

Erosivity index (EI₃₀) in the Paraíba River Upper Course watershed - Paraíba - Brazil

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Abstract

Rainfall erosivity, defined as the potential of this in causing soil erosion, is a function only of the physical characteristics of the rain itself, ie its amount, intensity, drop diameter, terminal velocity and kinetic energy. Aims to evaluate the erosivity index (EI₃₀) from rainfall variability distributed in the basin of the Upper River Paraíba Course - PB/Brazil, considering the number of higher rainfall than 57 years of data for the 12 municipalities that make up the study area. To determine the erosivity factor was used the equation proposed by [29; 30 and 31, the R factor, rainfall erosivity is the sum of the monthly values of erosivity. The results showed no significant correlations to the Barra de São Miguel municipalities, Camalaú, Monteiro, Silver, São João do Tigre, San Jose of the Lambs and São Sebastião do Umbuzeiro, while for the municipalities of Cabaceira, Caraúbas, Congo and Sierra White were identified moderate erosion rates to weak in a few months the wettest quarter of the region.

Keywords: Erosive potential; Semi-arid northeast; Spatiotemporal variability of precipitation

1. Introduction

Precipitation is a meteorological element that presents great variability, both in quantity, and in monthly and annual distribution from one region to another, being the main factor used in subdividing the climate of a region and /or locality [2]. Rain exerts a fundamental influence on environmental conditions, acting directly on the water balance in the soil and indirectly through other variables such as air temperature, soil temperature, air humidity and solar radiation, which acting together limit or favor the growth and development of a civilization in each region of the globe. Particularly in tropical areas, [7] highlighted that the most important climatological parameter to be considered is rain.

In the Northeast of Brazil (NEB), especially in its semi-arid portion, which frequently faces the problems of prolonged drought and drought, the occurrence of precipitation variability, even in the rainy season, is one of its most striking characteristics, being considered a situation very serious [20], taking into account the high dependence that agriculture in this region has on rainfall. [24] carried out a study in the semi-arid region of Minas Gerais, and demonstrated that the variability of the rainy season depended solely and exclusively on the factors causing rain.

The relief is generally quite diversified, consisting of forms worked by different processes, acting under different climates and on little or very different rocks. In this case, there are three groups formed by the most significant climatic types: humid, sub-humid and semi-arid. Current use and vegetation cover are characterized by forest formations defined as open tree shrubbery, closed tree shrubbery, closed treehouse, coastal board, mangroves, humid forest, semi-deciduous forest, Atlantic forest and sandbank.

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Floods, floods and floods have already caused damage and removals to several villages, towns and villages. Historically, the greatest floods occurred between the middle, low and high Paraíba stretches, with their occurrence being almost periodic (depending on the quality and quantity of the rainy season). It is known that in this area there are no flood containment systems and their flow rates are random, aided by relief [28].

Other expected problems are the reduction in rainfall, which may reach a range of 60% of monthly values, with this the water storage reservoirs will become obsolete, further restricting drinking water for human and animal survival, will also undergo changes to the fauna and flora, and some species may become extinct [18].

Studies have shown that the frequency distribution has been used to characterize the rainfall regime in a region, although the incomplete gamma distribution is the theoretical model that best fits the original data in accordance with [21]. According to [2] a very common error in data analysis is to neglect the characteristics of the most appropriate probability distribution for the data under study.

According to the United Nations (UN), the occurrence of desertification is considered restricted to arid, semi-arid and dry sub-humid environments, where the ratio between annual precipitation and potential evapotranspiration is between 0.05 and 0.65. Desertification is one of the biggest problems today, standing out among the main environmental issues considered worldwide. The areas susceptible to desertification are beyond the drought polygon, involving the states of Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais and Espírito Santo, reaching a total of 1.482 municipalities.

Authors such as [17; 26; 3; 12 and 5] analyzed the causes and consequences of environmental degradation in some locations in the upper Paraíba River. However, a more detailed investigation of such aspects is necessary in the entire basin of that river, following its regionalization, starting with the high course until its mouth.

The susceptibility index is a stable index over time and can be valid for a long period and only needs to be recalculated when there is evidence of change in any indicator. Desertification involves change in time, with worsening environmental, agricultural and/or social conditions. The indicators referring to both aspects, in many cases, are the same, and what differentiates the propensity indicators for the desertification indicators is the worsening in time.

