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Precipitation Patterns and Rainfall Erosivity Return Period Under Savanna Conditions in Formosa, Goiás, Brazil

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Abstract

Losses of soil and nutrients affect a large part of agricultural areas in tropical regions, regardless of the level of technology adopted. This study evaluated the physical attributes and erosivity indices associated with rainfall patterns and return periods in the region of Formosa, State of Goiás, Brazil. Using series of pluviographic (2002-2008) and pluviometric (1975-1998), the erosive potential (EI_{30} and KE>25), rainfall patterns (advanced, intermediate and delayed) and the erosivity associated with the rainfall return periods were determined. The average annual rainfall of the region was 1,391.6 mm with 87.4% of the rains concentrated in October to March. The average annual values of EI_{30} and KE>25 corresponded to 8,041.6 MJ mm ha^{-1} h^{-1} $year^{-1}$ and 125.7 MJ ha^{-1} $year^{-1}$, respectively. The months of the year did not differ based on rainfall pattern. The advanced hydrological pattern had the highest frequency of occurrence, followed by the delayed and intermediate patterns. The highest EI_{30} and KE>25 indices for individual rainfall seasons occurred under the intermediate and the advanced patterns in February and under the intermediate pattern in October for the index KE>25. The average annual erosivity index (R factor of USLE) (8,041.6 MJ mm ha^{-1} h^{-1} $year^{-1}$) is expected to occur at least once every 1.89 years, corresponding to a probability of occurrence of 52.84%. The average annual values of EI_{30} estimated for the return periods of 2, 5, 10, 25, 50 and 100 years were 8,230, 10,225, 10,889, 11,222, 11,421 and 11,488 MJ mm ha^{-1} h^{-1} $year^{-1}$, respectively.

Keywords: Soil conservation, USLE, R factor, hydrological patterns

1. Introduction

Water erosion is one of the main causes of soil degradation and environmental contamination. The extent of water erosion and can be estimated using the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). This equation is used to facilitate the design of erosion control structures, assess soil management practices and conduct environmental planning (Back et al., 2019).

The erosive process depends on the capacity of the rain to produce erosion, i.e., on its erosivity (R factor) as well as other factors (Wischmeier & Smith, 1958). Thus knowledge of the patterns and distribution of rainfall erosivity is extremely important in estimating the occurrence of periods of erosion in a region (Almagro et al., 2017). This information facilitates the reduction of costs associated with losses of soil, water and nutrients that are found in the superficial most fertile layers of soil that are first removed by erosive processes (Bertol et al., 2017).

Numerous studies in Brazil have sought to identify the erosivity index that is closely related with soil losses (Marques et al., 1997; Silva et al., 1997a; Silva et al., 1997b; Cassol et al., 2008; Machado et al., 2013).According to by Wischmeier & Smith (1958) and Wischmeier (1959), the product of the rainfall's kinetic energy with its maximum intensity in 30 min (the $EI_{30\ index}$) best estimates soil erosivity; this index is currently used to obtain the R factor of the Universal Soil Loss Equation (USLE). Although the EI_{30} index was developed for use in temperate regions, it has been used with success in different localities in Brazil (Marques et al., 1997; Silva et al., 1997a; Bertol et al., 2002). In tropical regions, it is recommended that an index of KE>25 (Hudson, 1995), which is calculated from the kinetic energy of rainfalls with intensity above 25 mm h^{-1}, be used.

Rainfall characteristics are a crucial factor in determining the variability in soil losses as evidenced by erosion plot experiments (Ran et al., 2012). However, understanding the relationship between erosivity and soil losses poses a challenge due to the absence of knowledge on the physical characteristics of rainfall (Wischmeier, 1959; Arai et al., 2010).

On different occasions, rainfall of equal magnitude can lead to varying levels of soil losses based on the moment of occurrence of the rainfall's peak intensity relative to its' total duration (Flanagan et al., 1988; Eltz et al., 2001; Aquino et al., 2013). The current evaluation aims to define the rainfall patterns (Horner & Jens, 1942) that are known to influence the erosive process, especially runoff, soil loss and particle distribution (Wang et al., 2016). Another factor known to influence rainfall erosivity is the return period associated with the rainfall, since the greater the recurrence of rain, the greater its erosive potential. When Edwards & Owens (1991) studied soil losses in nine micro-basins in Ohio – USA, they concluded that five extreme patterns of rainfall were responsible for 66% of the soil losses and the return period associated with these patterns exceeded 100 years of recurrence.

The municipality of Formosa and all the eastern region of Goiás (GO) have experienced expansive socio-economic growth in the last few decades. The gross domestic product (GDP) of the agricultural sector increased by 135.6% between 2010 and 2017 (IBGE, 2017). Formosa is comprised of a region of about one million hectares under agricultural use with 20% of this area being irrigated. It presents a highly technified production region with the farming of beans, corn, soy, horticultural and wheat crops that has industries installed for the processing of cereals and is equipped with superb logistical structure (Tejon, 2018). In view of this, research is required to inform improvements in soil quality such as the estimation of factors related erosion degradation to support conservation planning (Schick et al., 2014; Valvassori & Back, 2014). Thus, this study was conducted to evaluate the physical attributes and erosivity indices associated with rainfall patterns and return periods in the region of Formosa - GO, Brazil.

