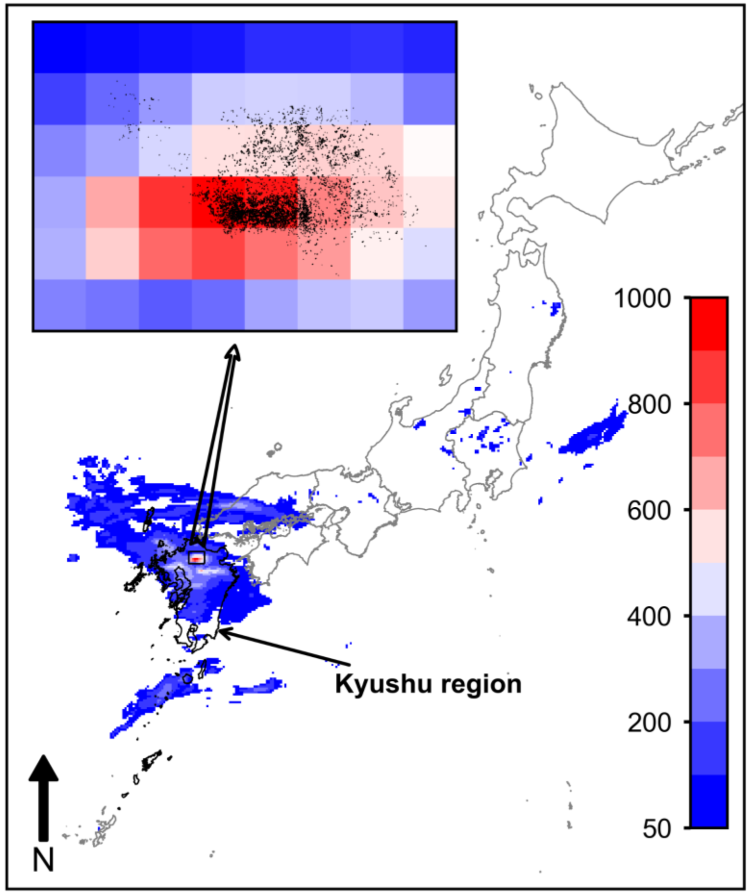
Research motivations:

During the last decade, the frequency of large-scale extreme precipitation events in Japan has increased.

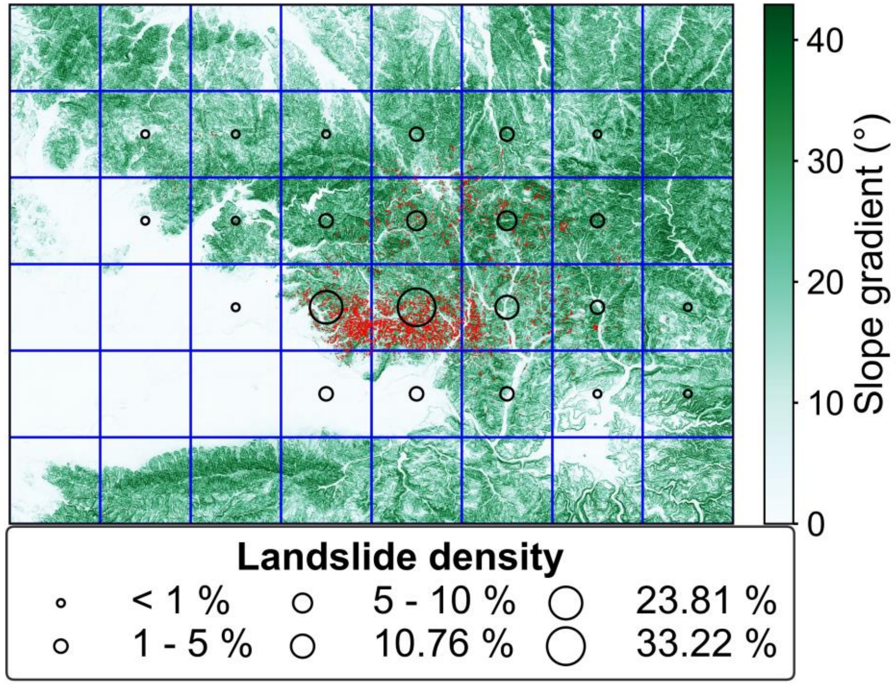
➔ Large-scale catastrophic disasters (e.g., widespread landslides, floods, debris flow).