Soil degradation is a worldwide problem and has several implications for the social and economic structures of the populations that occupy the areas where this phenomenon occurs. In Brazil it is more present in the Northeast region, mainly in the semi-arid region, where the impacts can be seen through the destruction of biodiversity (flora and fauna), the decrease in the availability of water resources, through the silting up of rivers and reservoirs and the loss soil physics and chemistry [11].

In recent years, modernization has led to the growth of cities, and with the increase in urbanization, conditions have arisen that have been causing changes in the local climate, mainly due to the construction of works, such as buildings, soil waterproofing, deforestation, absence of urban planning. to improve the coexistence between human beings and the environment, which has been excluding natural elements, and inducing the appearance of extreme events, which has consequences in large cities: floods, floods, floods, landslides, increased pests, diseases and deaths [25].

[6], one of the first scholars on the subject, highlights two main effects of desertification: a) soil erosion, either by the laminar process or by the ravination, processes that would install themselves as a consequence of the removal of vegetation; b) worsening of the soil water deficit, due to their greater exposure to solar radiation and the action of dry winds.

[23], states that the desertification process, in general, occurs in areas where the ratio between precipitation and potential annual evapotranspiration is less than 0.65, this corresponds to arid, semi-arid and sub-humid dry areas, in which a combination of anthropic and natural factors act in a way to accelerate or not in this process.

Studies on this degradation process are of paramount importance because they strongly compromise the economy and the environment and affect both the urban and rural population of the municipality, and it expands in the surroundings, very quickly through the morphoclimatic domains of the Caatinga [4 and 23].

Rain erosivity, defined as the potential of rain to cause soil erosion, is solely a function of the physical characteristics of the rain itself, including its quantity, intensity, droplet diameter, terminal speed and kinetic energy. In the expectation of detailing the studies of this erosive agent, research has shown that the characteristics of rain that provide the highest correlations with soil losses are the intensity and kinetic energy according to [19].

Water erosion is a major problem for soils with agricultural use. In addition to reducing crop productivity, the erosion process can cause serious environmental impacts, especially siltation and pollution of water resources in accordance with [8]

The objective is to carry out rainfall and erosion analysis in the area of the hydrographic basin of the upper course of the Parnaíba River (BHACRPB).

2. Material and methods

BHACRPB, between latitudes $6^{\circ}51'31''$ and $8^{\circ}26'21''$ South and longitudes $34^{\circ}48'35''$; and $37^{\circ}2'15''$; West of Greenwich, it is the second largest in the State of Paraíba, considered one of the most important basins in the northeastern semiarid, it is composed of the sub-basins of the Taperoá river and regions of the Upper, Middle and Lower Course of the Paraíba river. The study area refers to the High Course (Figure 1). The sub-basin encompasses, totally or partially, the area of Paraíba municipalities (Barra de São Miguel, Cabaceiras, Camalaú, Caraúbas, Congo, Coxixola, Monteiro, Prata, São João do Tigre, São Sebastião do Umbuzeiro, Serra Branca and São José dos Cordeiros), distributed between the Western and Eastern Cariri micro-regions of the State of Paraíba.



Source: AESA (2022).

Figure 1 Location of the Paraíba River hydrographic basin. In the southwestern part, its Upper course

The basin is made up of regions affected by local, regional and large-scale synoptic events causing rain such as the Intertropical Convergence Zone and the contributions of the High Level Cyclonic Vortexes when active over the Brazilian Northeast, in addition to the effects of the northeast trade winds together with the effects of sea breeze, aided by the formation of the South Atlantic Cyclonic vortexes and the formation of the instability lines, of the Dipole Pattern in the Tropical Atlantic Ocean and wave disturbances in the field of trade winds, providing events for droughts, floods, floods, flooding, overflow of rivers, dams, muds, ponds, lakes and streams. With regard to drainage, the flow of rivers at the headwaters of this basin is mostly temporary due to poor rainfall distribution.

It used series of monthly and annual rainfall data collected by the Northeast Development Superintendence ([27] and provided by the Paraíba State Water Management Agency [1], with observation period and highlighted in Table 1.