2. Material and Methods

The study was conducted in Formosa-GO, Brazil, which has Aw (tropical savanna climate), characterized by hot, rainy summers and mild, dry winters based on Köppen's classification (Alvares et al., 2013). The regional topography is predominantly flat, with an altitude of 927 m, an average annual temperature of 22.1 ºC and savanna vegetation (Climate-Data.org., n.d. 2020). The municipality is located in the eastern region of Goiás (GO) state, at 15.55º South latitude and 47.34º West longitude.

The study used daily pluviographic data from 2002 to 2008 from Formosa station (15° 32' 56.04 S" and 47° 20' 17.16" W), code 01547003, belonging to National Meteorological Institute of Brazil (INMET), with temporal resolution of 10 min and precision of 0.2 mm, which were digitized in an electronic spreadsheet. After individualization of rainfalls, CHUVEROS software was used to calculate the erosivity indices EI_{30} (Wischmeier & Smith, 1958) and KE>25 (Hudson, 1995), and classify the rainfalls in terms of rainfall patterns into three categories: Advanced, Intermediate and Delayed. This software program also computes the number of rainfall events, rainfall depth and other physical attributes of rainfall.

As most pluviographic databases in Brazil, information pertaining to the minimum period for obtaining the R factor of the USLE (i.e. 22 years) is not available in station 01547003 (Wischmeier & Smith, 1978). In place of this, pluviometric data which have been used due to their greater availability and quality, and due to their correlation with pluviographic from the same meteorological station or a nearby station, were used (Machado et al., 2013).

Using pluviometric series of the same meteorological station, available at the Hidroweb/ANA database, regression analyses were conducted to assess the relationship between the rainfall erosivity indices (EI_{30} and KE>25), which obtained by means of pluviograms and pluviometric data of average monthly precipitation (p), for equal periods of the series. This process provided the models: $EI_{30} = 5.3945p + 44.553$ ($R^2 = 0.96$) and $KE{>}25 = 0.0865p + 0.446$ ($R^2 = 0.97$). Despite the data being obtained from the same meteorological station, these equations were further evaluated using confidence interval (CI) analysis (Moreti et al., 2003), that demonstrated the comparability of the pluviometric series (1975 to 1998) to the pluviographic series (2002 to 2008).

The historical pluviometric series and the equations generated were then used to calculate the erosivity indices (EI_{30} and KE>25) for each month, within each year, as done by Moreti et al. (2003). The sum of the indices from each month was used to calculate the erosivity of that specific year for all the years between 1975 and 2008, (except for the years 1979, 1999, 2000 and 2001, due to historical series failures). These data were then used to evaluate the monthly, annual and average annual distribution, as well as to determine the probability of occurrence (P) and return period (T) of the erosivity indices.

To fit the data with Log-normal distribution typical of hydrological events, (Roque et al., 2001), the values of the erosivity indices (EI_{30} and KE>25) were put in decreasing order associated with a column of increasing values (1 to 30). Then, the value of the frequency coefficient (Z) was estimated using equation 1:

$$Z = \frac{\mathrm{Log}(EI) - \overline{EIl}}{SDl} \qquad (1)$$

where:

EI = erosivity index;

$\overline{IEl}$ = mean of the logarithm of the EI values; and

SDl = standard deviation of the logarithm of the EI values.

Following this, the values of theoretical probability (P) were estimated using the log-normal probability distribution in an MsExcel application. To verify the data fit to the log-normal distribution, the Kolmogorov-Smirnov (K-S) adherence test was used at 0.05 probability level (Evangelista et al., 2006). In this analysis, for each value of order, the difference between calculated probability and the theoretical value was estimated. Lastly, the theoretical values of probability, return period and erosivity indices were used to generate (in the Matlab 2000) environment curves and linear equations to allow the estimation of EI_{30} and KE>25 for different return periods (2, 5, 10, 20, 50 and 100 years) and probability of occurrence of erosivity indices, according to Roque et al. (2001) and Evangelista et al. (2006).

Cluster analysis was performed using the Ward`s method and Euclidean distance with the variables EI_{30} and KE>25 for the 12 months (treatments) of the year in the series from 1974 to 2014 using the software Statistica 12.0. To evaluate the effect of months of the year and rainfall patterns on the attributes rainfall depth and the erosivity indices (obtained from pluviographs) the data were subjected to analysis of variance (ANOVA) and means comparison by Scott-Knott test (0.05 level), using the software SISVAR (Ferreira et al., 2007). The data were analyzed in completely randomized design in factorial scheme (7 x 3), corresponding to the treatments: months of the rainy period (October to April, 7 months) and rainfall patterns (3).

3. Results and Discussion

The average annual rainfall observed in the station of Formosa (GO) between 1975 and 2008 was 1,428.2 mm. From October to April (considered the rainy period), 94.5% of the average annual rainfall fell, and this period was favorable to summer planting (predominant crops in the municipality Formosa: soy, corn and bean), as well as second-crop planting (predominant crops in the region corn, sorghum, millet, wheat, oats and buckwheat) in the region (Figure 1). With 92.3% of the annual erosivity (EI_{30}) being concentrated to this period. The erosivity indices EI_{30} and KE>25 were proportional the monthly rainfall accumulated along the year. May to September period (mainly from June to August) with lower levels of rainfall, and consequently the erosive potential (Figure 1), characterizes the dry season in central Brazil.

