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Erosivity Index (EI_{30}) in the Paraíba River Upper Course - Paraíba – Brazil

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ABSTRACT

The determination of rainfall erosivity is of paramount importance for the management and conservation of soil and water in a basin, as human actions promote direct impacts on runoff, resulting from rainfall, which can often lead to death and material damage. The Paraíba River basin covers an area of 20,071.83 km², being considered the second most important for the state of Paraíba, with problems of generalized erosion, water scarcity, degradation of riparian forest, among others. The objective of this study was to determine the Erosivity Index (EI_{30}) based on the rainfall variability distributed in the Upper Course basin of the Paraíba River - PB / Brazil, considering rain series over 57 years of data, for 12 municipalities that make up the area under study. To determine the erosivity factor, the equation proposed by Wischmeier (1971) and Wischmeier and Smith (1958, 1978) was used. The results found showed no significant correlations for the municipalities of Barra de São Miguel, Camalaú, Monteiro, Prata, São João do Tigre, São José dos Cordeiros and São Sebastião do Umbuzeiro. For the municipalities of Cabaceira, Caraúbas, Congo and Serra Branca, moderate to weak erosive indexes were identified in some months of the rainiest four-month period in the region.

INTRODUCTION

Precipitation is a meteorological element that presents great variability, both in quantity and in monthly and annual distributions from one region to another, being the main factor used in subdividing the climate of a region and/or locality (Almeida, 2003). 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, Bastos (1990) 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, the occurrence of precipitation variability, even in the rainy season, is one of its most striking characteristics, being considered a situation very serious (Nobre *et al*., 2001), taking into account the high dependence that agriculture in this region has on rainfall. Santana *et al*. (2007) 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.

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 (SUDENE, 1999).

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 empty or with little water, further restricting drinking water for human and animal survival, and will also undergo changes to the fauna and flora, and some species may become extinct (Marengo, 2011).

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 (Reis et al., 1995). According to Assis et al. (1996) 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. In Brazil, 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 Moura (2006), Souza et al. (2010), Alves et al. (2012), Maracajá (2007) and Araújo (2010) 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 (Lacerda et al., 2004).

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 constructions such as buildings, soil waterproofing, deforestation, and the absence of urban planning for improvement in the coexistence between human being and the environment. This excludes natural elements, inducing the appearance of extreme events, with consequences in large cities, such as: floods, landslides, increased pests, diseases and deaths (Santos, 2007).

Aubreville (1949), 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 ravinat, 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.

Silva et al. (2011) 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.

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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 (MRPC, 1972).

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 (Moreti et al., 2003).

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 (Cassol et al., 2007).

The objective of this work was to carry out rainfall and erosion analysis in the area of the hydrographic basin of the upper course of the Paraíba River (BHACRPB).

MATERIAL AND METHODS

The BHACRPB, comprised between the geographical coordinates 6º51'31 "and 8º26'21" south latitude, and 34º48'35 "and 37º2'15" longitude west of Greenwich, 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.

Figure No. 1: Location of the Paraíba River basin and its Upper Course in the southwestern portion. Source: EFSA (2020).

The basin is made up of regions affected by local, regional and large-scale synoptic events, causing rain, such as the Intertropical Convergence Zone (ZCIT) and the contributions of the High Level Cyclonic Vortexes (VCANs) systems, when active over the Northeast of Brazil. Add to this the effects of the northeast trade winds together with the effects of sea breeze, aided by the formation of the South Atlantic Cyclonic vortexes (VCAS) and the formation of the Instability Lines (LI), of the Dipole Pattern (PD) in the Tropical Atlantic Ocean and wave disturbances in the field of trade winds. All of this provides events for droughts, floods, floods, floods, 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.

Series of monthly and annual precipitation data were used, collected by the Superintendência de Desenvolvimento do Nordeste (SUDENE, 1990) and provided by the Agência Executiva de Gestão das Águas do Estado da Paraíba (AESA, 2020), with the observation period highlighted in Table 1.

Table No. 1: Geographic coordinates, altitudes and observation period for monthly and annual rainfall in municipalities in the upper Paraíba River basin. Source: Medeiros (2021).

