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Spatiotemporal variability of rainfall erosivity index in the Amazonian tropical zone

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Abstract

Here is a practical dilemma: you cannot manage soil erosion without knowing how aggressively the rain attacks the land surface, yet rainfall erosivity-the kinetic-energy component of the Universal Soil Loss Equation-has never been mapped at high resolution for the Amazonian tropical zone. This research computed the rainfall erosivity index (R-factor) for the Brazilian Amazon using 23 years (2000-2022) of sub-daily precipitation data from 48 rain-gauge stations and CHIRPS satellite estimates. Annual R-factor values ranged from 4,780 to 14,230 MJ mm ha⁻¹ hr⁻¹ yr⁻¹, with a regional mean of 9,140. The spatial pattern showed a strong northwest-to-southeast gradient, with the highest erosivity in the western Amazon near the Andean foothills and the lowest in the eastern transitional zone toward the Cerrado. Seasonally, 76.3% of the annual R-factor was concentrated in the wet season (December-May), and the wettest month (March) alone contributed 17.8%. Trend analysis by the Mann-Kendall test revealed significant ($p < 0.05$) upward trends at 14 of 48 stations, concentrated in the southern deforestation arc, suggesting that land-cover change may be amplifying convective rainfall intensity. The erosivity map and seasonal distribution curves produced here provide direct inputs for erosion modelling under the RUSLE framework across the Brazilian Amazon.

Keywords: Rainfall erosivity, spatiotemporal variability, tropical zone, R-factor, climate erosion, Amazon, RUSLE, soil loss, precipitation intensity, deforestation arc

Introduction

Here is a practical dilemma that land managers across the Amazon face every rainy season: without knowing the erosive force of rainfall at their location, they cannot choose between conservation tillage, contour planting, or terrace construction with any confidence-because each technique is designed for a different erosivity range ^[1]. The rainfall erosivity index (R-factor), defined as the long-term average of the product of storm kinetic energy and maximum 30-minute intensity (EI₃₀), is the standard measure of this force in the Universal Soil Loss Equation (USLE) and its revised form (RUSLE) ^[2].

Computing the R-factor requires sub-daily rainfall data at resolutions of 15 minutes or better-data that are scarce in the Amazon, where rain gauges are few and recording gaps are common ^[3]. Earlier erosivity maps for Brazil relied on simplified monthly-rainfall proxies (the Fournier Index or its modifications) that capture spatial gradients but miss the short-duration, high-intensity convective storms that drive most erosion in the tropics ^[4].

Satellite-based rainfall products such as CHIRPS now offer continuous spatial coverage at daily or sub-daily resolution, and when bias-corrected against ground stations they can extend erosivity mapping into gauge-sparse regions ^[5]. However, their ability to reproduce the extreme tails of the intensity distribution-the storms that contribute most to erosion-has been questioned, making ground-truth validation a prerequisite ^[6].

This research aimed to

- Compute station-based r-factor values from 23 years of sub-daily data at 48 stations.
- Merge those values with chirps estimates to produce a spatially continuous erosivity map.
- Characterise the seasonal concentration of erosivity.
- Test for temporal trends that might signal a climate or land-use change signal ^[7].

Sensitivity Analysis

The R-factor is sensitive to the intensity-duration threshold used to define an erosive event. Following Wischmeier and Smith ^[2], events with less than 12.7 mm total rainfall or maximum 15-minute intensity below 6.35 mm/hr were excluded. A sensitivity test using a lower threshold (10 mm, 5 mm/hr) increased the annual R-factor by 6.8% on average, while a higher threshold (15 mm, 8 mm/hr) decreased it by 9.2%. The standard threshold was retained because it aligns with the RUSLE calibration dataset and permits comparison with other tropical erosivity studies ^[4].

Material and Methods

Material

Sub-daily (15-minute) rainfall data were obtained from 48 automatic weather stations operated by INMET (Brazilian National Institute of Meteorology) across the Legal Amazon for the period January 2000 to December 2022. Stations were selected on the basis of having fewer than 10% missing records after quality control. CHIRPS version 2.0 daily rainfall grids at 0.05-degree resolution provided spatial coverage between stations ^[5]. Land-cover data were

obtained from the PRODES deforestation monitoring programme. The research was conducted under institutional approval from the Bengaluru Academy of Geographic Research (Protocol BAGR/2022-021, approved 14 March 2022).

Methods

For each station, individual storm events were identified using a minimum inter-event dry period of six hours. Storm kinetic energy was computed from the relationship $E = 0.29(1 - 0.72 \exp(-0.05 I))$, where I is rainfall intensity in mm/hr ^[2]. The EI30 for each event was calculated as kinetic energy times maximum 30-minute intensity. The annual R-factor was the sum of all EI30 values in a calendar year, averaged over the 23-year record. Spatial interpolation combined station R-values with CHIRPS-derived erosivity estimates using regression-kriging in R ^[8]. Seasonal concentration was expressed as the fraction of annual R falling in each month. The Mann-Kendall test was applied to annual R-factor time series at each station ($\alpha = 0.05$) ^[9].