With the cluster analysis (Figure 2), it was possible to separate two major groups of months that differed (dissimilarity close to 100%) with respect to rainfall erosivity (EI_{30} and KE>25), but had similar characteristics within each group. The period from April to October (comprising May and September) differed from that from November to March (which is part of October to April), in which the highest annual erosivity is concentrated, in agreement with previous results (Figure 1).

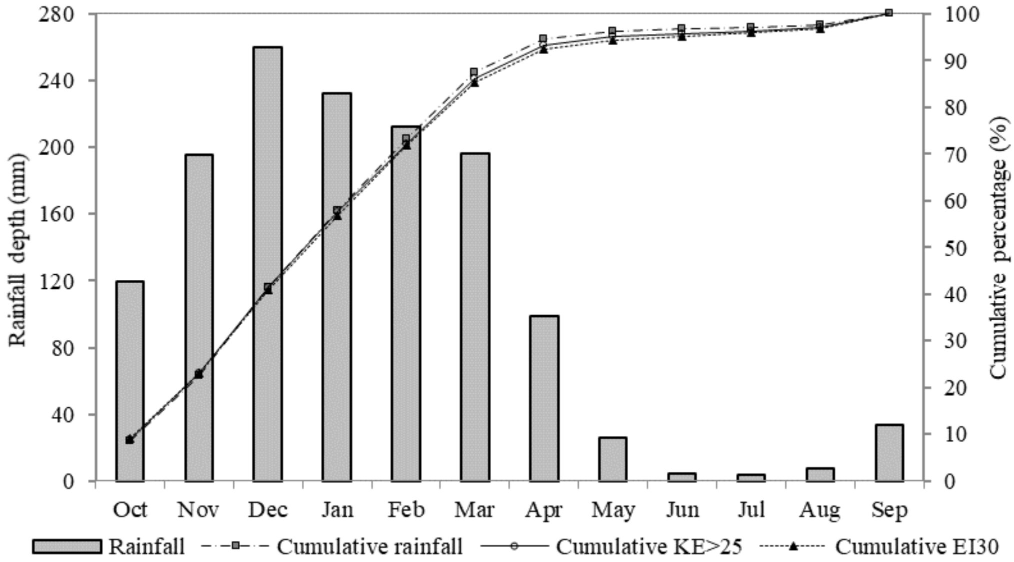

Figure 1. Monthly average values of rainfall (mm) and cumulative percentage of rainfall and erosivity indices EI_{30} and KE>25 of the station of Formosa (GO), in the 1975 - 2008 period