Example: The extreme rainfall event that hit the northern Kyushu region in Southern Japan on July 5–6, 2017.



Spatial pattern of cumulative rainfall (> 50 mm) for 5–6 July 2017 and location of the triggered landslides (black polygons).

More than 7,600 shallow landslides were triggered and caused catastrophic debris flows, especially in areas that experienced a high density (i.e., number) of landslides.



Triggered landslides (red polygons) and their density (black circles) within the radar-based precipitation dataset grid cells (blue fishnet)

➔ **Revealing the factors that control landslide occurrences is crucial for predicting the magnitude of landslide hazards.**

Research questions:

Exploring the rainfall pattern at the temporal and spatial scales can reveal the factors controlling landslide occurrences because rainfall is the main trigger of landslides during extreme events. However, current knowledge of how rainfall should be examined and characterized remains unclear.

- Landslides can be triggered by disparate rainfall periods depending on rainfall and hillslopes conditions.
  - ➔ The effective rainfall duration “D” that favors landslide occurrences is a spatial variable.
  - ➔ It is difficult to determine “D”.
  - ➔ Using a single “D” for all triggered landslides may introduce an uncertainty in rainfall characterization.

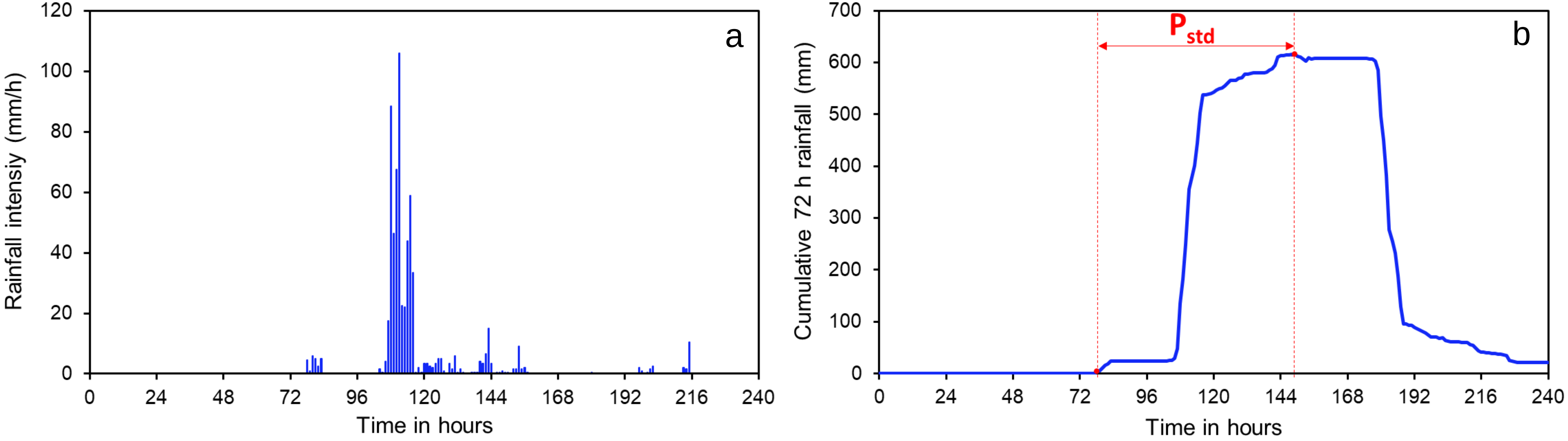
- What is the best rainfall attribute that can characterize the critical conditions for landslide occurrences and subsequently can be used to forecast landslide density?
  - The cumulative amount, average intensity, total duration.
  - The antecedent rainfall or soil moisture.
  - Rainfall amount or intensity normalized by local mean annual precipitation.
  - Rainfall anomaly (e.g., event rainfall normalized by the 10-year return period rainfall amount).

(First three items above:) Depend on the definition of “D”

Research methodology:

The use of multiple timescales in rainfall analysis may consider the disparate effective rainfall durations needed for the occurrence of the different landslides from short to long timescales.

1. We assumed that all landslides occurred within a standardized duration of 72 h (P_{std}) accumulating the maximum rainfall totals during the triggering rainfall event.
2. We computed the maximum rainfall intensity (rainfall intensity maxima) for multiple durations (1–72 h) within the P_{std}.