Table 1 Geographic coordinates, altitudes and observation period for monthly and annual rainfall in municipalities in the upper Paraíba River basin. Source: [13]

| Municipalities/months | Latitude | Longitude | Altitude | Period |
|----------------------------|----------|-----------|----------|-----------|
| Barra de São Miguel | -7,45 | -36,19 | 520 | 1962-2019 |
| Cabaceiras | -7,29 | -36,17 | 338 | 1926-2019 |
| Camalaú | -7,53 | -36,49 | 565 | 1962-2019 |
| Caraúbas | -7,43 | -36,29 | 460 | 1931-2019 |
| Congo | -7,47 | -36,39 | 500 | 1962-2019 |
| Coxixola | -7,37 | -36,36 | 465 | 1962-2019 |
| Monteiro | -7,53 | -37,07 | 590 | 1911-2019 |
| Prata | -7,41 | -37,04 | 600 | 1962-2019 |
| São João do Tigre | -8,04 | -36,5 | 616 | 1934-2019 |
| São José dos Cordeiros | -7,23 | -36,48 | 600 | 1963-2019 |
| São Sebastião do Umbuzeiro | -8,09 | -37,00 | 600 | 1962-2019 |
| Serra Branca | -7,28 | -36,39 | 450 | 1962-2019 |

Source: Medeiros (2022).

To determine the erosivity factor, equation (1) proposed by [29; 30 and 31] was defined as:

$$EI_{30} = 67,355 \left(\frac{r^2}{p}\right) e^{0,85} \dots\dots\dots (1)$$

being:

EI_{30} = the monthly average of the rainfall erosivity index (MJ. Mm ha⁻¹.h⁻¹);

r = the average monthly precipitation (mm); and

p = the average annual precipitation (mm).

The R factor, rain erosivity, allows the assessment of the erosive potential of the precipitations of a given location, making it possible to know the capacity and the potential of rain to cause soil erosion [7 and 14]. The calculation of this factor is the sum of the monthly values of erosivity, according to equation (2):

$$R = \sum_1^{12} EI_{30}$$

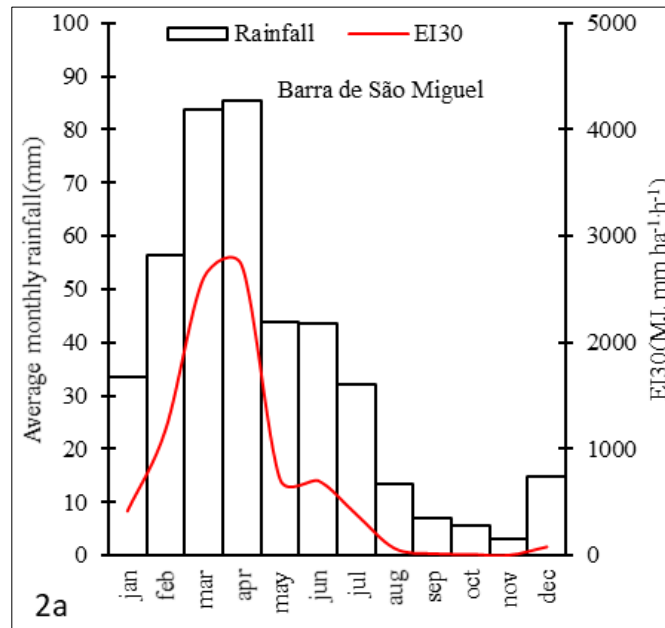
The erosivity classes were determined by the erosive limits represented in Table 2.

Table 2 Erosive limits and their erosivity classes

| Erosivity (MJ mm ano ⁻¹ ha ⁻¹ h ⁻¹) | Erosivity Class |
|---|----------------------------|
| R ≤ 2452 | Low Erosivity (BE) |
| 2452 < R ≤ 4905 | Medium erosivity (ME) |
| 4905 < R ≤ 7357 | Low / High Erosivity (BAE) |
| 7357 ,R ≤ 9810 | High Erosivity (AE) |
| R ≤ 9810 | Very high erosivity (MAE) |

