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Erosivity and rainfall patterns for Pirenópolis, Goiás, Brazil

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Abstract

Water erosion is one of the biggest environmental problems, causing a reduction in agricultural productivity and compromising the quality and quantity of water resources. Therefore, the development of researches that help in the planning of land use and management aiming at sustainable agriculture is a necessity in the state of Goiás. This work was carried out with the objectives of analyzing the annual distribution of rainfall erosivity, determining the factor erosivity of rain (R fator) of the universal soil loss equation (USLE) and the rainfall patterns of Pirenópolis - Goiás (GO). A pluviographic series from the period from 2002 to 2007 and a rainfall series from 1986 to 2014 were used. Data were analyzed in a completely randomized design in a 7 (months) x 3 (patterns) factorial scheme. Through the results, it was possible to verify that: the erosive potential was concentrated between the months of October and April, corresponding to 94.2% of the average annual to index EI_{30}. The factor R of the USLE for the locality of Pirenópolis - GO was 7,799.5 MJ mm ha^{-1} h^{-1} $year^{-1}$, and 130.2 MJ ha^{-1} $year^{-1}$, for the index KE> 25. The advanced hydrological pattern was the most frequent among the analyzed precipitations, followed by the delayed and intermediate patterns. According to the analysis, the intermediate pattern presents higher erosivity values for individual precipitation events for the months of November, December and April.

Keywords: soil conservation, hydrological pattern, USLE, R factor

1. Introduction

Soil is a limited natural resource, because it takes centuries to form, but its deterioration by water erosion can occur in a short period of time due to processes brought about by land use and unsuitable agricultural practices. The energy of the impact of raindrops on the soil and the transport of sediment, organic matter, nutrients, agrochemicals (pesticides & herbicides, fertilizers) and particles suspended by surface runoff, make water erosion the main cause of soil degradation (Martins et al., 2020).

In Brazil, water erosion is the main factor of unsustainability of agricultural production systems and the environmental impacts from it are reflected in the increase in costs of production (Sadeghi et al., 2017). Each year, erosion losses continue to increase, since most farmers do not use soil management or conservation techniques (Back & Poleto, 2017). Several mathematical models have been developed and used to predict the magnitude of soil losses by erosion, aimed at minimizing soil losses with the purpose of assisting in agricultural planning (Back & Poleto, 2017).

Among the prediction models, Universal Soil Loss Equation (USLE), which is one of the commonly used model is highlited. Among the factors included in the USLE model is the factor erosivity of rain (R), which is a numerical index that expresses the capacity of rain to cause erosion (Back & Poleto, 2017). Thus, the determination of soil erosivity indices throughout the year allows identification the months in which the risks of soil loss are higher, and thus enables planning of conservation practices in critical times of greater erosive capacity of rains (Silva Neto, 2020).

To determine the erosivity of rainfall in a given region according to the USLE, a series of rainfall data of at least 22 years is required (Wischmeier & Smith, 1978). However, in many regions of Brazil this information does not exist, scarce or of low quality (Martins et al., 2020), and for this purpose, estimates based on rainfall data with validation have been used (Diaz et al., 2018). In the state of Goiás, rainfall erosivity was calculated for some localities inculding Goiânia (Silva et al., 1997a), Alto da bacia do rio Araguaia (Santana et al., 2007), Norte do Bacia Hidrográfica do Ribeirão Santo Antônio em Iporá (Sousa & Silva, 2009), Morrinhos (Cabral et al., 2005), Aragarças e Formosa (Andrade et al., 2020 a, b) and Goiás (Castro et al., 2021) among others. However, the data is still scarce, due to the vastness of the state and climate variability. Many brazilian localities do not have data on factors that cause water erosion to serve as a decision-making tool.

Given the impact of agriculture on the quality of soil and water resources, actions to mitigate soil loss and conservation of resources are necessary and, for this, the evaluation of erosive processes is a valuable tool (Oliveira et al., 2010). Therefore, the present study aimed at determining the factor R of the universal equation of soil loss - USLE, the distribution of rainfall erosivity throughout the year and the rainfall patterns of the Pirenópolis - GO region.

