Evaluating rainfall erosivity index from CHIRPS and INMET data in southeast region of Goiás (Brazil)

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Abstract

Soil erosion is a form of land degradation commonly observed in different regions of the world, especially in tropical regions. In Brazil, soil erosion caused by rainwater (pluvial erosion) is the most common and worrying form of erosion, causing various environmental, economic and social damage. The main aim of this work was to evaluate the Erosivity Index (EI) relationships based on CHIRPS and INMET data in the municipality of Catalão-GO, that is located in one of the world's largest agricultural frontiers, the Brazilian Cerrado. The results found indicated that the CHIRPS data it is an alternative for calculating EI in the context of municipality of Catalão, southeast region of Goiás state, from a previous stage for statistical validation.

1. Introduction

Soil erosion is a form of land degradation commonly observed in different regions of the world, especially in tropical regions (Koch et al., 2013; Amundson et al., 2015; Borrelli et al., 2017; Browning and Sawyer, 2021). In this context, it is considerate a dynamic and complex phenomenon that must be overcome, given the adverse impacts that unleashes in ecosystems and it services (FAO, 1980, 2011, 2015). Although is understood as a phenomenon resulting from natural causes, soil erosion can be significantly intensified by human activities, especially in scenarios of intense land use and land cover changes (Steinhoff-Knopp et al., 2021). This phenomenon show shows a tendency to become much more frequent and intense in climate change scenarios with extreme weather events, causing adverse socioeconomics and environmental impacts (IPCC, 2021; Makhtoumi et al., 2023).

In Brazil, soil erosion caused by rainwater (pluvial erosion) is the most common and worrying form of erosion (Oliveira, Wendland e Nearing, 2013). This is explained by the fact that it not only breaks down and transports eroded material very easily and quickly, but also causes major environmental, economic and social damage (Guerra, 1995; Minella et al., 2007). The splash effect is a important contributor to the disintegration and release of particles from the cohesive soil matrix, their transportation and deposition down the hillsides (Zhu et al., 2023). In fact, detachment of soil particles by raindrop splash on the ground surface is the first stage in the soil erosion process, resulting in diffuse or concentrated surface runoff and, consequently, in the disintegration and transportation of soil particles (Fernández-Raga et al., 2017).

Considering this climate-soil interface, some studies indicate a contribution around 75% of rainfall erosivity to soil loss in hillsides and areas with pronounced land use changes, like agricultural lands without management practices and degraded pasturelands (Robichaud and Brown, 2002; Makhtoumi et al., 2023; Zhao et al., 2024). In this sense, emphasizing the association between intensity, duration, frequency and energy produced by the impact of rain, Wischmeier and Smith (1978) proposed the Erosivity Index (EI30). Calculated from the kinetic energy released by the impact of raindrops in events of maximum rainfall intensity over 30-minute periods, this index provides a high correlation with soil loss, being one of the most widely used in various studies in Brazil (Lombardi Neto and Moldenhauer, 1992; Bertol, 1994; Silva et al., 1997).

The EI values it is estimated from a historical series of at least 30 years of rainfall, to identify the apparent cyclic pluviometric patterns in the region of study (Wischmeier and Smith, 1978). Considering the climatic conditions inherent to each region, different adjustment coefficients are necessary to estimate the EI (Nascimento et al., 2018). From this context, emerges one of the main challenges to obtaining the EI, the availability of precipitation data that is temporally and spatially representative (Colodro et al., 2002). Given the large size of the Brazilian territory, there is still a low density in relation to the network of rainfall stations and a gap in relation to the homogeneity of their spatial distribution, which overlaps with the lack of data in long time series (Oliveira et al., 2010).

In order to overcome this lack of rainfall data, many studies have evaluated the performance of data from global rainfall estimation models, like Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data, obtaining satisfactory statistical results compared to measurements from conventional stations (Nogueira et al., 2018; Costa et al., 2019). In view of these aspects, the objective of this work is to evaluate the relationships of the EI from CHIRPS and INMET data, in municipality of Catalão-GO, located in the southeastern region of Goiás, close to the core area of the Brazilian Cerrado, to assess their applicability in the surrounding areas where the density of stations is low. With the fast changes in land use and land cover in the Brazilian Cerrado (Souza et al., 2020), land degradation caused by erosive processes it is increasingly been observed (Alves et al., 2022).

Data from global rainfall estimation models, like Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), it is an alternative for calculating rainfall erosivity in large areas without measured data from rainfall stations, contributing to assessment of the potential soil erosion and land degradation by erosive processes (Kim et al., 2020). In addition, it can contribute to territorial planning in context of intensive land use, such as the municipality of Catalão-GO.

