Effects of Mean Annual Rainfall on the Rainfall Thresholds for Occurring Landslides

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1. Introduction

Rainfall thresholds for occurring landslides are playing a significant role to forecast the possible occurrence of landslides in many early warning systems against rain induced landslides thereby protecting the lives and properties of vulnerable communities (e.g., Osanai *et al*., 2010). Generally, rainfall threshold for rain induced landslides represents the lower bound of rainfall condition that caused in landslides (Reichenbach *et al*., 1998). The determination of rainfall thresholds may be influenced by site-specific conditions such as lithology, soil conditions, topography, land use, land cover, season, and mean annual rainfall (MAR) (e.g., Peruccacci *et al*., 2017; Jia *et al*., 2020; Lee *et al*., 2022). Clarifying and quantifying of the effects of those controlling factors on the rainfall thresholds are crucial to enhance the predicting power of the landslide early warning systems. Recently, there has been a considerable increase in the number of studies on rainfall thresholds for rain-induced landslides (Gonzalez *et al*., 2024). However, the role of site-specific conditions has not been fully examined through intercomparison. Therefore, this study aims to clarify the role of MAR on the rainfall thresholds for occurring landslides by comparing previously defined rainfall thresholds for targeting different MARs available in the literature.

2. Methodology

Intensity-Duration (*I-D*) and total Event rainfall - Duration (*E-D*) type rainfall thresholds are most common and widely used among different types of rainfall thresholds (Segoni *et al.*, 2018; He *et al.*, 2020). So, in this study we focused on these two types. *I-D* type rainfall thresholds can be generalised as a power law equation as $I = \alpha D^{-\beta}$ (eq. 1) where, D is the responsible rainfall duration (h), and I is the average rainfall intensity for the relevant rainfall period (mmh^{-1}), α and β (gradient) are parameters of the power law. Furthermore, $I = E / D$ (eq. 2) where, E is cumulative (total) event rainfall in millimetres (mm). Hence, the above eq. 1 can be re written as $E = \alpha D^{\gamma}$ (eq. 3) where, $\gamma = -\beta + 1$ and it's the generalised power law equation for the *E-D* type rainfall thresholds. Therefore, it is possible to convert given *E-D* type rainfall threshold to its *I-D* version.

In this study we collected 21 *I-D* type and 30 *E-D* type rainfall threshold equations through a literature survey. Some of the rainfall thresholds covered the entire world and large regions with varying mean annual rainfall (MAR). Therefore, we selected rainfall thresholds with a relatively narrow target area and for which MAR can be identified. First, we tried to gather threshold equations which author directly show the information about the targeted MAR category for those thresholds in the original article and next we collected some rainfall thresholds which able to find targeted MAR category of those thresholds from the outside data sources (ex: other research articles, MAR data bases and maps). Finally, we selected 22 rainfall thresholds and categorised in to two categories according to their targeted MARs as low mean annual rainfall (applicable for MAR < 1300 mm), and high mean annual rainfall (applicable for MAR > 1300 mm). We analysed the variation of β values and 10 h threshold rainfall intensities (I_{10}) of the selected rainfall thresholds according to their targeted MAR categories.

3. Results

Most of the instances the *I-D* thresholds belong to low MAR category are lower than the *I-D* thresholds belong to high MAR category and β values (gradients) belong to low MAR category are higher than the β values belong to high MAR category (Figs. 1 and 2). So, *I-D* thresholds defined for targeting low MARs are commonly steep than the *I-D* thresholds defined for targeting high MARs (Fig. 1). Generally, I_{10} of low MAR category are lower than the I_{10} of high MAR category (Fig. 3).

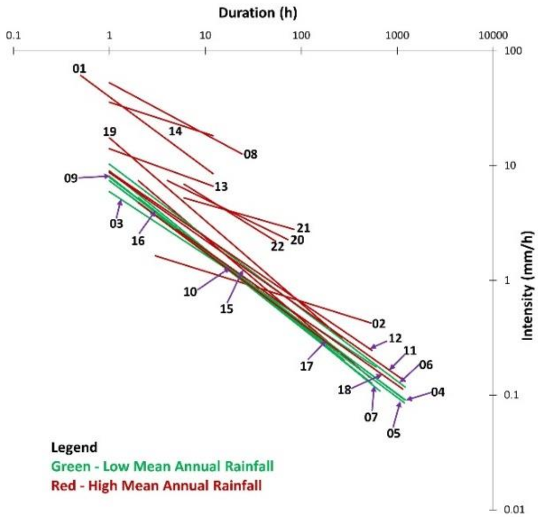

Figure 1: categorisation of the *I-D* thresholds according to their targeted MAR category. Sources: (01) Jibson (1989); (02) Saito *et al*., (2010); (03) Brunnetti *et al*., (2010); (04)-(07) Peruccacci *et al*., (2012); (08) Ma *et al*., (2015); (09)-(12) Peruccacci *et al*., (2017); (13)-(14) Nawagamuwa and Perera (2017); (15) Melillo *et al*., (2018); (16)-(18) Jordanova *et al.*, (2020); (19) Maturidi *et al*., (2021); (20)-(22) Lee *et al*., (2022). Targeted areas of the *I-D* thresholds: (01)-(02) Japan; (03) Abruzzo, Central Italy; (04)-(07) Abruzzo, Marche, and Umbria, central Italy; (08) Zhejiang province of China; (09)-(12) Italy; (13) Sri Lanka; (14) Badulla District, Sri Lanka; (15) Liguria region of Italy; (16)-(18) Slovenia; (19) Peninsular Malaysia; (20)-(22) South Korea.