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

To determine the erosivity factor, equation (1) proposed by Wischmeier (1971) and Wischmeier and Smith (1958, 1978), was defined as:

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

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 (Barbosa *et al*., 2000; Menezes *et al*., 2011). The calculation of this factor is the sum of the monthly values of erosivity, according to equation (2):

$$R = \sum_{1}^{12} EI_{30} \quad (2)$$

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

Table No. 2: Erosive limits and their erosivity classes

Erosivity (MJ mm $year^{-1}$ ha^{-1} h^{-1})	Erosivity Class
$R \leq 2452$	Low Erosivity (BE)
$2452 < R \leq 4905$	Medium erosivity (ME)
$4905 < R \leq 7357$	Low/High Erosivity (BAE)
$7357 < R \leq 9810$	High Erosivity (AE)
$R \leq 9810$	Very high erosivity (MAE)

RESULTS AND DISCUSSION

In Figure 2a, there is the distribution of historical precipitation and the variability of the EI_{30} for the municipality of Barra de São Miguel, between the period 1962 to 2019. It is observed that the buoyancy of the EI_{30} 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 Lemos and Bahia (1992) and Medeiros *et al*. (2015).

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 Medeiros (2015) and Marengo *et al.* (2011) corroborate the discussions presented.

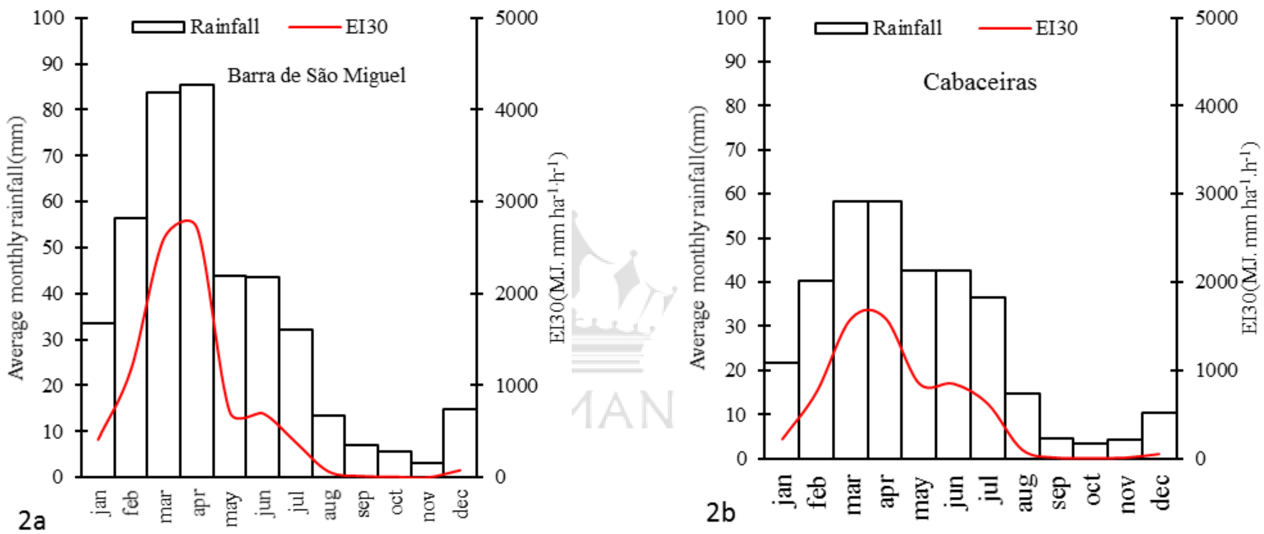

Figure No. 1*:* Distribution of historical precipitation and erosivity in the municipality of Barra de São Miguel (2a) and Cabaceiras (2b), in the period 1962-2019. Source: Paraíba State Agrometeorological Study (2021)

As pointed by Aubreville (1949), the main effects of desertification: are soil erosion, 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 Luvissolos Crômicos, which cover all the existing crystalline in the coverage area of the Upper course of the Paraíba River.

Medeiros *et al*. (2015) 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 was from 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 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$.

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. Sales (1997), 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.

