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SOIL EROSION RISK IN RELATION TO RAINFALL EROSIVITY IN GUNUNG ALAB AND INOBONG OF CROCKER RANGE PARK IN SABAH, MALAYSIA

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Abstract: The rainfall ability to erode and detach soil particles, resulting in soil erosion, is referred to as rainfall erosivity (R). This research aims to estimate the risk of soil erosion from rainfall intensity in Gunung Alab and Inobong of Crocker Range Park, Sabah. Daily rainfall data from 2017 and 2020 where an observed mild La Nina were extracted. The 30-minute Maximum Rainfall Intensity (I_{30}) and Rainfall Kinetic Energy (E) were determined for estimating the R Factor. ROSE Index was then referred to in classifying the soil erosion risk. The estimated monthly R Factor in Gunung Alab ranged from 15282.2 to 32029.2 MJ.mm $(ha.h)^{-1}$ in 2017 and from 16069.5 to 35401.6 MJ.mm $(ha.h)^{-1}$ in 2020. Gunung Alab was rated as having an "extremely high" and "critical" risk of soil erosion 80% of the time in 2017 and 50% in 2020. At the Inobong substation, the monthly R Factor in 2017 (16069.5 to 58348.0 MJ.mm $(ha.h)^{-1}$) and 2020 (16863.6 to 36246.4 MJ.mm $(ha.h)^{-1}$) translates to an erosion risk (extremely high-critical) throughout 67% and 92% of the time, respectively. Given the possibility of landslides, rainfall erosivity is useful information in assessing soil erosion risk and could be used in soil and land management.

Keywords: R factor, rose index, rainfall intensity, La Nina, monsoon.

Introduction

Erosion has long been a focal concern in many countries, as agriculture and deforestation cause accelerated erosion rates (Aslam *et al.,* 2020; Gharibreza *et al.,* 2020). On land, enhanced erosion may also occur naturally when induced by heavy rain and strong winds. Strong convective winds often precede heavy rains, and wind and water erosion occur almost simultaneously (Visser & Cornells, 2004). According to Oldeman (1989), tropical forests receive more rainfall than other forest type (over 4000 mm annually). Hence, they are more likely to experience higher soil erosion rates. Due to its rainfall distribution, Malaysia is categorised as a high rain erosion country in the generalised rain erosion map (Panagos *et al.,* 2017).

In tropical montane forests, heavy rainfall will put the area at higher risk due to their sensitive ecology and high relief (Bussmann, 2002; Piacentini *et al*., 2018). It has also been mentioned that climate change may cause higher rainfall, higher intensity rain, and unequal rainfall distribution, thus, putting highland watersheds at risk of increasing soil erosion (Sholagberu *et al*., 2016). According to Nasidi *et al*. (2021), among the essential characteristics of rainfall are its intensity, amount, event duration, and frequency. Besides the increases in extreme rainfall events, the global average temperature was also anticipated, especially in the tropics (Nasidi *et al*., 2021; Robinson *et al*., 2021).

Crocker Range Park (CRP) is Sabah's largest terrestrial park, and it includes a diverse landscape of highland and lowland forests. It is a matter of concern that more areas adjacent to the park are being or would be developed either for socio-economic or local community-use purposes. Nonetheless, there is limited information on the possibility and risk of soil erosion associated with land conversion.

Rainfall erosivity or R-factor (R) refers to the ability of rainfall to erode and detach soil particles in an area, eventually leading to erosion and soil loss (Wischmeier & Smith, 1958). It is one of the parameters in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1958; Wischmeier, 1984; Suif *et al*., 2018) and its revised version, the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*.,1991). For reliable estimates of the R-factor, high temporal resolution rainfall data with a maximum of 30-minutes intensities for at least 20 years is required (Meusburger *et al.,* 2012). However, such high-resolution data may not always be available. Thus, several reports proposed a R-factor estimation method based on daily, monthly, or annual rainfall data. On the other hand, the ROSE Index (Table 1) was developed to show the severity of soil erosion induced by rain regarding the rainfall erosivity value (Bouyoucos, 1962; Naimah & Roslan, 2015; Suif *et al*., 2018).