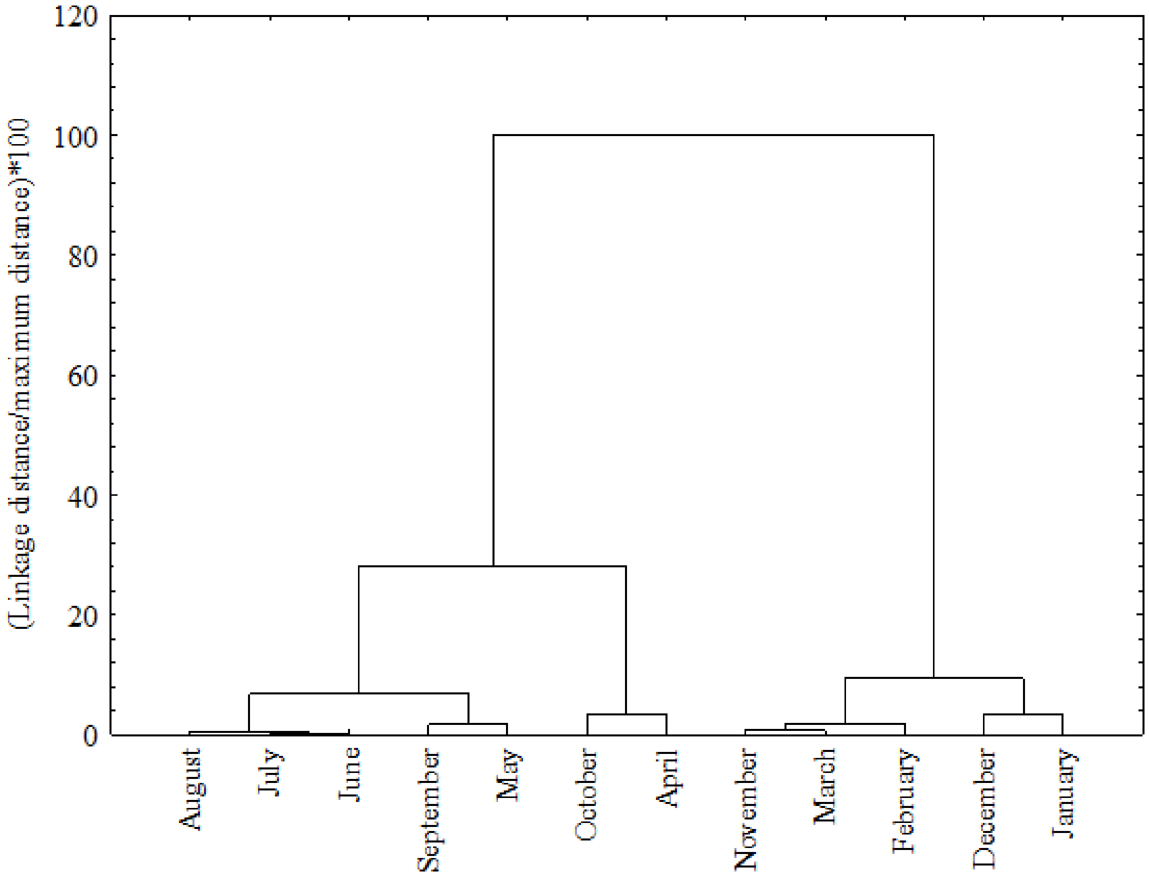

Figure 2. Ward's cluster analysis for months of the year in relation to the erosivity indices of the rainfalls of Formosa (GO) for the period from 1975 to 2008

In the first major group (months April to September), it is possible to note a subgroup with the months from May to September (drought period) and a second subgroup with the months of April and October, which characterize the transition between rainy/drought and drought/rainy periods, respectively in the region (Figure 2). Within the second major group (November to March; right side of the Figure 2), the months of December and January stood out from the others with higher rainfall erosivity, as shown in Figure 1, Table 1 and Table 2.

The monthly average values of EI_{30} in the rainy period varied from 566.2 to 1,432.8 MJ mm ha^{-1} h^{-1} in April and December, respectively. The standard deviation and coefficient of variation for erosivity were very high, demonstrating the variability of this phenomenon in nature even in periods regular rainfalls. December was the month with lowest variability in erosivity (lower CV and SD) and, consequently, indicates higher rainfall regularity (Table 1). The rains in Brazil have high temporal and space variability. This may be related to the different types of rainfall, mainly those of the convective type (Fich et al., 2007), which predominate in the central Brazilian savanna (Silva et al., 1997b).

According to Wischmeier & Smith (1978) the USLE is recommended for predicting average soil losses over long periods because this model utilizes as R factor; the average annual rainfall erosivity is not efficient in predicting short term losses due to their high variability.

September to early November is usually the period that precedes soil tillage which is then followed by planting of annual summer crops in Goiás and in most of Brazil. In recent decades, conventional tillage has been practically replaced by the no-tillage system in the Formosa region. When converting pastural areas to crop farms, conventional tillage is still used by producers to eliminate forage grass, destroy termite mounds and incorporate corrective materials such as limestone and gypsum. However, many areas just stopped doing conventional annual soil preparation, which lead to surfaces with low coverage of cultural residues that were prone to erosive processes. Due to this, the soil remains unprotected until the establishment of cover by aerial parts of crops. This increases the risk of erosion because 25.7% of the annual erosivity occurs in the period between September and November. This low soil coverage is attributed to the rapid decomposition of straw due to climatic conditions in the savanna (Silva et al., 2019). This requires the adoption of strategies such as the use and management of specific cover plants.

Likewise, in many rural properties harvesting is followed by second-crop planting in March, which has on average 13.9% of erosivity of the region. To favor the maintenance of soil cover with residues from the previous crop and to reduce the disturbance operations, farmers could adjust the tillage system or adopted a no-tillage system. From late autumn to early spring (between May and September), there are low risks of soil losses from erosion because rainfall erosivity corresponds to only 8.4% of the total annual EI_{30}.

Table 1. Month and annual values of erosivity EI_{30} obtained from pluviometric and pluviographic series for the Formosa (GO) station