2. Material and Methods

The city of Pirenópolis is located in the east of the state of Goiás, at a latitude of 15º51' South and 48º57' West of Greenwich, approximately 117 km from the capital Goiânia and 150 km from the capital Brasília, occupying an area of 2,189.4 km^2 (Sanches et al., 2011). The climate of the region according to the Köeppen classification is of the type Aw, specific to tropical humid climates (A), characterized by dry winter and rainy summer. The average annual temperature is 22°C, ranging from 16 to 34°C and the average annual rainfall is 1,800 mm (Sanches et al., 2011).

Data of 2002 to 2007 obtained in pluviograms format from the meteorological station of Pirenópolis code 83376, provided by INMET (Instituto Nacional de Meteorologia) were converted to digital format, using a handheld spreadsheet. The start and end times and the corresponding blade of each rain segment (same intensity; inclination of the trace) and the total precipitation of the rainfall were determined for later correction. Then, the individualization of erosive rains was performed. To this end, the criteria proposed by Cabeda (1976) that considers an individual rain when it is separated from another for a minimum period of 6 hours, with precipitation of less than 1 mm, and erosive when the blade is more than 10 mm or more than 6 mm in a maximum period of 15 minutes.

In sequence, the data with a maximum recording interval of 10 minutes, were organized in spreadsheets and saved in Windows DAT files and submitted to the software CHUVEROS (Cassol et al., 2008), for the calculation of the erosivity indices EI_{30} and KE>25, which also provides other rain attributes. The attributes analyzed include precipitated height, kinetic energy and precipitation duration, in addition to the rain patterns that were organized and tabulated for later analysis.

A series of erosivity data was expanded to obtain the R factor of the USLE, which requires a series of at least 22 years (Wischemeier & Smith, 1978). The equations were adjusted between the rainfall erosivity indices (EI_{30} and KE>25) obtained by rainfall, and rainfall data of monthly precipitation average (p) and rain factor Rc for the same assessment period. The Rc factor is defined as the quotient between the square of the average monthly rainfall (p) and the average annual rainfall (P) (Foster et al., 1981).

Linear adjustments of EI_{30}= 5.4884P + 41.548 (R^2 =0.96) were obtained for monthly precipitation "p" (Figure 1A) and EI_{30}= 3.4689Rc + 67.332 (R^2 =0.79) for rainfall coefficient (Rc) (Figure 1B).

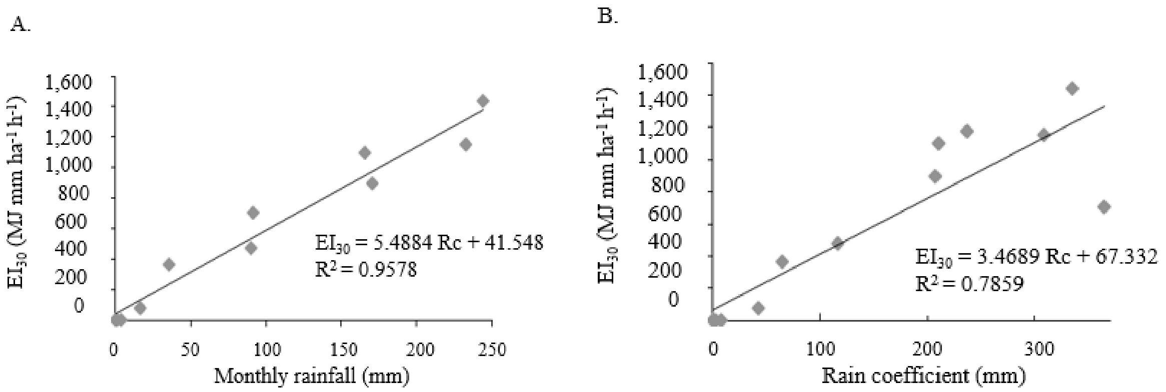

Figure 1. Correlation between mean monthly values of erosivity EI_{30} and (A) Mean monthly precipitation and (B) Rainfall coefficient (Rc)

Regarding the KE>25 index, the adjustments were KE>25 = 0.0865P + 0.446 (R^2 =0.98) (Figure 2A) and KE>25 = 0.0524Rc + 1.321 (R^2 =0.71) (Figure 2B), for the mean precipitation "p" and for the Rc coefficient, respectively.