Erosivity potential could not be determined by rain amount alone. Kinetic energy from individual raindrops is transferred to the soil particles. Therefore, rainfall erosivity or R factor is the product of rainfall energy (E) and its maximum 30-minute rainfall quantity (I_{30}), resulting in the total energy and peak intensity combined in a specific rain event (Wischmeier & Smith, 1978). This research aims to evaluate rainfall erosivity in the Crocker Range Park and assess soil erosion potential using the ROSE Index. This study will provide essential data for soil monitoring and management activities to mitigate soil erosion. Considering the high demand for socioeconomic development in the study area, we suggest that the relevant authority establish a rigorous policy and system for monitoring land use and land cover change.

Materials and Methods

Study Area

In addition to ecological richness, one of the primary reasons for the designation of Crocker Range Park (CRP) as a protected area in 1984 was that it is an important freshwater catchment. It functions as a headwater catchment for several major rivers on the west coast and interior of Sabah (Mahali *et al*., 2020; Sabah Parks, 2021). Comprising an area of 139,919 ha, CRP spans eight districts with elevations ranging from 100 to 2,050 metres above sea level (m.a.s.l) (Sabah Parks, 2021). This study has focused on two substations of CRP, namely Gunung Alab (5°49’18.8’’N, 116°20’28.4’’E) and Inobong (5°51’23.95’’N, 116°08’17.03’’E). Figure 1 shows the approximate location of the study sites. The climate in Inobong is equatorial, with an annual rainfall of 4,189 mm (2010-2011). Gunung Alab has a lower tropical montane climate, with a mean annual rainfall of 3,527 mm (2007-2018) (Nainar *et al.,* 2022). Inobong substation is in the Penampang district, while Gunung Alab is in the Tambunan district. Both are approximately 44 kilometres apart and accessible by road. Generally, it has been observed that the Penampang district has a high development rate, possibly due to its proximity to the capital, Kota Kinabalu. As for Inobong, the lower elevation area was mostly developed as community settlements, agricultural lands, and other economic activities. However, the forested areas within the CRP boundary are still intact, being conserved, and remain a recreational attraction for local nature lovers.

Table 1: Rainfall erosivity category (ROSE Index)

ROSE Index [MJ.mm $(ha.h)^{-1}$]	Category
< 5,000	Low
5,000-10,000	Moderate
10,000-15,000	High
15,000-20,000	Very high
> 20,000	Critical