YEAR	MONTH												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Sum
1975	1,010.6	856.2	648.3	712.7	103.7	0.0	46.1	0.0	125.1	582.1	512.4	511.4	5,108.6
1976	557.0	1,421.5	648.8	162.1	739.9	0.0	33.1	0.0	549.5	585.6	1,579.3	1,038.3	7,315.2
1977	1,753.6	759.0	595.5	943.7	270.4	186.9	0.0	0.0	236.7	363.4	360.9	1,923.2	7,393.3
1978	1,330.7	915.7	1,076.0	712.1	316.0	0.0	239.2	0.0	119.7	1,260.7	1,385.7	916.6	8,272.3
1980	2,182.1	2,925.5	925.0	807.8	188.1	175.3	0.0	0.0	205.8	152.7	1,516.5	1,770.9	10,849.7
1981	872.6	427.8	1,167.4	462.5	304.9	402.2	40.3	50.0	0.0	1,908.9	1,840.3	790.4	8,267.4
1982	2,956.9	623.2	1,898.2	495.7	780.0	0.0	20.2	0.0	115.7	637.3	352.5	1,067.2	8,946.8
1983	2,625.7	1,496.2	1,250.5	799.0	85.7	0.0	216.1	0.0	148.0	916.3	1,327.9	1,499.1	10,364.4
1984	779.9	1,088.0	870.0	1,274.9	80.2	0.0	0.0	243.8	261.0	614.3	716.1	777.1	6,705.2
1985	2,384.9	882.5	1,432.4	396.6	62.2	0.0	0.0	27.1	238.1	964.5	1,076.5	3,114.9	10,579.7
1986	1,520.6	1,006.1	786.9	222.8	19.4	0.0	213.2	944.9	51.1	1,105.1	415.3	1,683.6	7,969.1
1987	614.0	1,056.0	1,129.8	757.0	148.0	0.0	0.0	0.0	745.9	391.0	1,281.9	2,039.9	8,163.5
1988	446.9	1,408.6	1,819.6	1,086.0	70.5	0.0	0.0	0.0	0.0	1,522.5	1,598.4	1,284.0	9,236.6
1989	944.1	776.4	911.5	61.8	0.0	296.5	0.0	141.7	219.3	779.6	1,602.3	3,766.9	9,500.2
1990	405.0	1,033.0	405.8	211.1	379.6	0.0	824.1	141.7	846.8	566.6	572.5	583.1	5,969.3
1991	1,271.5	1,543.3	2,062.1	331.3	9.7	0.0	0.0	0.0	317.5	647.6	1,545.1	1,898.7	9,626.8
1992	1,687.1	2,411.9	593.8	718.5	41.5	0.0	0.0	118.8	174.9	969.7	1,378.4	1,351.2	9,445.8
1993	585.5	2,036.8	222.3	435.7	94.0	0.0	0.0	60.4	515.2	469.6	680.2	1,845.9	6,945.6
1994	943.0	722.0	2,824.9	843.3	89.9	260.4	0.0	0.0	0.0	190.6	2,027.2	1,336.2	9,237.5
1995	1,324.0	771.4	1,283.1	586.7	271.7	0.0	0.0	0.0	0.0	699.8	1,572.0	1,235.1	7,743.9
1996	794.4	170.7	1,563.7	478.2	74.7	0.0	0.0	396.9	196.4	647.6	1,073.1	1,931.0	7,326.7
1997	1,464.8	377.3	1,295.4	878.3	323.6	348.0	0.0	0.0	111.0	617.2	813.8	1,131.7	7,361.1
1998	1,361.4	1,478.8	944.6	274.7	207.4	92.8	5.8	0.0	0.0	385.2	1,165.1	1,260.1	7,176.0
2002	197.3	1,414.4	484.0	8.3	16	4.3	0	0.9	22.2	16.4	206.1	671.2	3,041.1
2003	1,968.5	190.2	931.3	166.1	432.2	0	0	6.1	19.7	1.2	582.6	1397	5,694.9
2004	2,512.5	3,256.8	1,632.8	793.8	0.4	0	0	1.2	0	76.9	72.8	2,025.2	10,372.4
2005	987.5	661.2	1,998.8	244.1	80.7	0	0	0	1,146.0	20.3	1,227.3	1,802.6	8,168.5
2006	299.5	1,367.8	528.3	700.8	2.8	0	0	2.1	1,286.6	4,580.9	1,264.4	994.7	11,028.7
2007	1,142.4	2,623.8	188.0	209.5	0	0	0	0	0	161.8	3,667.1	348.8	8,341.4
2008	958.5	577.5	516.7	1,209.3	0	0	0	0	85.4	94.7	667.1	988.4	5,097.6
MEAN	1,262.7	1,209.3	1,087.9	566.2	173.1	58.9	54.6	71.2	257.9	731.0	1,136.0	1,432.8	8,041.6
S.D.	715.0	761.6	602.4	334.7	199.8	116.7	157.5	184.3	333.8	842.5	695.0	718.9	1,847.7
C.V.	56.6	63.0	55.4	59.1	115.4	198.3	288.5	258.9	129.4	115.3	61.2	50.2	23.0

SD: standard deviation. CV. Coefficient of variation

Table 2. Month and annual values of erosivity KE>25 index obtained from pluviometric and pluviographic series for the Formosa (GO) station

YEAR	MONTH												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Sum
1975	16.0	13.5	10.2	11.1	1.5	0.0	0.6	0.0	1.9	9.1	8.1	8.1	80.1
1976	8.8	22.5	10.3	2.5	10.9	0.0	0.4	0.0	8.2	9.2	25.0	16.5	114.1
1977	27.8	12.0	9.4	14.7	4.0	2.3	0.0	0.0	3.5	5.7	5.7	30.5	115.6
1978	21.1	14.5	17.0	11.1	4.6	0.0	2.9	0.0	1.8	19.8	21.9	14.5	129.2
1980	34.5	46.2	14.6	12.6	2.8	2.2	0.0	0.0	3.1	2.4	24.0	28.1	170.4
1981	13.8	6.8	18.4	7.2	4.5	5.0	0.5	0.7	0.0	29.9	29.1	12.5	128.4
1982	46.8	9.8	30.0	7.7	11.5	0.0	0.2	0.0	1.7	10.0	5.6	16.9	140.3
1983	41.6	23.6	19.8	12.5	1.3	0.0	2.7	0.0	2.2	14.4	21.0	23.8	162.6
1984	12.3	17.2	13.7	19.9	1.2	0.0	0.0	3.2	3.9	9.6	11.3	12.3	104.7
1985	37.7	13.9	22.6	6.2	0.9	0.0	0.0	0.4	3.5	15.1	17.0	49.4	166.8
1986	24.1	15.9	12.4	3.5	0.3	0.0	2.6	12.4	0.8	17.3	6.6	26.7	122.5
1987	9.7	16.7	17.9	11.8	2.2	0.0	0.0	0.0	11.1	6.1	20.3	32.3	128.0
1988	7.1	22.3	28.8	16.9	1.0	0.0	0.0	0.0	0.0	23.9	25.3	20.4	145.5
1989	14.9	12.3	14.4	1.0	0.0	3.7	0.0	1.9	3.3	12.2	25.3	59.7	148.7
1990	6.4	16.3	6.4	3.3	5.6	0.0	10.1	1.9	12.6	8.9	9.0	9.2	89.7
1991	20.1	24.4	32.6	5.2	0.1	0.0	0.0	0.0	4.7	10.1	24.4	30.1	151.8
1992	26.7	38.1	9.4	11.2	0.6	0.0	0.0	1.6	2.6	15.2	21.8	21.4	148.6
1993	9.3	32.2	3.5	6.8	1.4	0.0	0.0	0.8	7.6	7.4	10.7	29.3	108.9
1994	14.9	11.4	44.6	13.1	1.3	3.3	0.0	0.0	0.0	3.0	32.0	21.2	144.9
1995	21.0	12.2	20.3	9.1	4.0	0.0	0.0	0.0	0.0	11.0	24.8	19.6	121.9