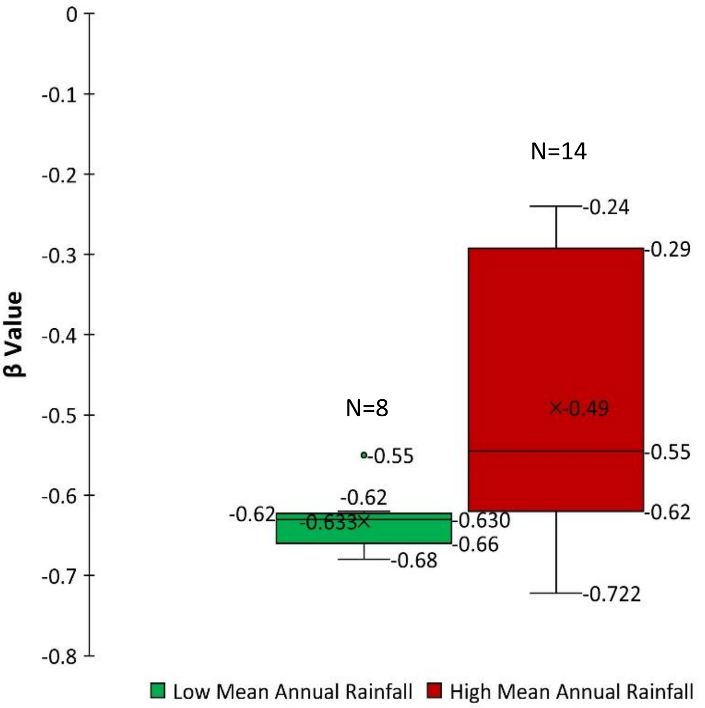

Figure 2: Variation of the β values of the *I-D* thresholds according to their targeted MAR category. N is the amount of data for each category.

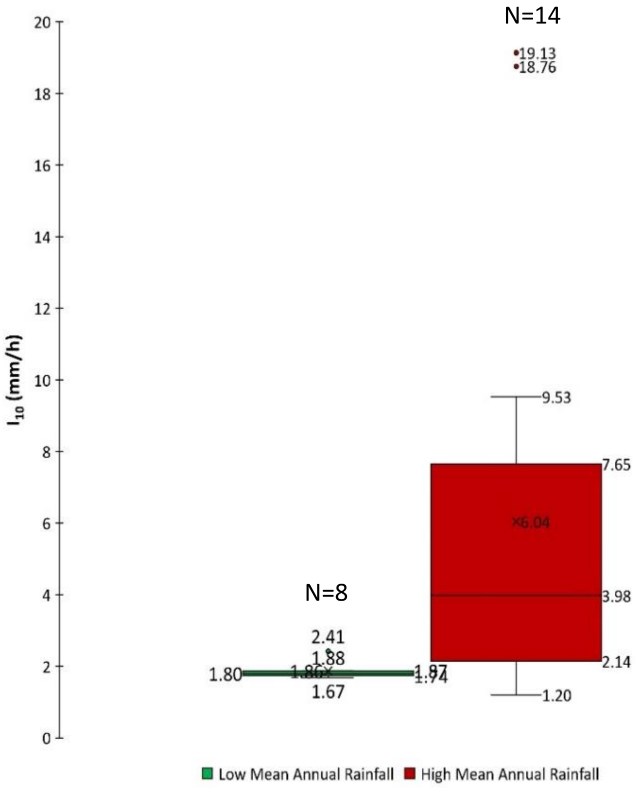

Figure 3: Variation of the I_{10} of the *I-D* thresholds according to their targeted MAR category. N is the amount of data for each category.

4. <u>Discussion</u>

Previous studies have evaluated the impact of MAR by analysing rainfall thresholds using a uniform method in a limited area, such as one country and/or focused on one type of landslide (e.g., Wilson, 2000; Peruccacci *et al*., 2017; Jordanova *et al.*, 2020). In contrast, this study evaluates the impact of MAR by analysing rainfall thresholds, which were defined for targeting different types of landslides using data of different quality and quantity from various regions with different topography, geology and so on. However, the observed effect of MAR in this study is still consistent with previous research, suggesting a significant impact of MAR on rainfall thresholds to induce sediment disasters.

The heterogeneity of the other controlling factors addition to the MAR of our studied threshold collection is also high. It may be influenced to the results also therefore, more studies are recommended to confirm the results furthermore.

5. <u>Conclusion</u>

The MAR considerably effects to decide the rainfall threshold for occurring landslides in a particular region. The findings of this study suggest the fact that where MAR is low it requires less amount of rainfall to trigger the landslides than where MAR is high. However, this scenario can be affected by the involvement of the other controlling factors which are responsible to decide the rainfall thresholds for occurring landslides.

6. <u>References</u>

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