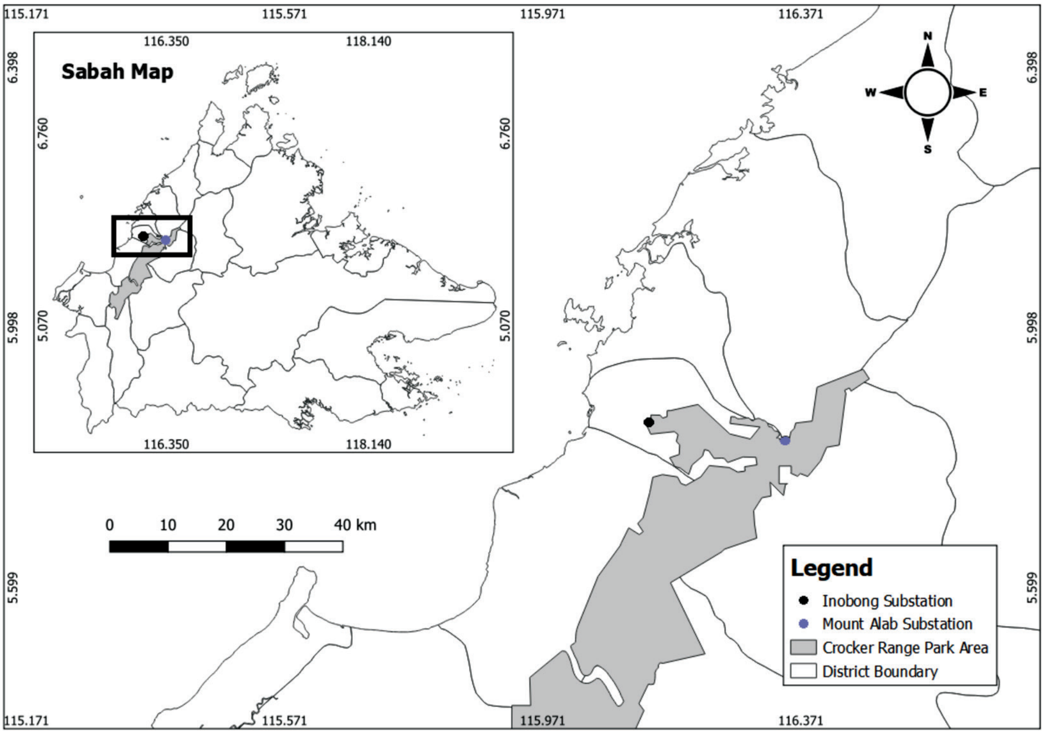

Figure 1: Location of study sites

Data Analyses

Daily rainfall data were obtained from Gunung Alab and Inobong substations meteorological stations. The meteorological stations were established as part of a collaborative research between Universiti Malaysia Sabah (UMS), Sabah Parks, and The University of Tokyo, with the support of the Japan International Cooperation Agency (JICA). The study examined rainfall data for 2017 and 2020, coinciding with some phases of the *La Nina* events. A weak *La Nina* was observed starting in December 2017 (Jabatan Meteorologi Malaysia, 2017), whilst in 2020, there were flooding events in parts of Sabah and Malaysia that were linked to the moderate *La Nina* during the monsoon transition phase (Borneo Post, 5th October 2020). In the analysis of Rainfall Intensity, I_{30} (cm h^{-1}) is the maximum 30-minute rainfall intensity. Rainfall Kinetic Energy, E (MJ ha^{-1}) and I_{30} were calculated using 10-minute intensity (Lee & Hsu, 2021) within a month. Rainfall Erosivity (R) was then estimated and utilised in the ROSE Index to classify soil erosion risk. Due to technical issues, rainfall data in Gunung Alab between January and February 2017 were unavailable. Therefore, only data from March to December were used for comparison purposes. The following equations were used in this study (Wischmeier & Smith, 1978):

Rainfall Intensity I_{30} (cm h^{-1})

$$I_{30} = \text{(Total Rainfall (cm))/(30 min duration of Rainfall (h))} \quad \textbf{(I)}$$

Rainfall Kinetic Energy, E (MJ ha^{-1})

$$E = 210 + 89 \log_{10} (I_{30}) \quad \textbf{(II)}$$

Rainfall Erosivity, R MJ.mm $(ha.h)^{-1}$

$$R = EI_{30} \quad \textbf{(III)}$$

Results and Discussion

According to Naimah and Roslan (2015), 20 mm day^{-1} of rain within a 25-kilometer radius could cause soil erosion. Figures 2-5 show the monthly sum of rainfall from events of ≥ 20 mm shows the cumulative rainfall in years 2017 and 2020 in the study sites. In 2017 Gunung Alab, the most days with monthly rainfall ≥ 20 mm day^{-1} occurred in October and December, whereas the least days with monthly rainfall ≥ 20 mm day^{-1} occurred in September and November (Figure 2). In 2020, October and November had the highest rainfall (Figure 3). Months with the least days of rainfall events ≥ 20 mm day^{-1} were February and March. In the year 2017 in Inobong, August and December have the most days with rainfall of 20 mm and above. On the other hand, February and March 2017 had the lowest count of days with monthly rainfall ≥ 20 mm day^{-1} (Figure 4). In 2020 in Inobong, the highest frequency of at least 20 mm daily rainfall was in July and December, whereas February and March had the lowest frequency of rainfall ≥ 20 mm day^{-1} (Figure 5). Aside from the localised climate, it is apparent that the annual monsoon season influenced the rainfall distribution at the study sites. The Southwest monsoon occurs from late May to September, whereas the Northeast monsoon occurs from November to March. The annual Malaysian northeast monsoon, which is known to bring more rain, contributed to higher rainfall at the end of 2017 and 2020.