1996	12.6	2.7	24.7	7.5	1.1	0.0	0.0	5.2	2.9	10.1	17.0	30.6	114.4
1997	23.2	6.0	20.5	13.7	4.8	4.4	0.0	0.0	1.6	9.7	12.9	17.9	114.5
1998	21.5	23.4	14.9	4.3	3.1	1.2	0.1	0.0	0.0	6.0	18.4	20.0	112.8
2002	2.1	3.3	9.3	0	0	0	0	0	0.7	1.2	4.6	14.8	36.0
2003	38.8	5.6	19.8	4.2	7.3	0	0	0.4	0	0	16.3	29.6	119
2004	45.5	46.1	28.9	12.3	0	0	0	0	0	3.2	1.1	30.5	167.6
2005	17.8	12.3	33	5.5	2.6	0	0	0	16.1	0	19.9	28.4	135.6
2006	6.4	16.5	8.9	9	0	0	0	0	13.6	55.6	20.9	14.4	145.3
2007	18.4	36.7	5.1	3.3	0	0	0	0	0	2.8	43.6	10.6	120.5
2008	16.8	9.3	9.5	16.2	0	0	0	0	1.1	1.4	15.9	12.9	83.1
MEAN	20.6	18.1	17.7	8.8	2.6	0.7	0.7	0.9	3.6	11.0	18.0	23.1	125.7
S.D.	11.9	11.5	9.5	5.0	3.0	1.5	1.9	2.4	4.4	10.8	9.2	11.2	28.7
C.V.	58.0	63.2	53.6	56.4	114.0	198.9	288.5	256.2	121.2	97.8	51.0	48.4	22.8

SD: standard deviation. CV. Coefficient of variation

On average, annual erosivity varied from 3,041.1 to 11,028.7 MJ mm ha^{-1} h^{-1} year^{-1}, for the index EI$_{30}$, and from 36 to 170.4 MJ ha year^{-1} through the index KE>25, in 2002 and 2006/1980, respectively. The average annual erosivity for Formosa (GO) in the period studied was 8,041.6 MJ mm ha^{-1} h^{-1} year^{-1} and to 125.7 MJ ha^{-1} year^{-1}, for EI$_{30}$ and KE>25, respectively (Table 1 and Table 2). The EI$_{30}$ value was close to those found in localities of Brasília (DF-Brazil) (8,319) (Dedecek, 1988), Goiânia (GO-Brazil) (8,353) (Silva et al., 1997b), Flechas (MT-Brazil) (7,830) (Morais et al., 1991) and Cuiabá (MT-Brazil) (8,810 MJ mm ha^{-1} h^{-1} year^{-1}) (Almeida et al. 2011), which are all under Aw climate.

Based on the classification proposed by Carvalho (1994), the erosivity of Formosa (GO) fits in the category Strong ($7,357 < R < 9,810$ MJ mm ha^{-1} h^{-1} year^{-1}). This suggests that special attention should be paid to agricultural practices that promote soil mobilization especially when terrain surface remains uncovered during the previously mentioned critical periods.

Working with clayey Dark Red Latosol in the municipality of Goiânia (GO), Silva et al. (1997a) found a soil loss of 29.3 t ha^{-1} year^{-1} for an average annual erosivity of 7,364.5 MJ mm ha^{-1} h^{-1} year^{-1}. These authors found soil loss of 112.58 t ha^{-1} year^{-1} associated with the extreme EI$_{30}$ index of 12,315 MJ mm ha^{-1} h^{-1} year^{-1}, which is close to the maximum annual EI$_{30}$ found for Formosa (GO) of 11,028.7 MJ mm ha^{-1} h^{-1} year^{-1} in 2006.

Based on the pluviographic series (2002 to 2008), there were 990 individual rainfalls, of which 295 were classified as erosive (29.8%), and responsible for 80% of the rainfall depth. Erosive rainfalls corresponded to 52.9%, 24.7% and 22.4% for the patterns Advanced, Intermediate and Delayed, respectively (Table 3). For rainfall depth and erosivity indices, similar results were obtained (Table 3). These results were consistent with the work of Evangelista et al. (2016) for Goiânia (GO) in relation to the patterns Advanced and Intermediate, but varied when compared to the pattern Delayed, which may be related to the effect of the urban area (higher surface temperature), as well as to the difference in the size of the data series.