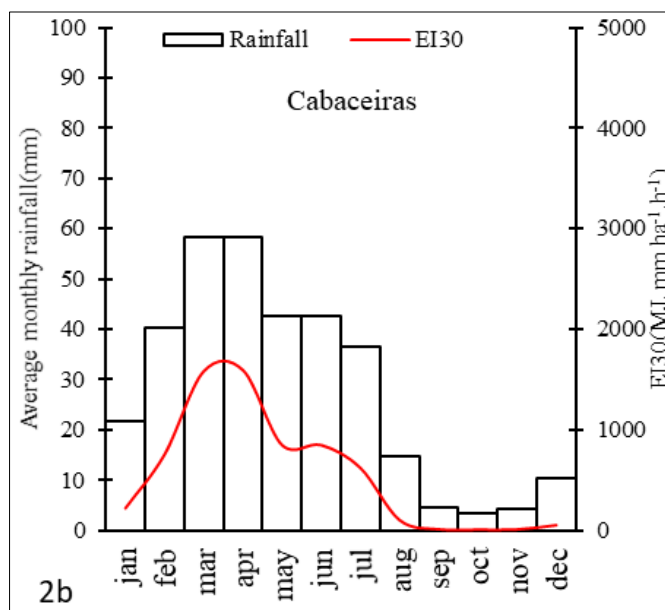
3. Results and discussion

In Figure 2a, there is the distribution of historical precipitation and the variability of the EI₃₀ for the municipality of Barra de São Miguel, between the periods 1962 to 2019. It is observed that the buoyancy of the EI₃₀ follows the distribution of the historical precipitation, thus suggesting that the rainfall indices enable the generation of moderate to intense erosion, thus corroborating the studies by [14 and 22].



Source: Paraíba State Agrometeorological Study (2021)

Figure 1a Distribution of historical precipitation and erosibility in the municipality of Barra de São Miguel in the period 1962-2019



Source: Paraíba State Agrometeorological Study (2021)

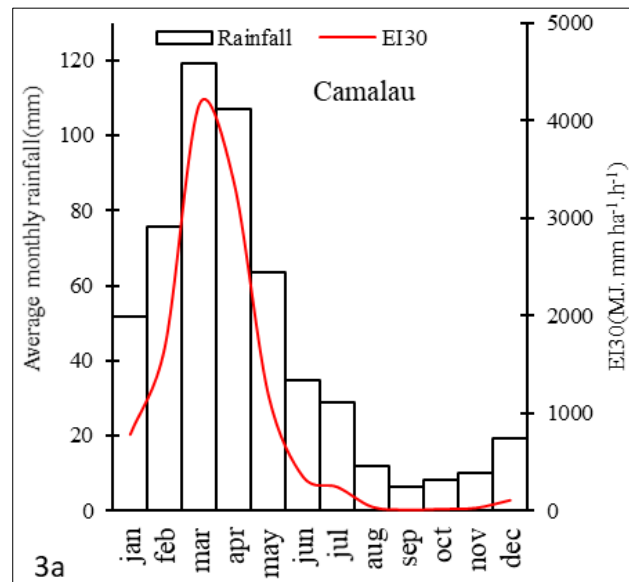
Figure 2b Distribution of historical precipitation and erosibility in the municipality Cabaceiras in the period 1962-2019

Figure 2b shows the variability of rainfall distribution and EI_{30} for the municipality of Cabaceiras - PB, in the period 1926-2019. The months of March, April, May and June stand out with greater erosive power than the pluviometric indexes. Between the months of July and February, the erosion rate is lower than the rainfall, these oscillations may have been caused due to the meteorological systems causing rain, which suffered blockages and their rainfall rates were reduced, studies such as those of [14 and 18] corroborate the discussions presented. [6], one of the first scholars on the subject, highlights two main effects of desertification: a) soil erosion, either by the laminar process or by the ravination, processes that would be installed as consequences of the removal of vegetation; b) worsening of the soil water deficit, due to their greater exposure to solar radiation and the action of dry winds. These points are seen in the study region and deserve governmental actions for soil management and conservation.

The predominant vegetation is of the hyperxerophilous caatinga type, deciduous forest and subcaducifolia. The predominant soils are of the type Chromic Luvisols that cover all the existing crystalline in the coverage area of the region of the upper course of the Paraíba River.

[18] evaluated the water balance and the erosivity of the rains according to the climate change scenario for the municipality of Cabaceiras - PB. Monthly and annual precipitation data for the period 1926-2010 and the estimated temperature series for the period from 1950 to 2010 were used. The methodology proposed by the IPCC AR4 was used. The Rainfall Erosivity Index (R) used the Universal Soil Loss Equation. The results showed that the optimistic scenario (B_2) and pessimistic scenario (A_2), indicated critical situations of soil conditions that will cause losses to water resources and rainfed crops; the rainfall indices for scenario A_2 are not sufficient for various types of crops; the study area is classified as being of high erosivity since the erosivity factor (R) found was $11,701.1 \text{ MJ.mm.ha}^{-1}.\text{h}^{-1}.\text{year}^{-1}$.