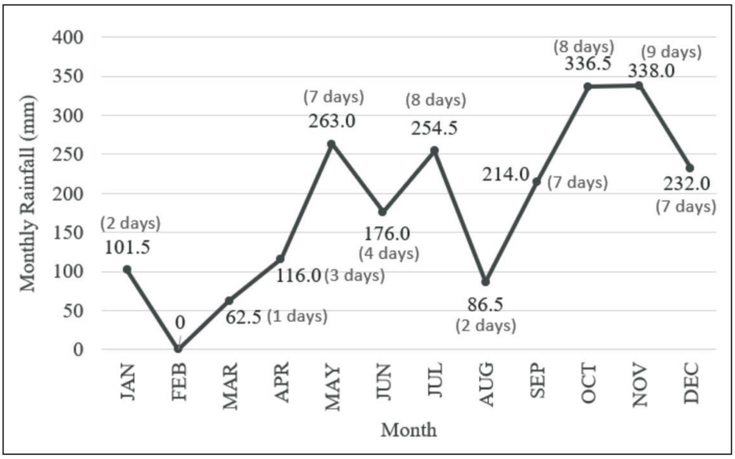

Figure 2: Monthly rainfall in Gunung Alab, year 2017. Number of days with rainfall of at least 20 mm were given in brackets

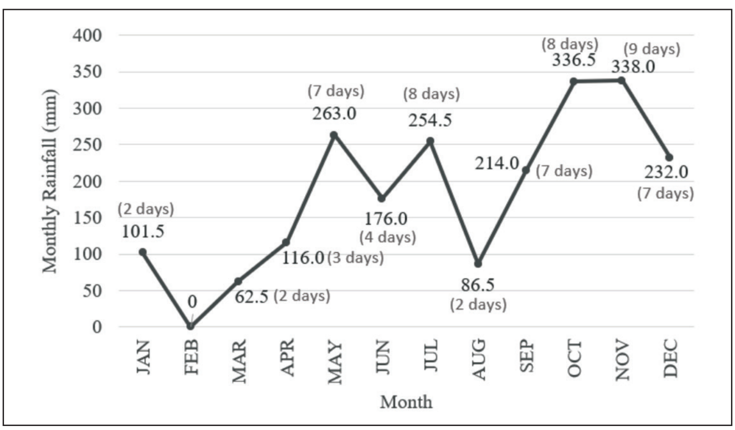

Figure 3: Monthly rainfall in Gunung Alab, year 2020. The number of days with rainfall of at least 20 mm was given in brackets

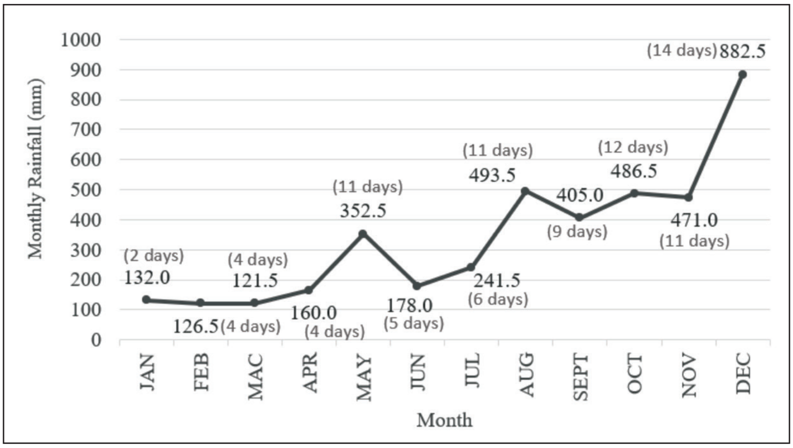

Figure 4: Monthly rainfall in Inobong, year 2017. The number of days with rainfall of at least 20 mm was given in brackets