Table 3. Number of erosive rainfalls, average annual rainfall depth and average annual cumulative erosivity indices in the rainfall patterns Advanced (AD), Intermediate (IN) and Delayed (DE) in Formosa (GO), in the period from 2002 to 2008

Rainfall pattern	Number of rains		Rainfall depth		Erosivity indices			
	Absolute	%	mm	%	EI_{30} MJ mm ha^{-1} h^{-1} year^{-1}	%	KE>25 MJ ha^{-1} year^{-1}	%
AD	156	52.9	548.1	54.1	4,102.2	58.2	64.4	57.0
IN	73	24.7	282.6	27.9	2,041.3	29.0	31.6	28.0
DE	66	22.4	183.1	18.1	902.4	12.8	17.0	15.0
TOTAL	295	100	1,013.79	100	7,045.86	100	113.0	100

Carvalho et al. (2010) studied erosion under natural rainfall in Argissolo Vermelho Amarelo (Ultisol) in Seropédica (RJ-Brazil) and found superiority of erosivity in the Advanced pattern in the frequency of erosive rainfalls and cumulative erosivity. These authors found soil losses of 35.1%, 6.6% and 58.3% for the patterns Advanced, Intermediate and Delayed, respectively. Bazzano et al. (2010) pointed out that those rainfalls with intensity peaks at the end of its duration led to larger soil losses due to the effect of accumulated moisture on disaggregation, surface sealing and capacity of transport of soil particles. Aquino et al. (2013) studied soil loss in typically dystrophic Red Latosol in Lavras (MG-Brazil) and also observed a predominance of rainfalls with Advanced pattern, but the total soil losses were larger in the patterns Advanced (54%), followed by Intermediate (28%) and Delayed (18%). In this study, the amount of rainfalls seems to have prevailed on the total soil loss when compared to the effect of previous moisture.

According to Table 4, there was no significant difference in the rainfall erosivity measured by the indices EI_{30} and KE>25 between the months of the rainy period in each rainfall pattern. The high coefficient of variation observed in these attributes may have contributed to this result. In a statistical analysis of the rainfall patterns for the index EI_{30}, the rainfalls in the patterns Advanced and Intermediate were more erosive than those in the Delayed pattern in February. This behavior was also observed between the means of the patterns (mean of all months in each pattern). In the February month, since usually summer crops cover all soil surfaces, the risks of erosion are lower than in the periods of soil tillage, crop establishment and harvest.

Table 4. Distributions of EI_{30} and KE>25, obtained based on erosive rainfalls for individual events along the rainy period for the rainfall patterns in Formosa (GO)

Month	Rainfall Pattern			Mean of the Month
	Advanced	Intermediate	Delayed	
		EI_{30} (MJ mm ha^{-1} h^{-1})*		
January	148.64 aA	208.80 aA	75.80 aA	146.24 a
February	212.48 aA	205.33 aA	73.75aB	178.64 a
March	138.00 aA	198.22 aA	53.27 aA	125.52 a
April	176.00aA	167.00 aA	26.00 aA	148.05 a
October	350.30 aA	345.00 aA	71.00 aA	283.64 a
November	268.27 aA	145.28 aA	56.87 aA	199.30 a
December	126.96 aA	209.14 aA	129.00 aA	149.67 a
Mean of the Pattern	187.06 A	200.73 A	79.06 B	
CV (%)		155.64		
		KE>25 (MJ ha^{-1})**		
January	2.64 aA	3.70 aA	1.40 aA	2.60 a
February	3.39 aA	2.78 aA	1.50 aA	2.75 a
March	2.46 aA	3.22 aA	1.54 aA	2.39 a
April	2.28 aA	2.78 aA	0.67 aA	2.26 a
October	4.50 aB	5.00 aA	0.50 aB	3.65 a
November	4.00 aA	2.43 aA	150 aA	3.16 a
December	2.26 aA	3.50 aA	2.33 aA	2.62 a
Mean of the Pattern	2.99 A	3.17 A	1.59 B	
CV (%)		117.67		

Means followed by the same letter, in the columns, for each pattern and mean of months (lowercase letters), and in the rows between rainfall patterns and means of the patterns (uppercase letters), do not differ by Scott-Knott test ($p<0.05$). * Values transformed in the analysis to log of the variable. **Values transformed in the analysis to log (variable +1).

For KE>25, based on the means of the patterns, similar to EI_{30}, the highest erosivity indices occurred with the rainfall patterns Intermediate and Advanced (Table 4). In October, the rainfall erosivity in the Intermediate pattern is higher than in other patterns in the municipality of Formosa (GO). Although this month corresponds to 9% of the annual erosivity, the erosion promoted by this pattern is of concern because due to accumulated moisture of the soil and uncovered soil using conventional tillage practices, or no-tillage practices accompanied by sowing along the ramp, regardless of slope, without adopting terraces.

In relation to the return period of erosivity (R factor), the average annual value of 8,041.6 MJ mm ha^{-1} h^{-1} $year^{-1}$ was associated with 52.84% of probability (P) of being equaled or surpassed, at least once on average, every 1.89 years in Formosa (GO) (Figure 3a). Based on Figure 3, it is possible to estimate rainfall erosivity for different return periods or probability of occurrence for this locality.