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2. Methodology

In this work, we used two different dataset to estimate EI. The first, made available from surface data by the National Meteorological Institute (INMET), refers to the records of the conventional weather station code 83526-GO. The second refers to CHIRPS, made available on Google Earth Engine Data Catalog, in raster format, with a grid of 5 km. Both dataset comprehend the time window 1990-2021, involving a monthly time series of 32 years of precipitation observations, in the same localization point, in the context of the municipality of Catalão-GO, located in Central-West Region of Brazil (Figure 1).

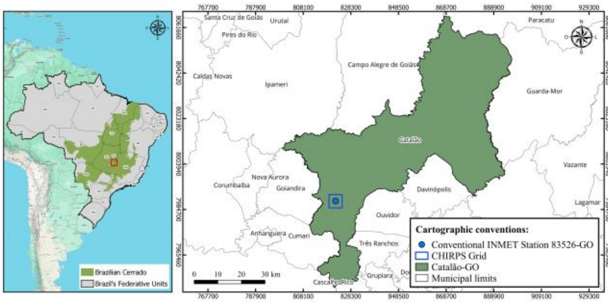

Figure 1. Localization map of the municipality of Catalão-GO.

Considering pluviometric patterns and observing what the literature says about the coherent adjustment coefficient for the study region (Costa et al., 2023; Medeiros et al., 2024), EI $MJ.mm.ha^{-1}.month^{-1}$ was calculated using equation (1). The R software, RStudio Integrated Development Environment (IDE), was used to analyse the correlation between the EI from each dataset (CHIRPS and surface data from INMET) and graphical representation of the data.

$$EI30 = 68.730\left(\frac{p^2}{P}\right)^{0.841} \quad (1)$$

Where EI is the monthly average Erosivity Index, in $MJ.mm.ha^{-1}.month^{-1}$; p is the average monthly precipitation in mm; and P is the average annual precipitation in mm.

3. Results and Discussions

The patterns of the EI accumulations obtained from CHIRPS and from INMET datasets (1991-2021) is presented in Figure 2. The acronyms WS, BDS, DS, and BWS represent the Wet Season, Beginning of Dry Season, Dry Season, and Beginning of Wet Season, respectively.

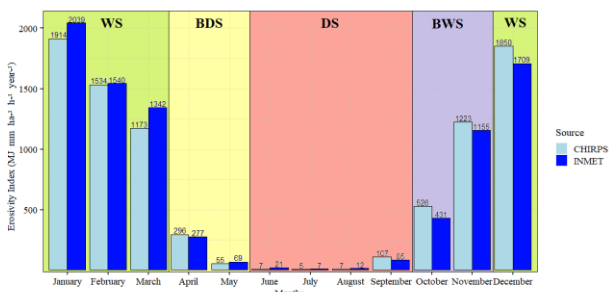

Figure 2. Average monthly EI for the municipality of Catalão-GO (1991-2021), based on CHIRPS and INMET data.

Note that there is an unequivocal relationship between the seasonality of precipitation and the average EI accumulations. According to the data, it is possible note that the highest EI values occur during the Wet Season, while the lowest values was found during the Dry Season. This can be identified in the EI derived from both datasets (CHIRPS and INMET).

In view of Figure 2, comparatively, the EI values derived from CHIRPS data seems to overestimate EI values from the end of the Dry Season, during the Beginning of Wet Season, until the first month (December) of the Wet Season. After January, when the EI values have the highest records, the pattern reverses, and the EI values derived from CHIRPS data remain below the EI calculated from INMET surface data. Specifically, this occurs during the Wet Season until the end of the Dry Season. Anyway, it is possible to observe in Figure 2 that, the EI derived from CHIRPS data does not seem to differ significantly from the EI derived from INMET data, establishing a similar pattern.

In Figure 3 are plotted the time series of EI obtained from CHIRPS and INMET datasets, ordered between January 1990 to December 2021. A regular succession of "peaks and valleys" it is identified in the EI values, demonstrating the climatic seasonality that characterizes the study area. Despite this, in both datasets, January 2007 is the month with the highest EI value, 6.207 $MJ.mm.ha^{-1}.month^{-1}$ for the EI obtained from CHIRPS data, and 6.571 $MJ.mm.ha^{-1}.month^{-1}$ for the EI obtained from INMET data. On the other hand, July and August, respectively, are the months in all years of the observed time series that record the lowest EI values, value 0 (zero), considering the EI derived of both datasets (Figure 3).