Based on the definitions proposed over the years, the definition of desertification was the degradation of land in arid, semi-arid and dry sub-humid areas, resulting from climatic variations, to a greater or lesser extent. [22], states that the municipality of Picuí, which is located in the Seridó Oriental Paraibano region, has a strong commitment to the economy and the environment due to the intensity of soil degradation, and constitutes one of the four-desertification centers in Brazil.



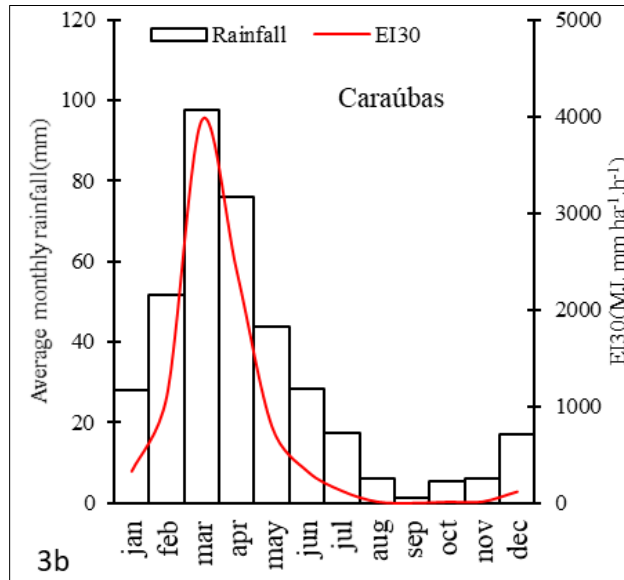
Source: Paraíba State Agrometeorological Study (2021).

Figure 3a Distribution of historical precipitation and erosivity in the municipality of Camalau in the period 1962-2019

In relation to Paraíba, [15], found the factor (R) for the municipality of Areia, of $31,528.8 \text{ MJ mm ha}^{-1}.\text{h}^{-1}.\text{year}$. They found that the highest levels of erosivity occurred in the months of March to August, that coincides with the rainy season, field capacity at maximum values. For the months of September and the first half of February, the lowest levels of erosivity occurred, corresponding to the dry period and the beginning of pre-season rains in the region where the municipality is located.

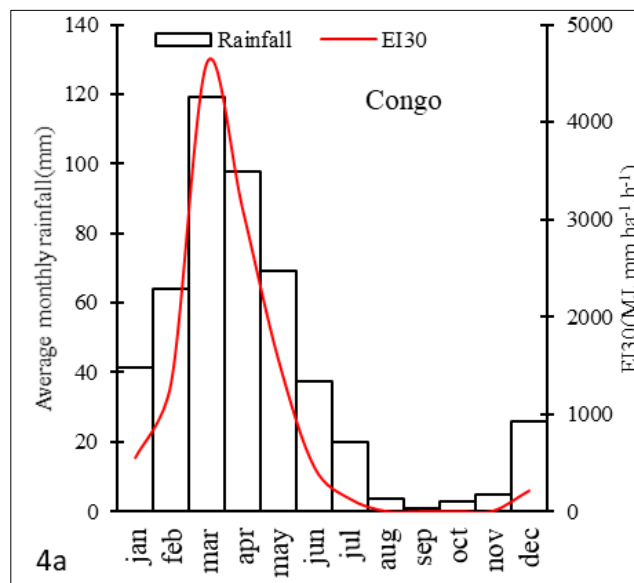
The rainfall and EI₃₀ study period for the municipality of Camalaú was from 1962 to 2019, as shown in Figure 3a, its variability. EI₃₀ was below the rainfall index, contradicting those observed by [14] In the municipality of Camalaú, precipitation is not a determining factor of erosion, so Camalaú has low erosion rates when compared to the two previously analyzed.

Caraúbas with a data period between 1931-2019 for the study of precipitation and erosivity, demonstrates that the month of March (Figure 3b) had a greater influence EI₃₀. In the other months, the EI₃₀ was normal to below, showing that rainfall variability directly affects erosion during the study period. Therefore, it is considered as low erosive power.