The values of T found were relatively close to those obtained by Almeida et al. (2012) for three municipalities in Mato Grosso (MT-Brazil) (P = 43% and T = 2.33 years) and Moreti et al. (2003) in São Manuel (SP-Brazil) (P = 42.9% and T = 2.3 years).

For the average annual erosivity measured by the index KE>25 for Formosa, the results were 53.48% and 1.87 years for P and T (Figure 3b), respectively, as observed for the index EI_{30}. For 30 localities in the Rio de Janeiro state, Machado et al. (2013) obtained results of KE>25 associated with P from 48.8 to 54.4% and T from 1.8 to 2.1 years, close to those found for Formosa, except for the climatic differences.

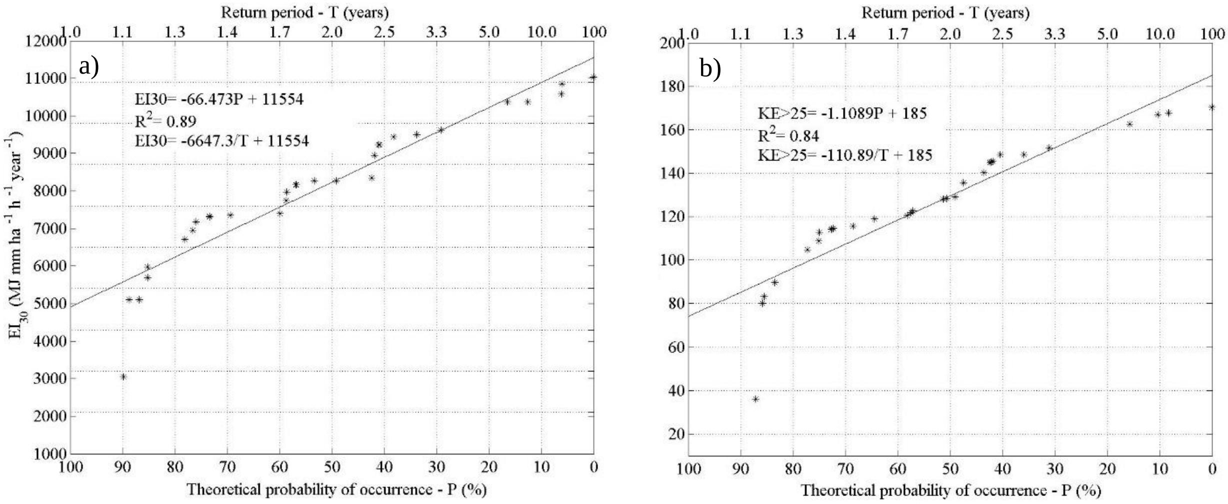

Figure 3. Return period and theoretical probability of occurrence of the erosivity indices EI_{30} (a) and KE>25 (b) for Formosa (GO)

The values of erosivity found for the station of Formosa were 8,230, 10,225, 10,889, 11,222, 11,421 and 11,488 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Figure 3) for return periods commonly used in the literature of 2, 5, 10, 20, 50 and 100 years, respectively. For the same return periods, the obtained values of KE>25 were 130, 163, 174, 179, 183 and 184 MJ ha^{-1} $year^{-1}$. The erosivity expected for the return period of 2 years, measured by both EI_{30} and KE>25, respectively, was close to the average annual erosivity of R factor (EI_{30}). This occurs because the probability of occurrence of these indices is almost 2 years (1.89 years). For the maximum erosivity observed in the pluviometric series, which was 11,028.7 MJ mm ha^{-1} h^{-1} $year^{-1}$ in 2006 (Table 1), this magnitude was related to return period (T) of 12.6 years.

Taking the EI_{30} index as an example, which does not vary much differently from KE>25, the variation in annual erosivity was 24.2%, 6.5%, 3.1%, 1.8% and 0.6% with the increase in the above-mentioned return periods from 2 to 100 years. This demonstrates that the largest variation in erosivity occurred from 2 to 5 years; for rainfall events related to return periods with more than 5 years of recurrence, there is little variation in the average annual erosivity corroborating the study of Carvalho et al. (2010) for Seropédica (RJ-Brazil). Thus, the use of the R factor of Formosa in the USLE as is normally done (without considering the return period) does not considerably underestimate erosivity for this locality.

4. Conclusion

In conclusion, this study demonstrated that rainfall erosive potential is concentrated in the periods between November and March (corresponding to 76.2% of EI_{30} and 77.5% of KE>25 of the annual erosive potential) with the months of December and January having the highest erosivity. The predominant hydrological pattern in the region is the Advanced. Rainfalls (individual events) of Advanced and Intermediate patterns have higher erosivity in the months of February (EI_{30}), October (KE>25 - intermediate pattern) and for the mean of the patterns. The average annual erosivity of the rainfalls is 8,041.6 MJ mm ha^{-1} h^{-1} $year^{-1}$ for EI_{30} (R factor of USLE) and 125.7 MJ ha^{-1} $year^{-1}$ for KE>25, and is expected to occur at least once every 1.89 and 1.87 years, on average, with theoretical probabilities of occurrence of 52.84% and 53.48%, respectively. Increment in return periods does not increase the expected erosivity at the same magnitude for the locality under study.

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