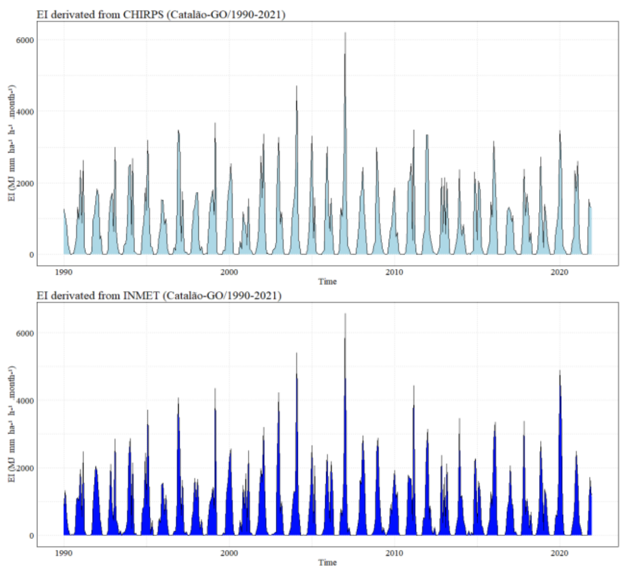

Figure 3. Monthly EI of the municipality of Catalão-GO (1991-2021).

In Figure 3 it is possible to identify that EI have an annual and intra-annual dynamic. This is something inherent in the variability of annual, seasonal and monthly volumes of precipitation between years with the usual regime and those that are exceptionally dry or rainy (Nascimento and Oliveira, 2018; Alves, Cabral and Nascimento, 2023), as also pointed out by Costa, Nascimento and Luz (2023). In this context, considering areas of intensive land use in agricultural activities, this data can be very important and useful for organizing the agricultural calendar and even productive rotation on a farm scale.

Knowing the periods of greatest potential for soil erosion by rainfall makes a big difference, because productive areas, which are the most susceptible, can plan practices to protect the soil surface, considering the use and management practices that best suit each type of soil (Cogo et al., 1984). The EI is a very useful data, both for making decisions about preventing land degradation by soil erosion in productive areas, contributing for a more sustainable agriculture in the Brazilian Cerrado (Dedecek, 1988), but it is also possible to incorporate it into other promising technologies that already exist (Zolin et al., 2021).

In order to better understand the pattern, variability and extreme records of the EI values over the months of the time series studied, in Figure 4 it is showed the boxplot for the EI derived from both datasets (CHIRPS and INMET). The median EI values present a decrease trend between January and August, and an increase trend between September and December.

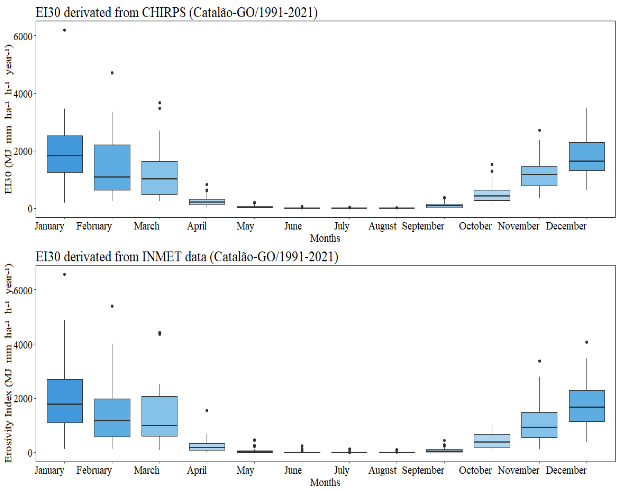

Figure 4. Monthly EI distribution of the municipality of Catalão-GO (1991-2021).

Between the Beginning of Wet Season and the end of Wet Season, the EI values show greater variability than the EI observed in the Beginning of Dry Season and the end of Dry Season. The EI values derived from CHIRPS data show a similar dispersion to the EI values derived from INMET data (Figure 4). However, for the month of February, note that the EI values derived from the CHIRPS data show a positive asymmetrical distribution, while the EI values derived from the INMET data show a much more symmetrical distribution. This pattern is reversed in March, when the EI values derived from INMET data show greater dispersion and positive asymmetry compared to the EI values derived from CHIRPS data.

For the EI values obtained from both datasets, it is possible observe that January, February, March and April are the months that historically show EI discrepant positive values, comprising outliers, occurring more frequently in the Beginning and end of Wet Season. In this context, on Figure 5 it is presented the variability of annual EI values obtained from CHIRPS and INMET datasets. For the annual EI values derived from INMET data, specifically, the observed historical average was 8,689.5 MJ.mm.ha^{-1}.year^{-1}. In this context, the years 2004, 2007, 2008, 2011 and 2020, recorded values above 10,000.0 MJ.mm.ha^{-1}.year^{-1}, with the last year recording the maximum value of 11,854.8 MJ.mm.ha^{-1}.year^{-1}. Considering EI obtained from the CHIRPS dataset, the observed historical average was 8,760.9 MJ.mm.ha^{-1}.year^{-1}. The highest values was observed in the same years as in the INMET dataset, with 2011 recording the extreme value of 11,315.6 MJ.mm.ha^{-1}.year^{-1}.