Source: Paraíba State Agrometeorological Study (2021)

Figure 3b Distribution of historical precipitation and erosibility in the municipality of Caraúbas in the period 1962-2019

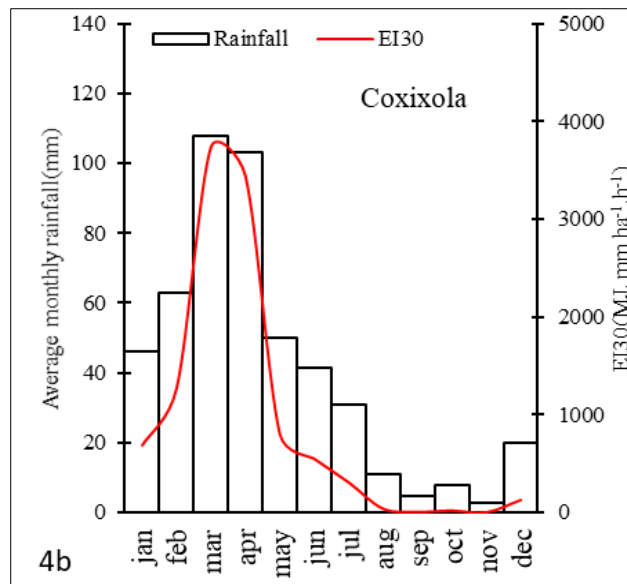


Source: Paraíba State Agrometeorological Study (2021)

Figure 4a Distribution of historical precipitation and erosibility in the municipality of Congo in the period 1962-2019

The distribution of precipitation and erosivity for the municipality of Congo for the period 1962-2019 is shown in Figure 4a. The months from February to April are noteworthy, when the EI₃₀ was higher than the rainfall indexes, and for the rest of the months, erosibility fluctuated below precipitation, a factor that contradicts the quote by [15].

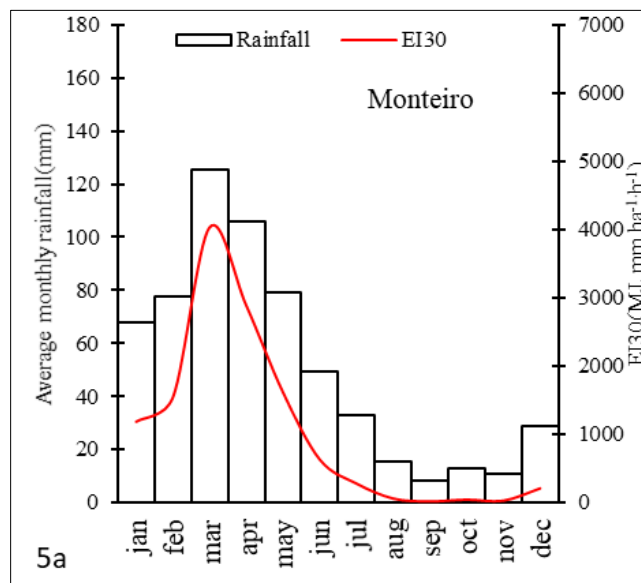
In Figure 4b there is the distribution of precipitation and erosivity for the period from 1962 to 2019 in the municipality of Coxixola, it was observed that the EI₃₀ was lower than the rainfall indexes, in the months of May to August the erosion index practically reaches the half of the rainfall index. Therefore, the municipality of Coxixola suffers erosive effects due to precipitation.



Source: Paraíba State Agrometeorological Study (2021)

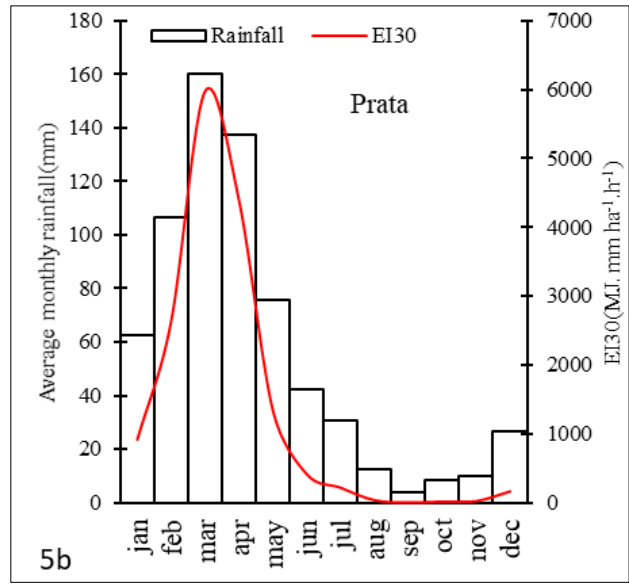
Figure 4b Distribution of historical precipitation and erosivity in the municipality of Coxixola in the period 1962-2019

The municipality of Monteiro with rainfall observed between the years 1911 to 2019 does not present conditions of erosivity through the pluviometric indices as shown in Figure 5a. In analogy, the same is true for the municipality of Prata as shown in Figure 5b.