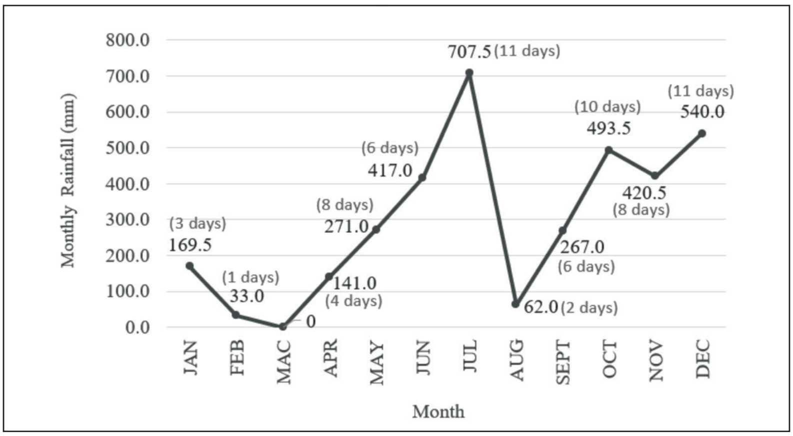

Figure 5: Monthly rainfall in Inobong, year 2020. The number of days with rainfall of at least 20 mm was given in brackets

Next, Figures 6 and 7 show the monthly rainfall trend for both Gunung Alab and Inobong substations. In 2017, *La Nina* started in December (Jabatan Meteorologi Malaysia, 2017), which increased rainfall in both sites. *La Nina* influence began in August of 2020 (World Meteorological Organisation, 2020) and faded in November (Jabatan Meteorologi Malaysia, 2021).

The annual rainfall in each substation for the years 2017 and 2020 is shown in Table 2. Gunung Alab's annual rainfall in 2017 was 786 mm higher than in 2020, whereas Inobong received an additional 214 mm in 2020 compared to 2017. During such periods, more moist air is expected to circulate over and around hills and mountainous regions, which significantly impacts precipitation patterns and results in higher rainfall (Houze, 2012; Somro *et al.,* 2019).

Table 2 shows the annual rainfall in 2017 and 2020 and Table 3 shows the ROSE Index percentage of rainfall erosivity, R for 30-minute rainfall events (classified from very high to critical degree of soil erosion risk). From the results, Gunung Alab had an R Factor of 67% month in 2017 and 50% month in 2020, classified as very high to a critical level of soil erosion occurrence. However, rainfall erosivity, R Factor range is greater in year 2020 (16069.5-