Specifically, for the years 2004, 2007, 2008, 2011 and 2020, the annual values of EI obtained from CHIRPS data was 10,302.4, 11,121.7, 9,620.9, 11,315.6 and 10,030.6 MJ.mm.ha^{-1}.year^{-1}, respectively. Using the same dataset made available by INMET, Costa, Nascimento and Luz (2023) show that the highest EI values was recorded precisely in the years classified as rainy and very rainy. Just like at the highest monthly EI values obtained from both datasets it is find in the Wet Season, the annual EI results show that the highest EI values follow the same trend, with highest EI values recorded in years rainy and very rainy.

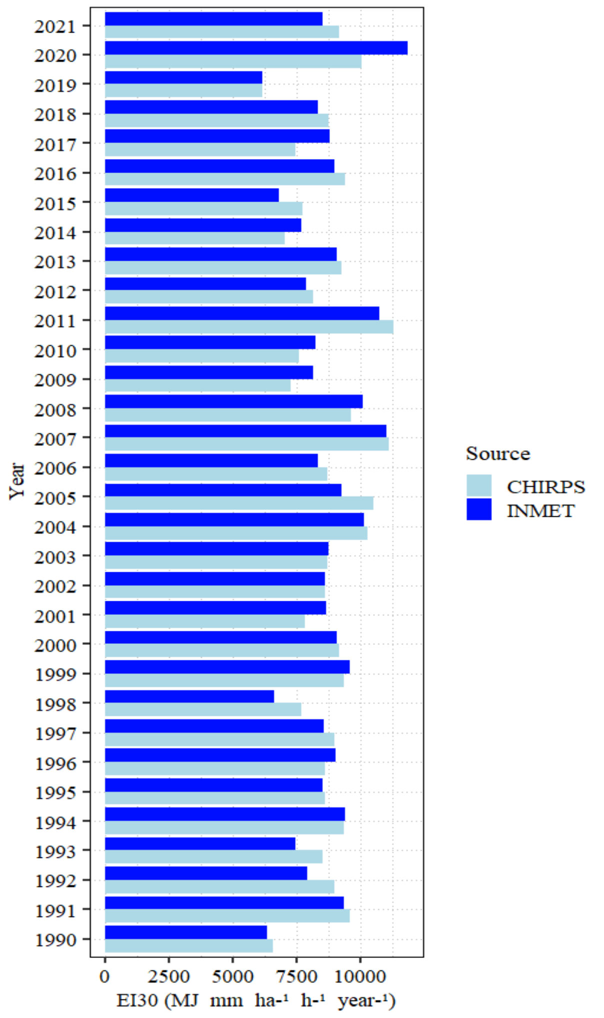

Figure 5. Annual EI from CHIRPS and INMET datasets.

In Figure 6, the annual EI from INMET are plotted against the annual EI estimated from the CHIRPS data, separately, for each crop year (corresponds to the period from July to June of the next year). The coefficients of determination varied between 0.79 (2016/2017) and 0.98, with the best result in 2006/2007, the second year of highest average EI. The best results between EI derived from INMET and from CHIRPS were obtained for the crop years 2006/2007 (R^2 = 0.98), 2002/2003 (R^2=0.97), 1994/1995 (R^2=0.97), and 1996/1997 (R^2 = 0.96), respectively.

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One the other hand, and the lowest coefficients were observed for the crop years 2016/2017 (R^2 = 0.79) and 2014/2015 (R^2 = 0.90). The worst performance of INMET and CHIRPS was on 2016/2017. According to Costa, Nascimento and Luz (2023), 2016 and 2017 is a period classified as dry and usual in terms of rainfall and EI.