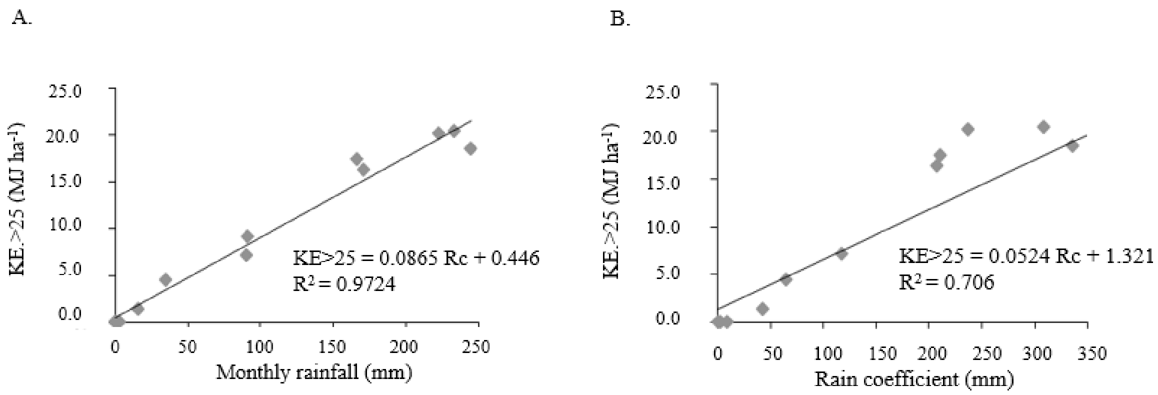

Figure 2. Correlation between mean monthly values of erosivity indices KE>25 and (A) Mean monthly precipitation and (B) Rainfall coefficient (Rc)

For the estimation of erosivity indices (EI_{30} and KE>25), the equation based on the mean monthly precipitation "p", was considered more appropriate, and therefore, used for the estimation of erosivity indices since it presented a higher coefficient of determination of the model. The interval of the rainfall series used in the "p" equation was evaluated beforehand, so that the largest possible interval was selected that was statistically similar to the rainfall slide for the rainfall series used to obtain the equations, using the Confidence Intervals (CI) analysis (Moreti et al., 2003). Overlapping of mean and/or CI of rainfall and rainfall data was found for all months, even using all data from the rainfall series (1986 to 2014), indicating adequacy for estimating EI_{30} and KE>25 indexes (Figure 3).

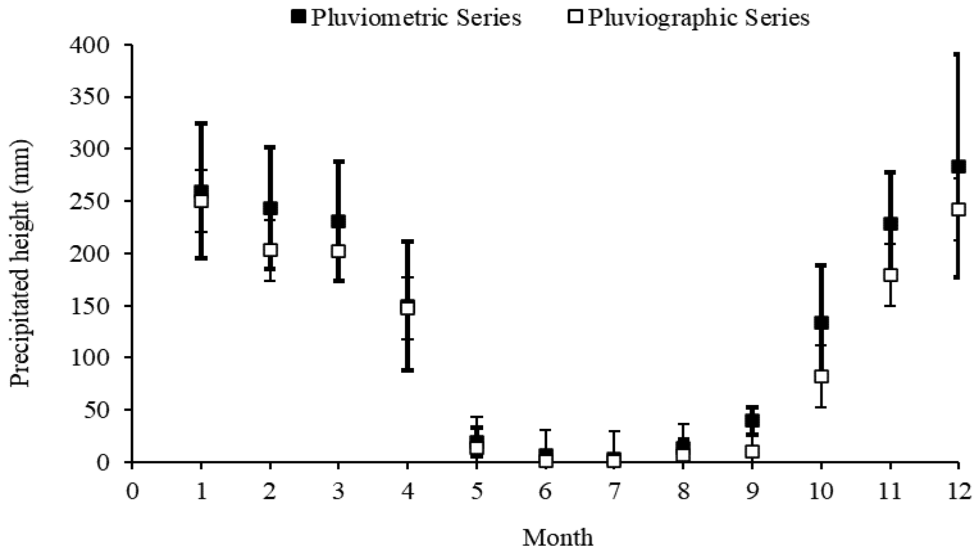

Figure 3. Mean and confidence interval of rainfall between rainfall and rainfall series of the Pirenópolis season (GO)

Given the equations, rainfall erosivity was estimated based on rainfall data from the same station (station code: 01548003), which has data available from 1986 to 2014 in the HIDROWEB/ANA database (available in: https://www.snirh.gov.br/hidroweb). The erosivity indices, month to month, within each year were estimated according to Moreti et al. (2003), from the general spreadsheet of distribution of rainfall for the analyzed season, by means of a simple three-rule, as follows:

$$Ei = \frac{(P.\ EI)}{Pa} \quad (1)$$

where:

Ei = erosivity index of one month i contained in a year j of the data series;

P = total precipitated in a month i contained in a year j of the data series;

EI = average monthly erosivity index (EI_{30} or KE>25), in which month i is contained in the data series; and

Pa = average monthly precipitation in which month i is contained in the data series.