Source: Paraíba State Agrometeorological Study (2021)

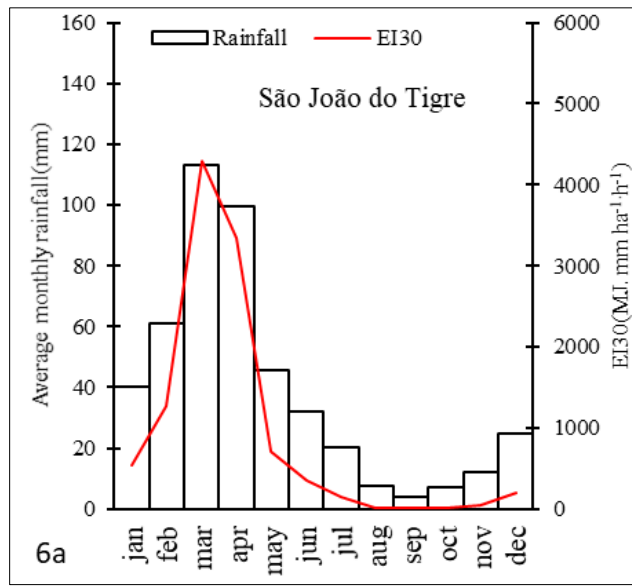
Figure 5a Distribution of historical precipitation and erosivity in the municipality of Monteiro, in the period 1962-2019



Source: Paraíba State Agrometeorological Study (2021)

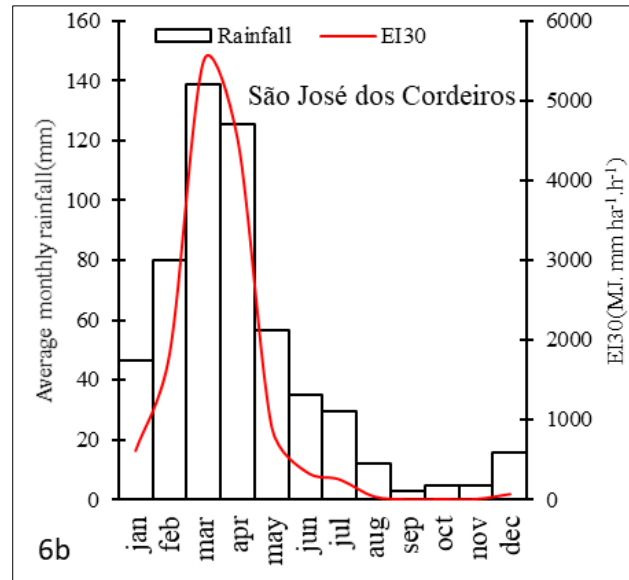
Figure 5b Distribution of historical precipitation and erosibility in the municipality of Prata, in the period 1962-2019

Figure 6a shows us that the erosive and low incidence index for the municipality of São José do Tigre. In the municipality of São José dos Cordeiros in accordance with Figure 6b, it is noted that the influence of rainfall levels on erosibility is of low intensity.



Source: Paraíba State Agrometeorological Study (2021)

Figure 6a Distribution of historical precipitation and erosibility in the municipality of São José do Tigre in the period 1962-2019