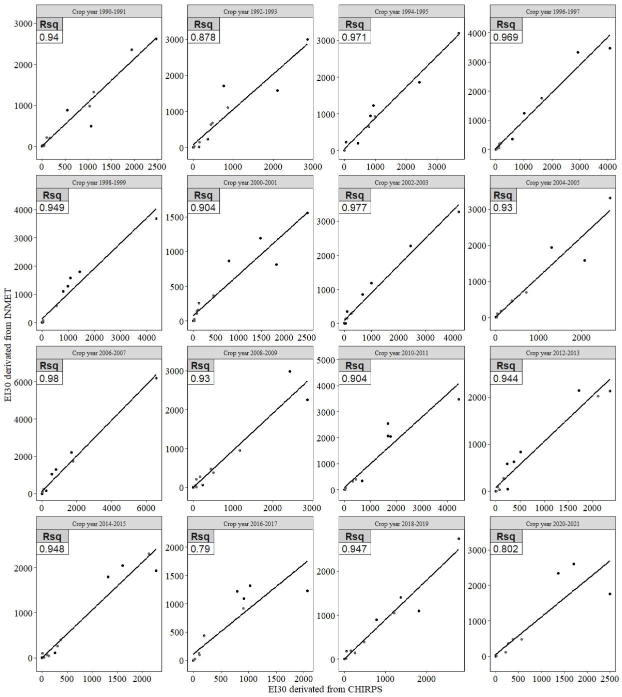

Figure 6. EI estimated from INMET data versus the EI estimated from CHIRPS data, per crop year.

In Figure 7, the monthly EI from INMET it is plotted against the monthly EI estimated from the CHIRPS data, considering the time series studied (1991-2021). The percentage of trend (PBIAS) was 0.10, indicating a good performance (=<10%). The Pearson correlation coefficient (r) was 0.95, demonstrating the high correlation of the EI derived from CHIRPS data with the EI derived from INMET data, and the coefficient of determination (R^2) exhibited a good quality fit with 0.90.

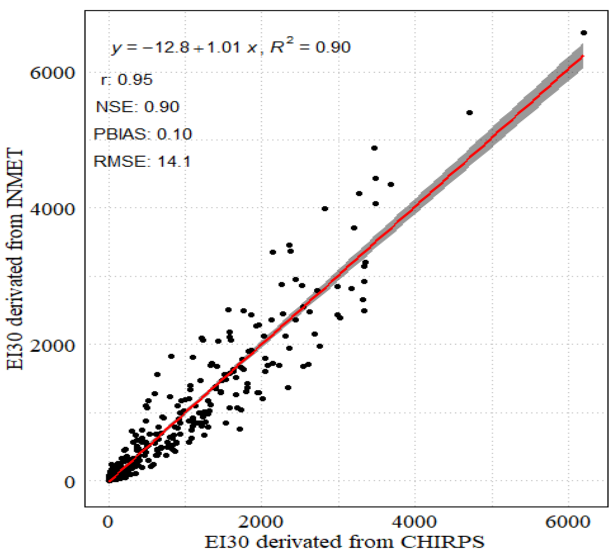

Figure 7. Monthly EI obtained from INMET data versus the EI estimated from CHIRPS data (1991-2021).

The Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.90, classified as good (=>0.90), and the Root Mean Squared Error (RMSE) was 14.1, indicating a good accuracy. These results showed that the EI obtained from CHIRPS data correlates well with the EI obtained from INMET data. In Figure 8 it is presented the average spatio-temporal variation of the annual EI observed in the municipality of Catalão-GO, obtained from CHIRPS data (1991-2021).

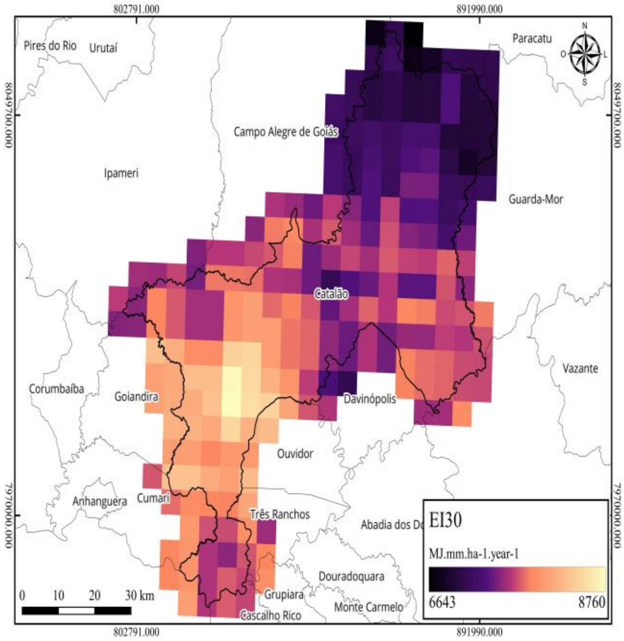

Figure 8. Annual average EI obtained from CHIRPS data to municipality of Catalão-GO (1991-2021).