The obtained rates of erosivity month by month, within each year, allowed determination of the rates of erosivity EI_{30} and KE>25 for the study location. From this, the sum of the erosivity indices month to month, within each year, were used to calculate the erosivity index for the year in question and the set of all years composed the historical series. Rains obtained from pluviographs (period 2002 to 2007) were classified in advanced, intermediate and delayed pattern according to Horner & Jens (1941), using the software CHUVEROS (CASSOL et al., 2008). The results were systematized in a spreadsheet and calculated the percentage of each hydrological pattern, as well as erosivity indexes and other attributes associated with each hydrological pattern.

The precipitated height attributes and the erosivity indices EI_{30} and KE>25 were statistically analyzed in a completely randomized design (IHD) in a factorial scheme 7 x 3, corresponding to the rainy period months (October to April; 7 months) and the three precipitation patterns. The data were submitted to analysis of variance (ANOVA) and comparison of means by the Scott Knott test (5%), using SISVAR software (Ferreira, 2003). Previously, the Cohran and Bartlet tests were applied; and Lilliefors, the residues of the model to meet the assumptions of the parametric analysis.

3. Results and Discussion

The average annual precipitation was 1,610.3 mm being uneven during the year, being the expected value according to Cardoso et al. (2012) for the climate Aw (Table 1). The months of December and January presented the highest rainfall rates, which correspond to 33.7% of the total annual precipitation volume. The lowest rates were in the period from June to September which corresponded to 3.8% of the total annual precipitation. Rainfall above 100 mm occurred from October to April, characterizing a rainy summer ("water season"), where 94.8% of the total rainfall occurs. Between May and September, 5.2% of the annual rainfall was recorded, being considered the prolonged dry season or "dry season" (Table 1).

Table 1. Average and relative values of rainfall, erosivity indexes EI_{30} and KE>25 of Pirenópolis (GO), obtained from 1986 to 2014

	PRECIPITATION		EI_{30}		KE>25	
	mm	%	MJ mm ha^{-1} h^{-1} $month^{-1}$	%	MJ ha^{-1}	%
JAN	259.7	16.1	1,246.1	16.0	20.9	16.0
FEB	243.5	15.1	1,169.0	15.0	19.6	15.0
MAR	230.7	14.3	1,108.2	14.2	18.6	14.3
APR	149.9	9.3	724.5	9.3	12.1	9.3
MAY	19.5	1.2	105.3	1.4	1.7	1.3
JUN	6.3	0.4	42.7	0.5	0.6	0.5
JUL	3.2	0.2	27.9	0.4	0.4	0.3
AUG	13.7	0.8	77.6	1.0	1.2	0.9
SEP	39.3	2.4	199.2	2.6	3.3	2.5
OCT	133.2	8.3	645.2	8.3	10.8	8.3
NOV	227.8	14.1	1,094.5	14.0	18.3	14.1
DEC	283.5	17.6	1,359.1	17.4	22.8	17.5
TOTAL	1,610.3	100	7,799.5	100	130.2	100

A similar result was found by Galdino (2015) for the state of Goiás and Distrito Federal, where the period of highest rainfall incidence occurred from October to March, totaling 87% of the total annual rainfall rate in the region and 94% of the total annual rainfall erosivity.

Regarding the average annual erosivity measured by the EI_{30} index for Pirenópolis (GO); the value found was 7,799.5 MJ mm ha^{-1} h^{-1} $year^{-1}$. This value was considered strong (4,905 < R < 7,357) according to Carvalho (1994), indicating the need for conservation practices in agricultural areas (Table 1). This erosive potential was concentrated between the months of October and April, which is naturally the "water period", with 7,346.6 MJ mm ha^{-1} h^{-1} $year^{-1}$, corresponding to 94.2% of the average annual EI_{30} index (Figure 4). This information reinforces the need to adopt soil and water conservation practices aimed at minimizing the harmful effects of rainfall erosion in this region, given its importance in agricultural production.