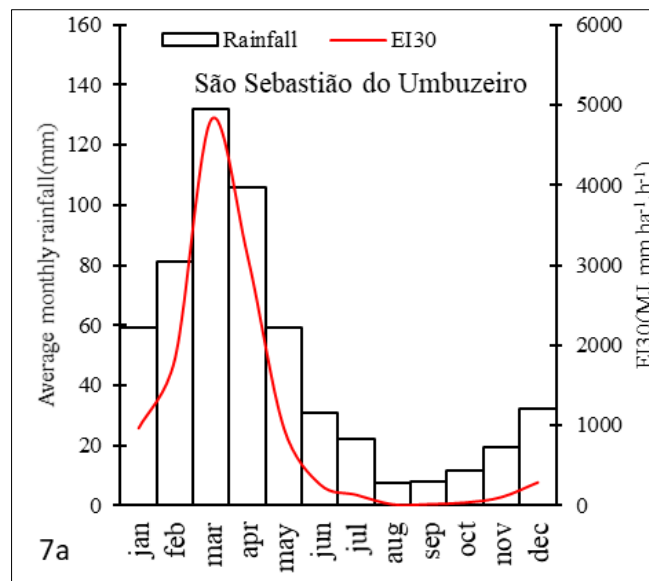


Source: Paraíba State Agrometeorological Study (2021)

Figure 6 Distribution of historical precipitation and erosibility in the municipality of São José dos Cordeiros, in the period 1962-2019

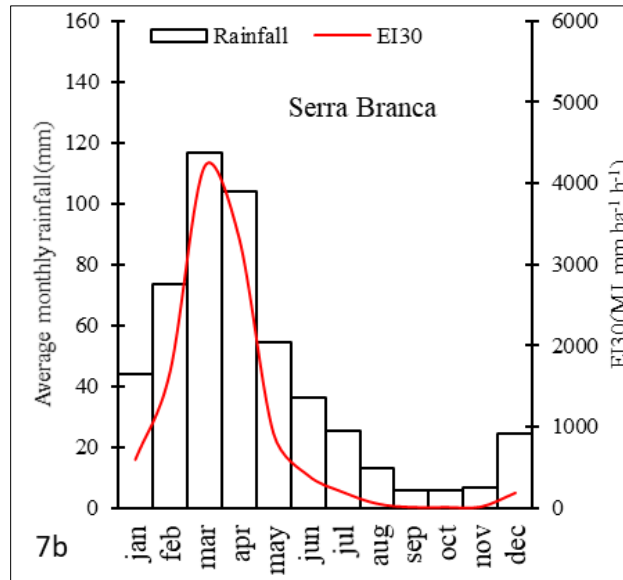
The variability of the erosive indices for the municipality of São Sebastião do Umbuzeiro is represented in Figure 7a. It is observed that the erosion rates were below the pluviometric indexes in all the months under study. Therefore, rainfall rates do not cause erosion in this area.

In Serra Branca (Figure 7b) the rainfall regime, with a well-defined dry season (August to November), associated with the poor distribution of rain during the rainy season (December to July) and the poverty of soil nutrients, in general, they require a high technical level for agricultural production, and it is recommended to adopt management practices that aim to conserve water and soil. It is observed that the erosive indices occur with low intensity in the months of March and April.



Source: Paraíba State Agrometeorological Study (2021)

Figure 7a Distribution of historical precipitation and erosibility in the municipality of São Sebastião do Umbuzeiro in the period 1962-2019



Source: Paraíba State Agrometeorological Study (2021)

Figure 7b Distribution of historical precipitation and erosivity in the municipality of Serra Branca in the period 1962-2019

4. Conclusion

No significant correlations were found between erosivity and precipitation in, Barra de São Miguel, Camalaú, Monteiro, Prata, São José do Tigre, São José dos Cordeiros, São Sebastião Umbuzeiro, contradicting what was stated.

In the municipalities of Cabaceira (February), Carnaúba (March), Congo (February to April) and Serra Branca (April), erosion rates were moderate to weak.

No significant correlations were found between erosivity and precipitation in, Barra de São Miguel, Camalaú, Monteiro, Prata, São José do Tigre, São José dos Cordeiros, São Sebastião Umbuzeiro, contradicting what was stated by Lemos and Bahia (1992), Since 62% of soils have a high level of susceptibility to erosion.

In the municipalities of Cabaceira (February), Carnaúba (March), Congo (February to April) and Serra Branca (April), erosion rates were moderate to weak.

Water erosion in terrain with a gradient greater than 15 degrees should be planted with native crops taking into account the level curves, thus avoiding soil loss.

The increase in anthropic susceptibility in relation to the natural occurs as a result of the removal of the natural vegetation cover and its replacement by that which appears as a result of agricultural activities, charcoal production and the removal of firewood for cuttings, which can, in the medium and long term, lead the intensification of the process of erodibility or water erosions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

Author's contribution

All authors had equal participation in the development of the article.

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