Example of rainfall temporal pattern in a given radar grid cell (a) and the determination of the P_{std} (b)

Research methodology:

During extreme rainfall events, the parts of the landscape where the computed rainfall intensity maxima are extreme and unprecedented (i.e., high return levels) may experience a high density of landslides.

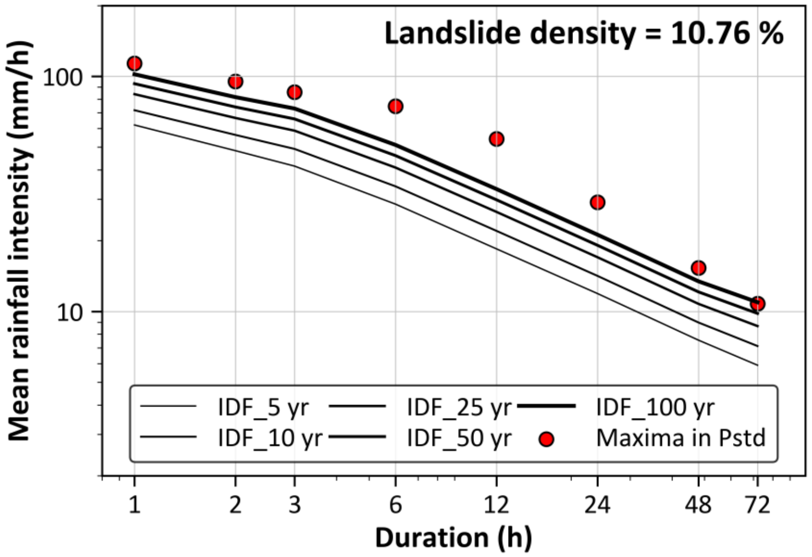
➔ The return levels of rainfall intensity maxima can be a proxy for the occurrence of landslides and therefore, can be used for evaluating the potential of forecast rainfall to trigger high density of landslides.

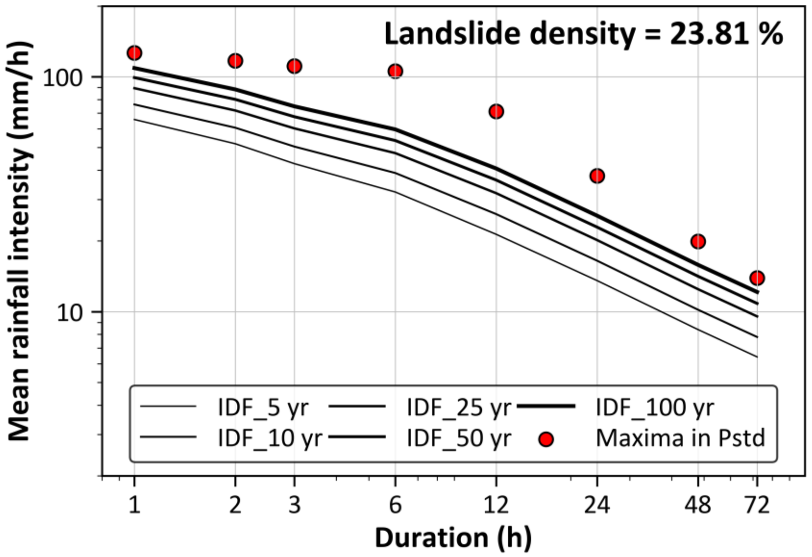
We investigated the return levels of the rainfall intensity maxima using the Intensity Duration Frequency (IDF) curves developed from:

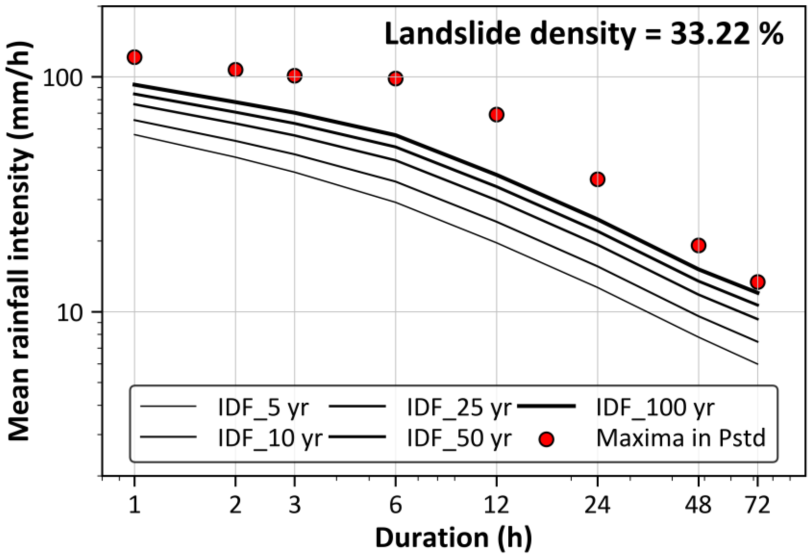
- Long-term radar-based rainfall (R/A) dataset (1988 – 2019).
- The Gumbel statistical model based on the L-moments method to fit the extracted annual maxima series (AMS). The estimated distributions were able to represent the extracted AMS as the Kolmogorov-Smirnov (KS) test could not reject the null hypothesis (p-value > 0.05).

Research outcomes:

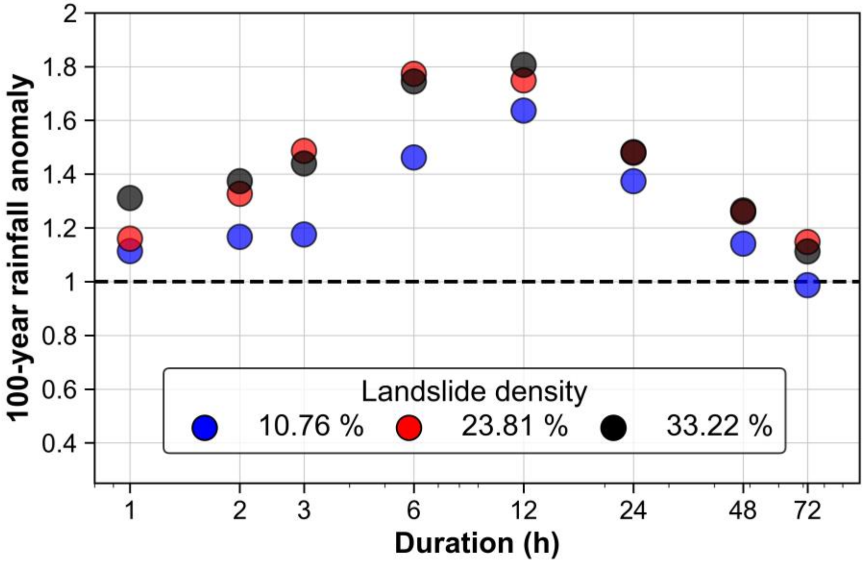
In three grid cells where more than 65 % of triggered landslides occurred, the return levels of all computed rainfall intensity maxima (from 1 – 72 h) exceeded or hit the 100-year return period.