In Figure 8, note that the average annual EI showed values with a spatial variation between 6643 and 8760 $MJ.mm.ha^{-1}.year^{-1}$. Note that the southern, southeastern, western and center-east regions of the municipality recorded the highest annual EI values. In these areas the terrain is predominantly undulating (slope 8-20%), characterized by low altitudes (between 520-560 metres) and a dense occurrence of river valleys. Latossolos, Cambissolos and Argissolos are the predominant soil classes.

In these areas, land uses related to agricultural and livestock activities predominate. On the other hand, the lowest values it is recorded in the center-north of the municipality, where the highest altitudes of the terrain occur.
The highest altitude recorded is 960m, occurring on a plateau. Other areas with high altitudes occurs in the northeast of the municipality, associated with ferruginous detrital-lateritic cover and the Canastra Group - Chapada dos Pilões Formation. In general, the slope of the terrain in these areas is predominantly flat, with the occurrence of Neossolos and Latossolos, the latter used intensively in agricultural activities (Silva and Rosa, 2019).

In Figure 9 it is presented the patterns of the monthly average spatio-temporal variation of the EI observed in the municipality of Catalão-GO, obtained from CHIRPS data (1991-2021). We identified that between November and all the months of the Wet Season (December, January, February and March), the highest EI values are concentrated in the south, southeast, west and center-east regions of the municipality. Between the Begeing of Dry Season and during the Dry Season, the highest EI values are significantly lower than those observed during the Wet

Season, concentrated in the north, northeast and east of the municipality.

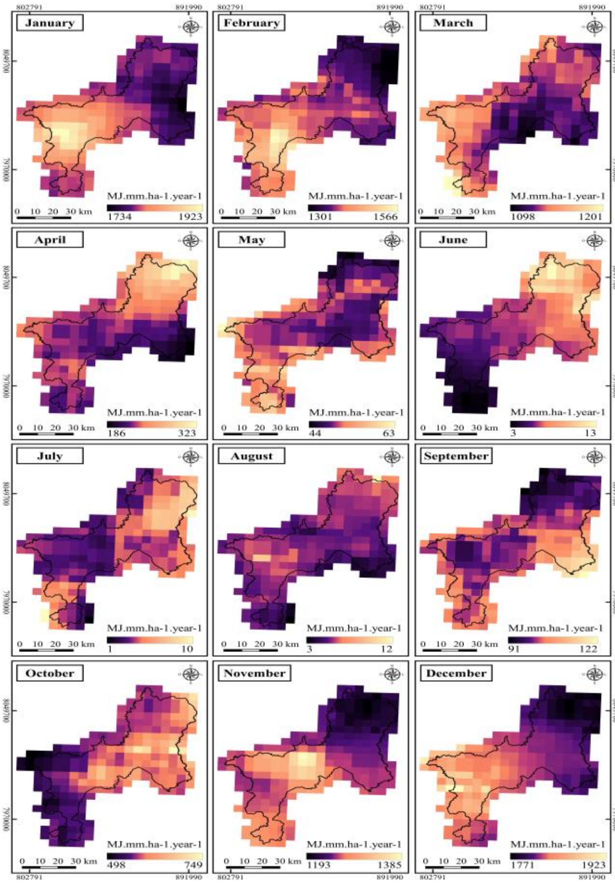

Figure 9. Monthly average EI obtained from CHIRPS data to municipality of Catalão-GO (1991-2021).

4. Conclusions

In this study, we demonstrate the potential of data from the CHIRPS algorithm, an open source dataset widely used by the community, with global coverage and a grid of 5 km, to retrieve rainfall erosivity index. The main aim of this work was to evaluate the EI relationships based on CHIRPS and INMET data in the municipality of Catalão-GO, that is located in one of the world's largest agricultural frontiers, the Brazilian Cerrado. The results found indicated that the CHIRPS data it is an alternative for calculating EI in the context of municipality of Catalão, southeast region of Goiás state, from a previous stage for statistical validation with surface data from INMET. It was observed that the EI derived from CHIRPS data does not differ significantly from the EI obtained from surface measurements made available by INMET, establishing a similar pattern in the time series analysed (1990-2021).

From the regression analysis between the EI obtained from both datasets, we obtained a trend percentage (PBIAS) of 0.10, indicating good performance (=<10%). A Pearson correlation coefficient (r) of 0.95 was observed, demonstrating the high correlation of the IE derived from CHIRPS data with the IE derived from INMET data, and the coefficient of determination (R^2) showed a good quality fit with 0.90. The Nash-Sutcliffe Efficiency Coefficient (NSE) was 0.90, classified as good (=>0.90), and the Root Mean Square Error (RMSE) was 14.1, indicating good accuracy. These results show that, for the municipality of Catalão-GO, the EI obtained from CHIRPS data correlated well with the EI obtained from INMET data.