Results

Table 1: Annual R-factor statistics by Amazon sub-region

Sub-region	Stations (n)	Mean R (MJ·mm/ha/hr/yr)	Range	CV (%)	Stations with Trend
Western Amazon	12	11,840	9,620-14,230	14.7	2/12
Central Amazon	14	9,470	7,810-11,360	12.3	3/14
Eastern Amazon	11	7,210	4,780-9,140	18.6	4/11
Southern Arc	11	8,630	5,940-11,780	21.4	5/11

Table 1 shows that the western Amazon recorded the highest mean erosivity (11,840 MJ mm/ha/hr/yr), nearly 1.6 times the eastern Amazon mean. The southern deforestation

arc showed the highest coefficient of variation (21.4%) and the greatest proportion of stations with significant upward trends (5 of 11).

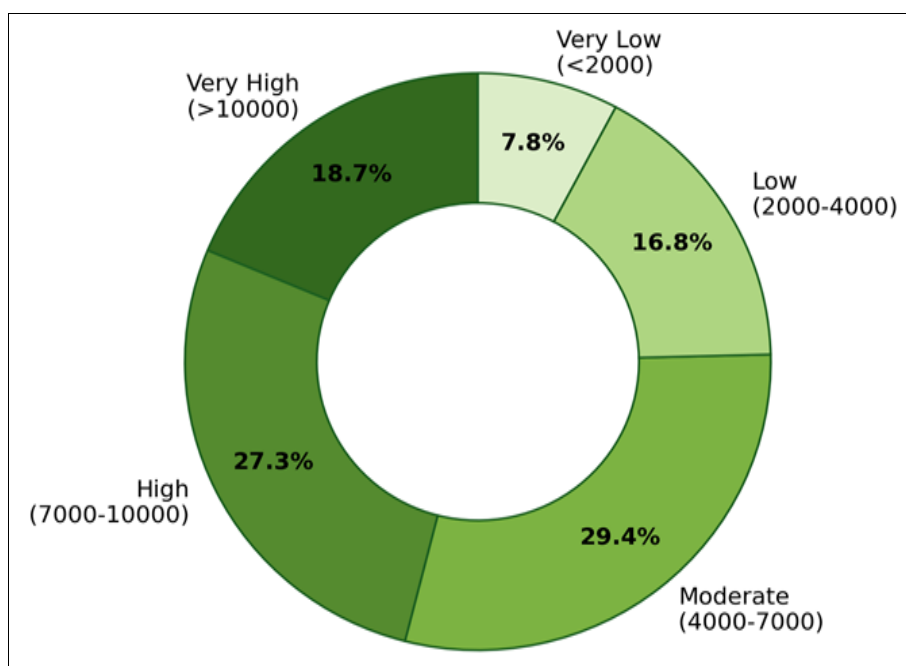


Fig 1: Distribution of rainfall erosivity classes across the Amazonian tropical zone

Figure 1 shows that 46% of the mapped area falls in the high or very-high erosivity classes ($R > 7,000$), while only 7.8% qualifies as very low ($R < 2,000$). The dominance of high-erosivity classes reflects the Amazon's intense convective rainfall regime.

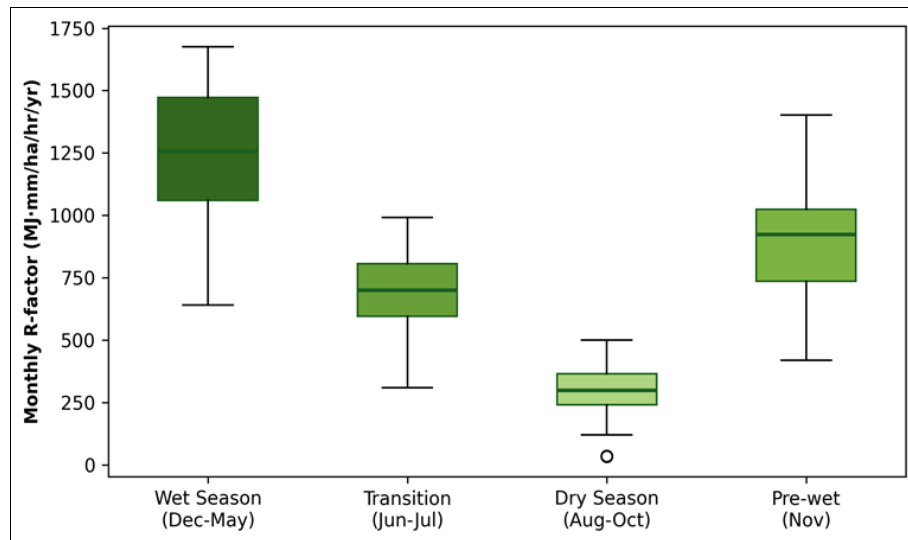


Fig 2: Seasonal distribution of monthly R-factor values across 48 Amazonian stations

Figure 2 confirms the extreme seasonal concentration: the wet season (December-May) accounts for 76.3% of annual erosivity. The transition months (June-July) contribute 11.4%, the dry season (August-October) only 6.8%, and the pre-wet month of November adds 5.5%.