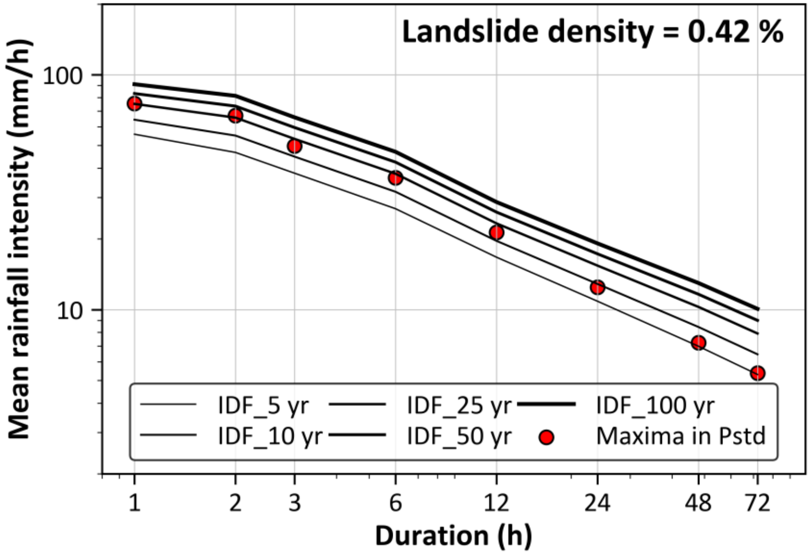


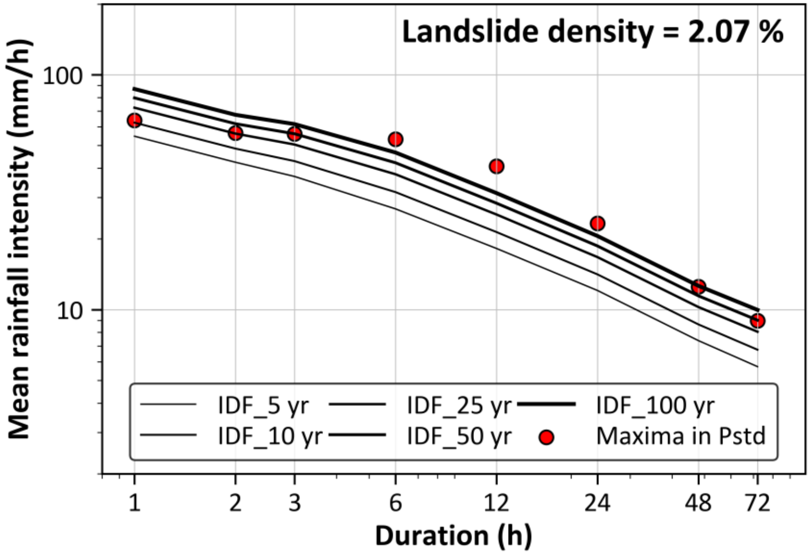
- ➔ Extreme rainfall conditions at multiple timescales.
- ➔ 100-year rainfall anomaly (Ratio between the rainfall intensity maxima within the P_{std} and the estimated rainfall intensity for a 100-year return period) >= 1 at the multiple timescales.

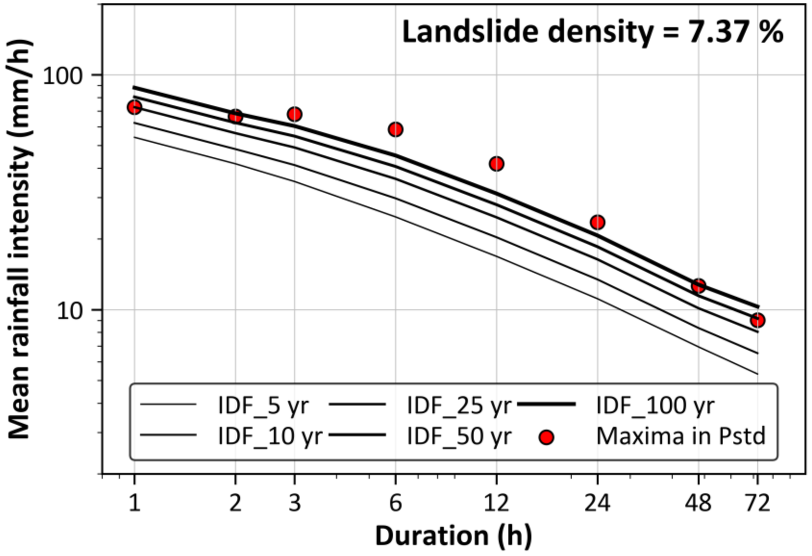


Research outcomes:

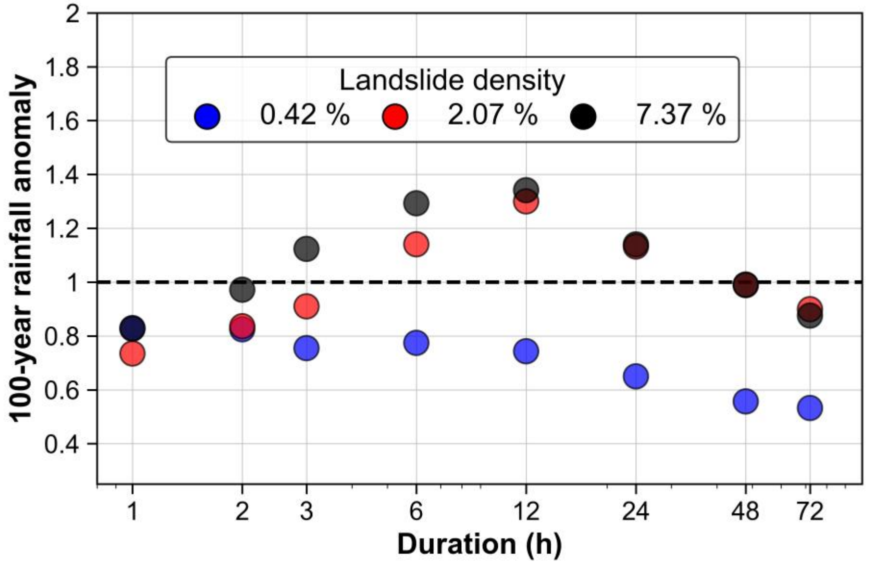
Over grid cells with low landslide density, the return levels of rainfall intensity maxima were generally lower than 100 year, or only short-duration rainfall intensity maxima exceeded the 100 years return period.







- ➔ Non-extreme rainfall conditions or only a short period of rainfall was extreme (3–24 h).
- ➔ 100-year rainfall anomaly was generally lower than 1 or exceeded 1 only at short timescales.

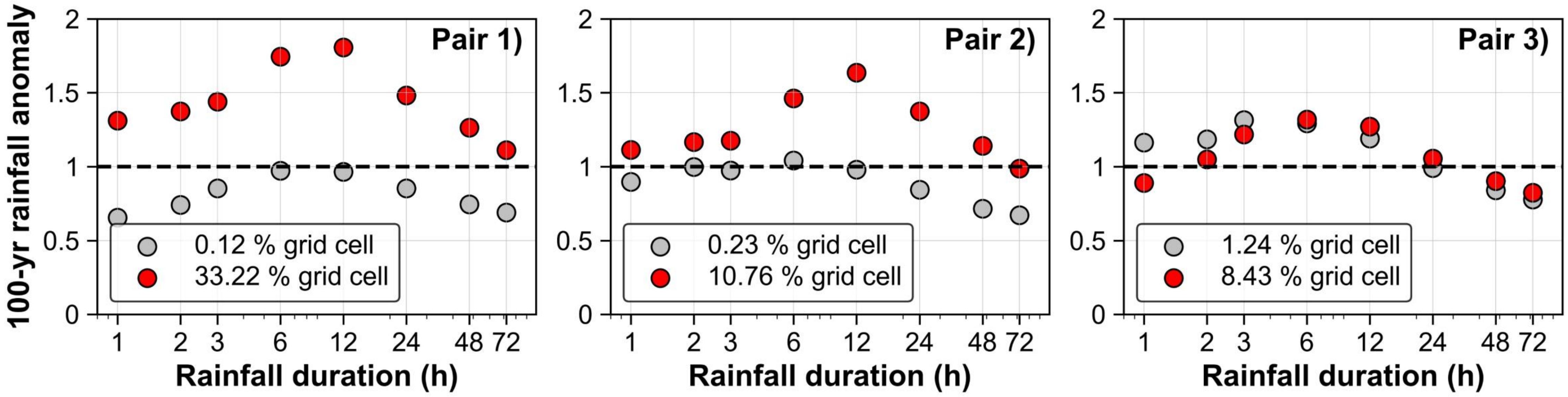


Research outcomes:

Calculated landslide densities can be affected by differences in topographic features (i.e., hills, mountains, plains, lakes) within the R/A grid cells because landslides commonly occur in hilly and mountainous areas rather than plains.

➔ Compare the return levels of rainfall intensity maxima over grid cells with similar topographic conditions

➔ Using the Dunn's test post hoc tests we identified 3 pairwise cells with similar topographic conditions.



For Pair 3: The spatial variability in hillslopes material characteristics (e.g., soil thickness, material strength, land-use) may also explain the differences in landslide density when rainfall characteristics and return level are comparable.

Take-home message:

- The 100-year rainfall return level can be used as a proxy for evaluating the potential of forecast rainfall to trigger high density of landslides.
- The 100-year return level can be used as an additional threshold alert for forecasting the magnitude of landslide hazards.
- The applicability of the proposed method can be valid for other extreme rainfall events to reveal the critical rainfall return level that may explain the spatial pattern of landslide density due to the consideration of multiple return periods.

Thank you for listening!