In general, the results found, presented and discussed corroborate with the results findings in the literature, and are in line with other studies carried out more recently in the context of the southeast region of Goiás. We highlight that EI is very important data for territorial planning, as it corroborates the implementation of sustainable practices in productive areas with intensive land use by agricultural activities. From the spatialization of the CHIRPS data, we can see that the results show the southern, southeastern, western and center-east regions of the municipality recorded the highest annual EI values. This pattern of high EI values was also identified at the beginning and during the Wet Season.

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References

Alves, W. S., Cabral, J. B. P., Nascimento, D. T. F., 2023: Influências do El Niño Oscilação Sul (ENOS) e da Oscilação Decenal Do Pacífico (ODP) na variabilidade dos totais anuais de chuva em Goiás e no Distrito Federal. *Caminhos de Geografia*, v. 24, p. 321-338. https://doi.org/10.14393/RCG249567458.

Alves, W. S., Martins, A. P., Morais, W. A., Pôssa, M., Castro, R. M., de Moura, D. M. B., 2022: USLE Modelling of Soil Loss in a Brazilian Cerrado Catchment. *Remote Sensing Applications: Society and Environment*. v.27, n.1, p.1-17. https://doi.org/10.1016/j.rsase.2022.100788.

Amundson, R., Berhe, A. A., Hopmans, J. W., Olson, C., Sztein, A. E., Sparks, D. L., 2015: Soil and human security in the ^{2}1st century. *Science*, n.348, v.1261071, p.1-12. https://doi.org/10.1126/science.1261071.

Bertol, I. 1994: Avaliação da erosividade da chuva na localidade de Campos Novos (SC) no período de 1981 a 1990. *Pesquisa Agropecuária Brasileira*. v.29, n.9, p.1453-1458. https://encr.pw/BKVJX.

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. V., Montanarella, L., Panagos, P., 2017: An assessment of the global impact of ^{2}1st century land use change on soil erosion. *Nature*, v.8, n.2013, p. 1-13. https://doi.org/10.1038/s41467-017-02142-7.

Browning, T. N., Sawyer, D. E., 2021: Vulnerability to watershed erosion and coastal deposition in the tropics.

Scientific Reports, n.11, v.885, p.1-11, 2021. https://doi.org/10.1038/s41598-020-79402-y.

Cogo, N. P., Moldenhauer W. C., Foster, G. R., 1984: Soil loss reductions from conservation tillage practices. *Soil Science Society of America Journal*, v.1, n.2, p.1-18. https://doi.org/10.2136/sssaj1984.03615995004800020029x.

Colodro, G., Carvalho, M. P., Roque, C. G., Prado, R. M., 2002: Erosividade da chuva: distribuição e correlação com a precipitação pluviométrica de Teodoro Sampaio (SP). *Revista Brasileira de Ciências do Solo*, v.26, n.1, p.809-818. https://doi.org/10.1590/S0100-06832002000300027.

Costa, J. C., Pereira, G., Siqueira, M. E., Cardozo, F. S., Silva, V. V., 2019: Validação dos dados de precipitação estimados pelo CHIRPS para o Brasil. *Revista Brasileira de Climatologia*, v. 24, n.2, p.1-16. https://encr.pw/DC2yw.

Costa, Q. S., Nascimento, D. T. F., Luz, M. P., 2023: Avaliação da erosividade entre anos-padrão habitual e excepcional: insumo para o diagnóstico do aporte de sedimentos para os reservatórios das usinas hidrelétricas Batalha e Itumbiara (Brasil). *Ciência Geográfica*, v.27, n.2, p.973-982. https://doi.org/10.5016/estgeo.v20i2.17174.

Dedecek, R. A., 1988: Fatores de erosividade da chuva, enxurrada e perdas de solo sob condições de Cerrado. *Pesquisa Agropecuária Brasileira*, n. 23, v. 12, p. 1431-1438. https://encr.pw/7uUcB.

Fernández-Raga, M., Palencia, C., Keesstra, S., Jordán, A., Fraile, R., Angulo-Martínez, M., Cerdà, A., 2017: Splash erosion: A review with unanswered questions. *Earth-Science Reviews*, v.171, n.2, p.463-477. https://doi.org/10.1016/j.earscirev.2017.06.009.

Food and Alimentacion Organization (FAO), 1980. La erosión del suelo por el agua: Algunas medidas para combatir la en la tierras de cultivo. Cuadernos de fomento agropecuário de la Organización de Las Naciones Unidas, Rome, Italy.