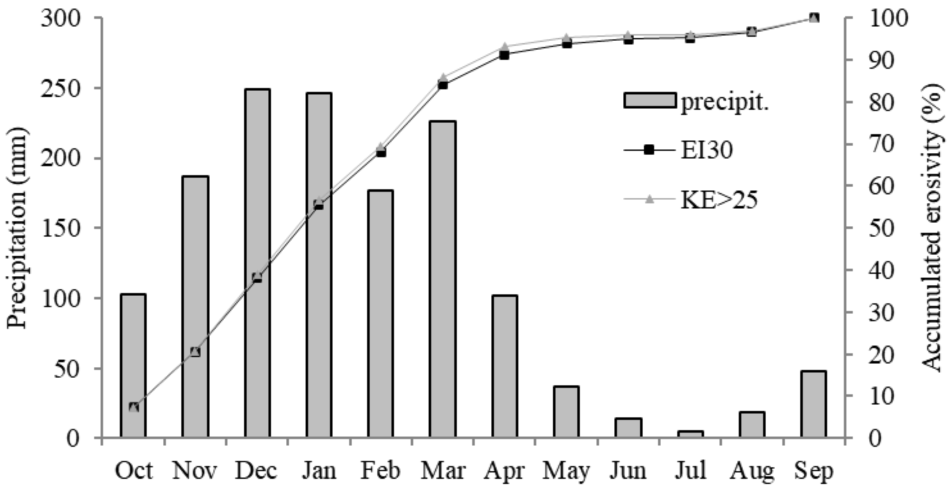

Figure 4. Average monthly and annual values of rainfall, erosivity indexes EI_{30} and KE>25 of Pirenópolis (GO), obtained from 1986-2014

The months of December and January in Pirenópolis, according to the series studied, present erosivity of 1,359.1 and 1,246.1 MJ mm ha^{-1} h^{-1} $month^{-1}$, respectively, being the most critical months of the year in the region (Table 1). According to Mazurana et al. (2009), months of exceptional peak in rainfall erosivity are responsible for great damage to cultivated crops due to the water erosion process. In these months usually summer crops such as soybeans and corn are already established, covering the surface of the soil and exerting conservationist function, which protects the soil from erosion. The months of September to November correspond to the period of soil preparation and the establishment of crops in the region, where the soil surface is unprotected. In this period, 24.9% of the annual erosivity (Table 1) corresponds to 1,938.9 MJ mm ha^{-1} h^{-1}.

Silva et al. (1997b) verified for a Dark Red Latosol in Goiânia - GO that an erosivity of 500 MJ mm ha^{-1} h^{-1} $month^{-1}$ was sufficient for soil losses to reach the tolerance of losses, indicating the need for conservation practices. Thus, the preparation of the soil and the establishment of crops in traditional production systems, which are commonly carried out in the region, should be done early in the agricultural year. For late planting, as well as those made at the beginning of the season or harvest, due to the characteristics of the rains and the distribution of their erosivity, among other reasons, it is advisable to replace the conventional methods of cultivation by no-tillage, due to the low movement and soil protection (Boarett et al., 1998).

The EI_{30} found for Pirenópolis - GO (7,799.5 MJ mm ha^{-1} h^{-1} $year^{-1}$) is within the range found for Brazilian conditions that according to Oliveira et al. (2012) goes from 1,672 to 22,452 MJ mm ha^{-1} h^{-1} $year^{-1}$, and these changes occur due to the territorial magnitude and oscillation of the climatic types of the country. Almeida & Casaroli (2016) studying the average erosivity and the agricultural calendar of the southwestern microregion of the state of Goiás, showed that the lowest EI_{30} occurred from May to September, the period corresponding to the harvest of corn (2nd crop), sorghum, cotton and sugar cane. The highest EI_{30} were detected in the period from November to March, months of planting of soybeans, corn (1st and 2nd crop), sorghum, cotton and sugar cane, as well as the harvest of soybeans and corn (1st and 2nd crop).