In relation to Paraíba, state of Brazil, Medeiros *et al*. (2012) found the factor (R) for the municipality of Areia, of 31,528.8 MJ mm $ha^{-1}h^{-1}year$. They found that the highest levels of erosivity occurred in the months of March to August that coincides with the rainy season, with field capacity at maximum values. For the month 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 EI_{30} study period for the municipality of Camalaú was from 1962 to 2019. The Figure 3a shows its variability. EI_{30} was below the rainfall index, contradicting those observed by Lemos and Bahia (1992). 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 EI_{30}. In the other months, the EI_{30} was normal to low, showing that rainfall variability directly affects erosion during the study period. Therefore, it is considered as low erosive power.

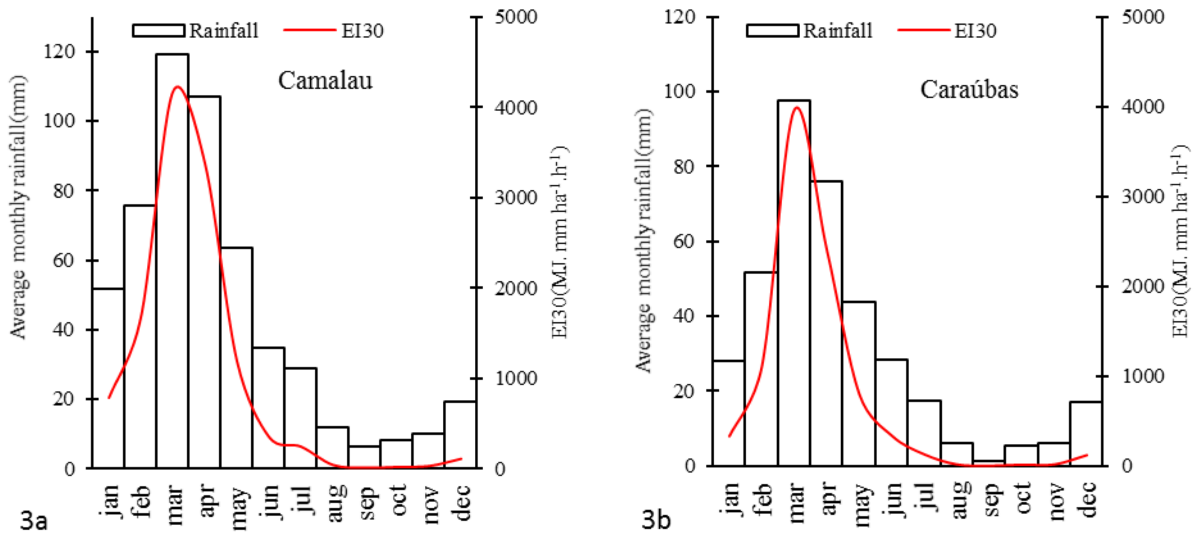

Figure No. 3: Distribution of historical precipitation and erosivity in the municipality of Camalaú (3a) and Caraúbas (3b), in the period 1962-2019. Source: Paraíba State Agrometeorological Study (2021).

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 EI_{30} was higher than the rainfall indexes, and for the rest of the months, erosibility fluctuated below precipitation, a factor that contradicts the quote by Lemos and Bahia (1992).

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 EI_{30} was lower than the rainfall indexes. In the months of May to August the erosion index practically reaches half of the rainfall index. Therefore, the municipality of Coxixola was subjected to erosive effects due to precipitation.