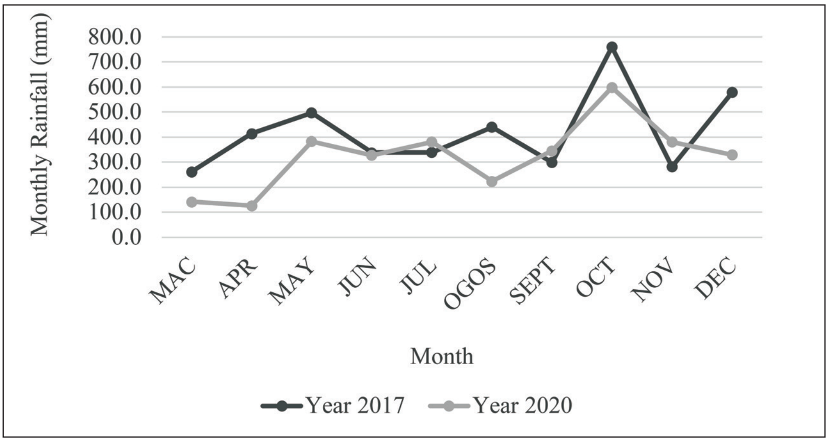

Figure 6: Monthly rainfall in 2017 and 2020 in Gunung Alab

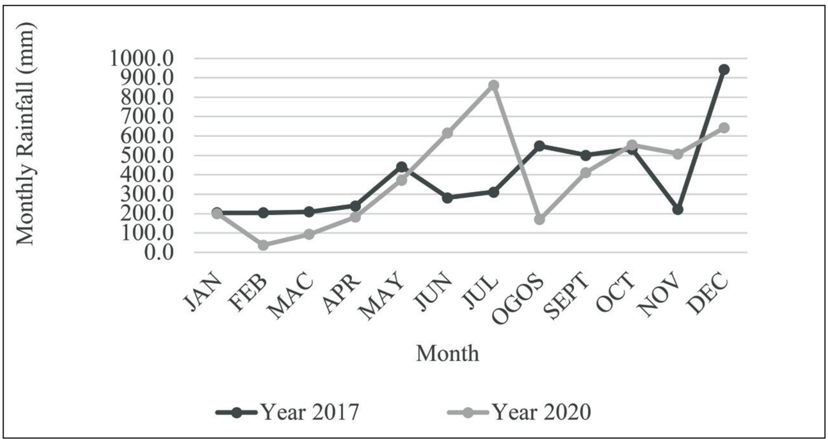

Figure 7: Monthly rainfall in 2017 and 2020 in Inobong

Table 2: Annual rainfall in Gunung Alab and Inobong

	Year 2017 (mm)	**Year 2020 (mm)**
Gunung Alab	5055	3427
Inobong	4646	4655

Table 3: Percentage of Rainfall Erosivity Level in Gunung Alab and Inobong

Station	**Year**	**Percentage Level of seriousness (%)**		**Total (%)**
		Very High	**Critical**	
Gunung Alab	2017	16.67	50.00	66.67
	2020	16.67	33.33	50.00
Inobong	2017	16.67	50.00	66.67
	2020	16.67	75.00	91.67

35401.6 MJ.mm $(ha.h)^{-1}$) than in year 2017 (15282.2–32029.2 MJ.mm $(ha.h)^{-1}$). This is because the rainfall intensity in 2020 is higher than in 2017. It has been reported that the erosive potential of rain is proportional to its intensity (Renard *et al*., 1997; Vallebona *et al*., 2015). Similar situations occurred in Inobong, whereby the ROSE Index percentage of rainfall erosivity, R, was lower, but R-Factor was higher in 2017, and vice versa in 2020. It was 92% month in 2020 compared to 67% month in 2017 for the R Factor percentage. However, the R Factor range in 2017 (16069.5-58348.0 MJ.mm $(ha.h)^{-1}$) was larger than the R Factor range in 2020 (16863.6-36246.4 MJ.mm $(ha.h)^{-1}$). It was found that *La Nina* events that coincided with the Malaysian Seasonal Monsoon increased the rainfall intensity, resulting in a larger R-Factor range for the study sites in 2017 and 2020.

Conclusion

The main parameter in estimating the R factor was rainfall intensity, an important parameter demonstrating rainfall erosive potential. The findings of this study indicated that a rainfall erosivity value (R) of 50% or higher in the Gunung Alab and Inobong substations was classified as very high to critical (based on the ROSE Index) for 2017 and 2020. It showed that the rainfall intensity in both sites has significant potential to cause soil erosion and loss. Future studies could further investigate this (e.g., surface runoff and sediment yield study). With the presence of *La Nina*, noticeable increases in rainfall amount and intensity were also observed. Based on these findings, landslides may also be expected to occur within the studied areas. In light of global concerns regarding extreme weather, excessive rain, and increased frequency of heavy rainstorms due to climate change, the management of Crocker Range Park and the district authority may consider conservation strategies to minimise or mitigate soil erosion risk.

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