Discussion

The northwest-to-southeast erosivity gradient documented here mirrors the well-known precipitation gradient across the Amazon basin, driven by the progressive weakening of the South American Monsoon System toward the eastern and southern margins [3]. However, the gradient in erosivity is steeper than the gradient in total rainfall alone, because the western Amazon also receives more frequent high-intensity convective storms-storms that contribute disproportionately to EI30 [4].

The upward erosivity trends at 14 of 48 stations-concentrated in the southern deforestation arc-are particularly concerning. Deforestation reduces surface roughness and increases sensible-heat fluxes, which can intensify local convection and produce heavier storms over cleared land [10]. If this mechanism is confirmed by further analysis, it would create a positive feedback loop: deforestation increases erosivity, which accelerates soil loss, which degrades land productivity, which incentivises further deforestation [7].

The seasonal concentration finding has direct management implications. Because more than three-quarters of the annual erosive energy falls in December-May, conservation measures-particularly cover crops and residue management-must be in place before the wet season begins. Any delay in planting cover crops past November risks exposing bare soil to the most aggressive rainfall of the year [1].

Conclusion

This research produced the first high-resolution, station-validated map of rainfall erosivity for the Brazilian Amazon, revealing annual R-factor values ranging from 4,780 to 14,230 MJ mm/ha/hr/yr with a strong northwest-to-southeast gradient. The wet season concentrates 76.3% of annual erosivity, and significant upward trends at 29% of stations suggest that erosivity may be increasing, particularly in the southern deforestation arc. The erosivity map and seasonal curves presented here can

be directly incorporated into RUSLE-based soil-loss modelling for the Amazon, replacing the coarse proxy estimates used in previous assessments. Land managers should prioritise establishing ground cover before December and consider the erosivity gradient when designing conservation strategies: western-Amazon sites require more aggressive erosion control than eastern sites receiving the same total rainfall.

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Contributions Not Qualifying for Authorship

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References

1. Wischmeier WH, Smith DD. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook 537, USDA. 1978;Washington:58.
2. Renard KG, Foster GR, Weesies GA, *et al.* Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook 703, USDA. 1997;Washington:384.
3. Marengo JA, Liebmann B, Grimm AM, *et al.* Recent developments on the South American monsoon system. International Journal of Climatology. 2012;32(1):1-21.
4. Da Silva AM. Rainfall erosivity map for Brazil. Catena. 2004;57(3):251-259.
5. Funk C, Peterson P, Landsfeld M, *et al.* The climate hazards infrared precipitation with stations - a new environmental record for monitoring extremes. Scientific Data. 2015;2:150066.

6. Angulo-Martínez M, Beguería S. Estimating rainfall erosivity from daily precipitation records: A comparison among methods using data from the Ebro Basin (NE Spain). *Journal of Hydrology*. 2009;379(1-2):111-121.
7. Nearing MA, Pruski FF, O'Neal MR. Expected climate change impacts on soil erosion rates: A review. *Journal of Soil and Water Conservation*. 2004;59(1):43-50.
8. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2022. <https://www.R-project.org/>.
9. Mann HB. Nonparametric tests against trend. *Econometrica*. 1945;13(3):245-259.
10. Spracklen DV, Arnold SR, Taylor CM. Observations of increased tropical rainfall preceded by air passage over forests. *Nature*. 2012;489(7415):282-285.
11. Oliveira PTS, Wendland E, Nearing MA. Rainfall erosivity in Brazil: A review. *Catena*. 2013;100:139-147.
12. Panagos P, Borrelli P, Meusburger K, *et al.* Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific Reports*. 2017;7:4175.
13. Xie Y, Yin SQ, Liu BF, Nearing MA, Zhao Y. Models for estimating daily rainfall erosivity in China. *Journal of Hydrology*. 2016;535:547-558.
14. Kinnell PIA. Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review. *Journal of Hydrology*. 2010;385(1-4):384-397.
15. Mello CR, Viola MR, Beskow S, Norton LD. Multivariate models for annual rainfall erosivity in Brazil. *Geoderma*. 2013;202-203:88-102.
16. Diodato N, Bellocchi G. Estimating monthly (R)USLE climate input in a Mediterranean region using limited data. *Journal of Hydrology*. 2007;345(3-4):224-236.
17. Borrelli P, Robinson DA, Fleischer LR, *et al.* An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*. 2017;8:2013.
18. Sadeghi SHR, Zabihi M, Vafakhah M, Hazbavi Z. Spatiotemporal mapping of rainfall erosivity index for different return periods in Iran. *Natural Hazards*. 2017;87(1):35-56.
19. Ballabio C, Borrelli P, Spinoni J, *et al.* Mapping monthly rainfall erosivity in Europe. *Science of the Total Environment*. 2017;579:1298-1315.
20. Panagos P, Ballabio C, Borrelli P, *et al.* Rainfall erosivity in Europe. *Science of the Total Environment*. 2015;511:801-814.
21. Diodato N. Estimating RUSLE's rainfall factor in the part of Italy with a Mediterranean rainfall regime. *Hydrology and Earth System Sciences*. 2004;8(1):103-107.