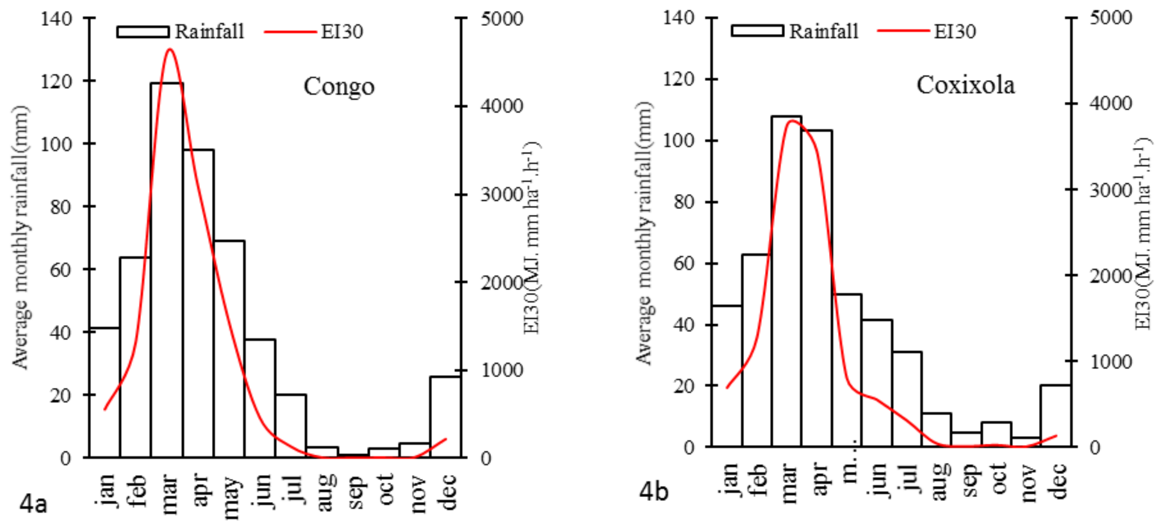

Figure No. 4: Distribution of historical precipitation and erosivity in the municipality of Congo (4a) and Coxixola (4b), in the period 1962-2019. Source: Paraíba State Agrometeorological Study (2021)

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

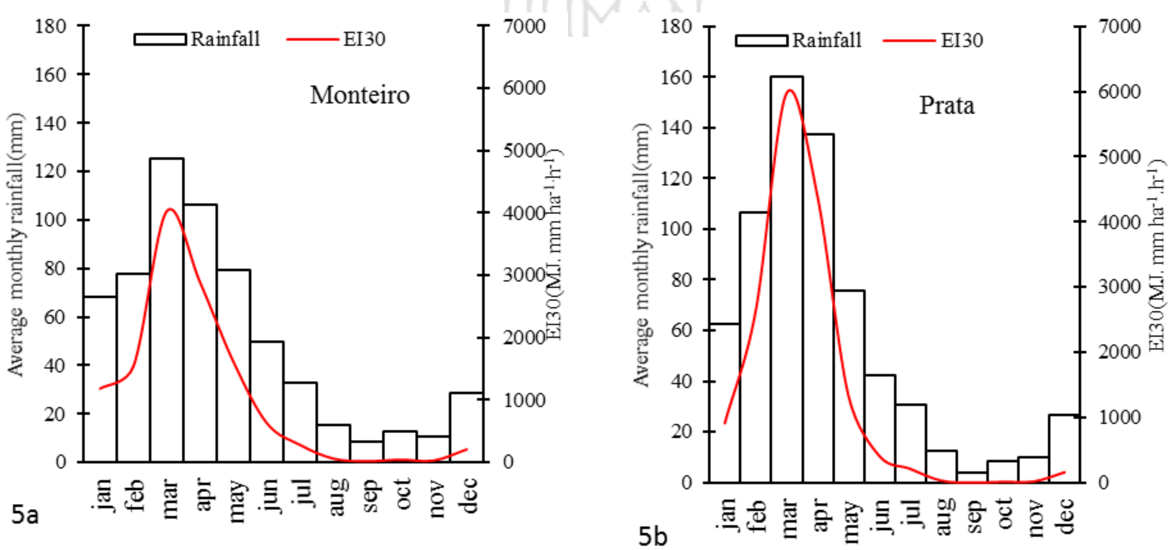

Figure No. 5: Distribution of historical precipitation and erosivity in the municipality of Monteiro (5a) and Prata (5b), in the period 1962-2019. Source: Paraíba State Agrometeorological Study (2021).

Figure 6a shows 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 erosivity is of low intensity.