Andrade et al. (2020b), found for the region of Formosa (GO) average annual erosivity of 8,041.6 MJ mm ha^{-1} h^{-1} $year^{-1}$ for the EI_{30} index, being from May to September (mainly from June to August) the period with lower and consequently greater erosive potential. Anjos et al. (2020) studying the intensity and space-time distribution of rainfall erosivity in the state of Goiás and Distrito Federal (Pirenópolis, Goiânia, Aragarças, Jataí, Rio Verde, Formosa, Ipameri, Posse, Goiás, Itumbiara, Catalão and Distrito Federal) found an average annual R factor of 8,834 MJ mm ha^{-1} h^{-1} $year^{-1}$, being classified as strong erosive potential.

The average annual KE>25 index observed for Pirenópolis (GO), was 130.2 MJ ha^{-1} $year^{-1}$ (Table 1). Being higher than that found by Castro et al. (2021) for the city of Goiás (GO), with an average annual value of 110.3 MJ ha^{-1} $year^{-1}$ and lower than that found by Andrade et al. (2020a) for Aragarças (GO), with an average annual value of 163.1 MJ ha^{-1} $year^{-1}$.

In the present work, referring to the rainfall series from 2002 to 2007, of the 896 rains, 248 were erosive, presenting an annual average of 41 erosive and 108 non-erosive. The erosive rains (27.7%) represented 77.3% of the total rainfall during the 6-year period of the series. In a study conducted by Andrade et al. (2020a) in the city of Aragarças (GO) during the period from 2002 to 2007, they obtained similar values in relation to erosive and nonerosive rainfall, corresponding to a total of 731 individual rainfall, of these 223 (31%) were erosive and 508 (69%) nonerosive, setting an average of 37 erosion and 85 nonerosive rains per year.

Table 2 shows the distribution of rainfall in the advanced, intermediate and delayed rainfall patterns in Pirenópolis (GO), from 2002 to 2007. The most frequent rain pattern in the region was advanced. In the annual average, the distribution of advanced, intermediate and delayed rain patterns was 53.1; 12.4 and 34.5%, respectively.

Table 2. Annual average values of advanced, intermediate and delayed precipitation patterns in Pirenópolis (GO), from 2002 to 2007

Hydrological Pattern	Number of Rains		Annual Average					
			Rains		Erosivity			
	Absolute	%	Total mm	%	EI_{30} Total (MJ mm ha^{-1} h^{-1})	%	KE>25 Total (MJ ha^{-1})	%
AD	78.5	53.1	720.8	53.4	4,195.9	50.1	78.0	51.8
IN	18.3	12.4	268.5	19.9	1,926.0	23.0	32.3	21.5
DE	51.0	34.5	361.0	26.7	2,245.8	26.8	40.3	26.7
TOTAL	147.8	100	1,350.3	100	8,367.7	100	150.6	100

It can be seen that the largest precipitated volume occurred also in the advanced pattern. Even presenting the highest volume in this pattern, the distribution of concentrated rainfall in the advanced pattern allows to expect lower soil losses than could occur due to the fact that at the time of peak rainfall this would be less humid than in the case of the other patterns; disintegration, sealing and soil transport would be smaller (Machado et al., 2008). However, it should always use soil management and agricultural practices that leave the soil protected during the period of water and implementation of mechanical practices, in order to minimize soil and nutrient losses in the region.

Eltz et al. (2001) working with a rain simulator in a Red-Yellow Argisol, observed greater loss of soil in delayed pattern rainfall in relation to soil losses of intermediate and advanced pattern rainfall, among which there were no significant differences. This was explained by the conditions of surface change and soil moisture during the rain. In the delayed pattern, when the peak of maximum intensity occurs, the soil is with greater moisture (in relation to the other patterns), favoring the disintegration, the surface sealing and the transport of its particles, thus occurring greater soil loss. As for the total precipitate, the highest accumulated erosivity values occurred in the advanced pattern with 4,195.9 and 78.0 of EI_{30} and KE>25, respectively (Table 2).

Table 3 presents the statistical analysis of rainfall and indexes as a function of the month and the hydrological pattern. For the precipitated height attribute there were no significant differences between the months of the year (columns). For the EI_{30} index, no significant differences were also found between months, but there was a trend of higher mean indices in the months of October and January in the advanced pattern; December and April in the intermediate; and April and November in the delayed pattern (Table 3). Regarding the KE>25, it was verified that statistically the behavior was very similar to the EI_{30} index and precipitated height for comparison of the months of the year.