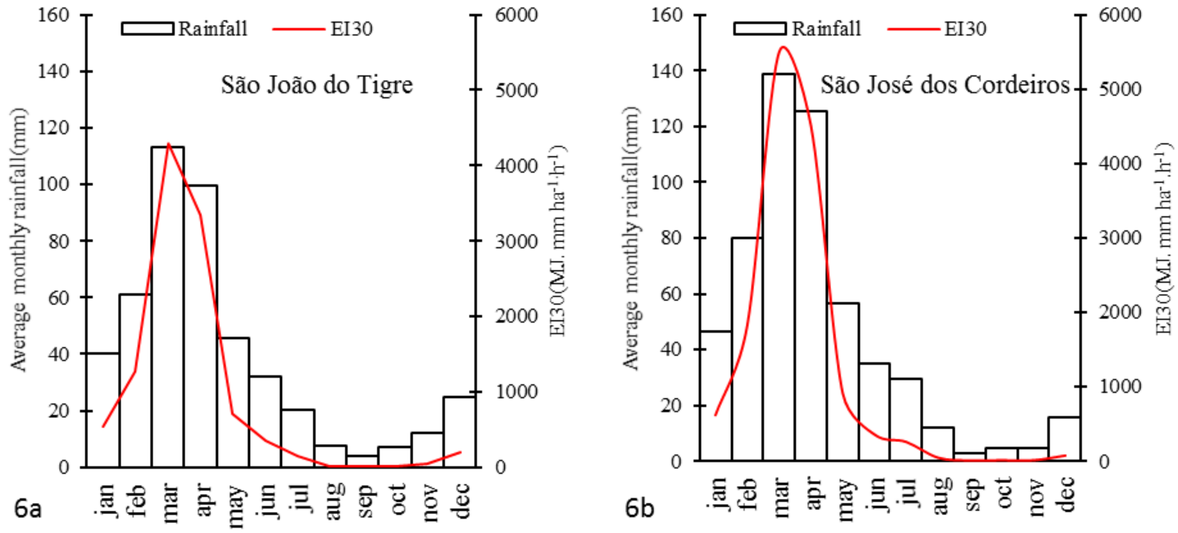

Figure No. 6: Distribution of historical precipitation and erosivity in the municipality of São José do Tigre (6a) and São José dos Cordeiros (6b), in the period 1962-2019. Source: Paraíba State Agrometeorological Study (2021).

The variability of the erosive indexes for the municipality of São Sebastião do Umbuzeiro is represented in Figure 7a. It is observed that the erosivity indexes s 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, 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 indexes occur with low intensity in the months of March and April.

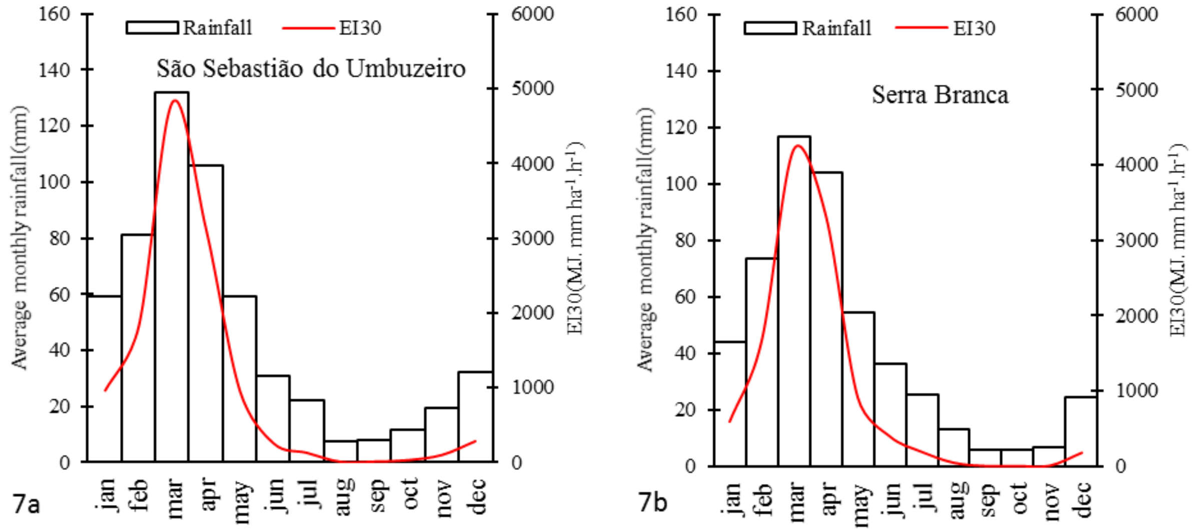

Figure No. 7: Distribution of historical precipitation and erosivity in the municipality of São Sebastião do Umbuzeiro (7a) and Serra Branca (7b), in the period 1962-2019.Source: Paraíba State Agrometeorological Study (2021).

CONCLUSION

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

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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 contour lines, thus avoiding soil loss.

The increase in susceptibility caused by anthropic actions, in relation to natural causes, 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 to an intensification of the soil erosion process.

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