Table 3. Precipitated height (mm), EI_{30} and KE>25 as a function of the months of the year and precipitation patterns for individual events for the 2002-2007 series

Month	Precipitation Pattern			Average of the Month
	Advanced	Intermediate	Delayed	
		Height Precipitated (mm)		
January^{ns}	27.07	24.00	22.56	25.67
February^{ns}	24.68	22.50	20.90	23.40
March^{ns}	25.78	20.67	23.11	23.90
April^{ns}	20.11	47.60	21.75	25.44
October^{ns}	26.88	19.50	14.75	22.36
November^{ns}	21.96	27.00	28.63	23.95
December^{ns}	25.05	39.88	22.00	26.70
Average of Patterns^{ns}	24.39	29.54	22.54	
CV(%)		71.19		
		EI_{30} (MJ mm ha^{-1} h^{-1})		
January	188.52 aA	126.50 aA	258.56 aA	194.67 a
February	144.68 aA	76.13 aA	204.80 aA	145.91 a
March	149.78 aA	178.00 aA	184.39 aA	168.64 a
April	155.11 aB	547.00 aA	285.75 aB	247.04 a
October	197.00 aA	113.50 aA	50.25 aA	143.14 a
November	176.84 aB	311.75 aA	266.13 aB	210.73 a
December	155.67 aB	464.00 aA	117.87 aB	198.84 a
Average of Patterns	165.22 A	265.56 A	190.22 A	
CV(%)		144.5		
		KE>25 (MJ ha^{-1})		
January	3.33 aA	1.83 aA	4.00 aA	3.26 a
February	2.80 aA	0.88 aA	3.10 aA	2.51 a
March	2.78 aA	2.83 aA	3.39 aA	3.05 a
April	3.22 aB	10.00 aA	4.50 aB	4.67 a
October	3.25 aA	2.00 aA	1.75 aA	2.64 a
November	3.08 aA	4.50 aA	4.25 aA	3.49 a
December	2.80 aB	7.63 aA	1.93 aB	3.39 a
Average of Patterns	3.03 A	4.31 A	3.18 A	
CV(%)		125.07		

Means of the same lowercase letter in the columns and uppercase in the rows do not differ from each other by the Scott Knott test ($p<0.05$). ns not significant ($p<0.05$)

It was observed that the coefficients of variation of these attributes (Precipitation, EI_{30} and KE>25) were high and may have prevented the occurrence of significant results between months (Table 3). However, in the case of natural rainfall, the high variability of this phenomenon in nature is considered normal, especially in tropical regions (Silva et al., 2021).

Analyzing the patterns for each month (line), it observed that there was a significant difference for the EI_{30} and KE> 25 indices (Table 3). For the EI_{30} index, the intermediate pattern presented for the months of November, December and April, higher erosivity (for individual rainfall events) than the other patterns which did not differ from each other. For KE>25, this behavior of the intermediate pattern was observed for the months of December and April. If soil losses in this pattern were very frequent as in the advanced, the potential for soil loss in the region would be very worrying.

However, considering that the intermediate pattern is only lower than the late in potential soil loss, the highest value found for the month of November is critical in conventional tillage systems, when summer crops have not yet covered the entire soil surface. Thus, the adoption of conservation practices such as no-tillage and agroforestry system, fertilization and correction of soil acidity are essential and have been shown to be efficient in controlling water erosion when applied correctly.

4. Conclusion

The average monthly precipitation adjust well with erosivity indexes EI_{30} and KE>25, allowing to obtain of models with longer rainfall series to estimate the erosivity indexes.

The value of the factor R of the Universal Equation of Soil Losses for the locality of Pirenópolis -GO was 7,799.5 MJ mm ha^{-1} h^{-1} $year^{-1}$, and 130.2 MJ ha^{-1} $year^{-1}$ for the index KE> 25, characterizing a high erosive potential of the rains in the region.

January and December were the months with the highest absolute values of total annual precipitation and erosivity indices EI_{30} and KE>25.

The most frequent rainfall pattern for Pirenópolis was the advanced (53.1%) concentrating most of the erosivity. The intermediate pattern was higher than the others patterns in erosive potential for individual rainfall for the months of November, December and April.

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