Food and Agriculture Organization (FAO), 2011. FAO in the 21st Century: Ensuring Food Security in a Changing World, Rome, Italy.

Food and Agriculture Organization (FAO), 2015. Status of the World's Soil Resources (SWSR)-Main Report; Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Guerra, A. J. T., 1995. Processos Erosivos nas Encostas. In: Geomorfologia: uma atualização de bases e conceitos. (Orgs). Guerra, A. J. T.; Cunha, S. B., Bertrand Brasil, Rio de Janeiro.

Intergovernmental Panel on Climate Change (IPCC), 2021. Climate Change 2021: The Physical Science Basis. Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cam-bridge, United Kingdom and New York, USA.

Koch, A., Mcbratney, A., Adams, M., Field, D., Hill, R., Crawford, J., Minasny, B., Lal, R., Abbott, L., O'donnell, A., Angers, D., Baldock, J., Barbier, E., Binkley, D., Parton, W., Wall, D. H., Bird, M., Bouma, J., Chenu, C., Flora, C. B., Goulding, K., Grunwald, S., Hempel, J., Jastrow, J., Lehmann, J., Lorenz, K., Morgan, C. L., Rice, C. W., Whitehead, D., Young, I., Zimmermann, M., 2013: Soil security: Solving the global soil crisis. *Global Policy*, n.4, v.4, p.434-441. https://doi.org/10.1111/1758-5899.12096.

Kim, J., Han, H., Kim, B., Chen, H., Lee, J. H., 2020: Use of a high-resolution-satellite-based precipitation product in mapping continental-scale rainfall erosivity: A case study of the United States. *CATENA*, v.193, n.2, p.1-17. https://doi.org/10.1016/j.catena.2020.104602.

Lombardi Neto, F., Moldenhauer, W. C., 1992: Rainfall erosivity - its distribution and relationship with soil loss at Campinas, state of São Paulo, Brazil. *Bragantia*, v.51, n.2, p. 189-196. https://doi.org/10.1590/S0006-87051992000200009.

Makhtoumi, Y., Abbasi, A., Seyedmakhtoom, B., Ibeanusi, V., Chen, G., 2023: Evaluating soil loss under land use management and extreme rainfall. *Journal of Contaminant Hydrology*, v. 256, n.1, p. 1-17. https://doi.org/10.1016/j.jconhyd.2023.104181.

Medeiros, G. F., Luiz, G. C., Romão, P. A., Sales, M. M., Luz, M. P., 2024: Estimativa e espacialização da Erosividade no entorno do reservatório da UHE Batalha (GO/MG) com base em dados pluviométricos. *GEO-UERJ*, v.44, n.1, p.1-28. https://doi.org/10.12957/geouerj.2024.74561.

Minella, J. P. G, Merten, G. H., Reichert, J. M., Santos, D. R., 2007: Identificação e Implicações para conservação do solo das fontes de sedimentos em bacias hidrográficas. *Revista Brasileira de Ciência do Solo*, v.31, n. 6, p. 1637-1643. https://doi.org/10.1590/S0100-06832007000600039.

Nascimento, D. T. F., Oliveira, I. J., 2018: Aplicação das estimativas de precipitação do Tropical Rainfall Measuring Mission (TRMM) no estudo da pluviometria habitual e excepcional de Goiás e Distrito Federal. *Revista Brasileira de Geografia Física*, v. 11, n.2, p. 1664-1679. https://doi.org/10.26848/rbgf.v11.5.p1664-1679.

Nascimento, D. T. F., Romão, P. De A., Sales, M. M., 2018: Erosividade e erodibilidade ao longo de dutovia cortando os estados de Minas Gerais e Goiás - Brasil. *Ateliê Geográfico*, v.12, n.1, p.97-117. https://doi.org/10.5216/ag.v12i1.46152.

Nogueira, S. M. C., Moreira, M. A., Volpato, M. M. L., 2018: Evaluating Precipitation Estimates from Eta, TRMM and CHRIPS Data in the South-Southeast Region of Minas Gerais State - Brazil. *Remote Sensing*. v.10, n.313, p.1-16. https://doi.org/10.3390/rs10020313.

Oliveira, L. F. C.; Fioreze, A. P.; Medeiros, A. M. M.; Silva, M. A. S., 2010: Comparação de metodologias de preenchimento de falhas de séries históricas de precipitação pluvial anual. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v.14, n.11, p.1186-1192. https://l1nq.com/fb5WJ.

Oliveira, P. T., Wendland, S. E., Nearing, M. A., 2013: Rainfall erosivity in Brazil: A review. *CATENA*, n.1, v.100, p.139-147. https://doi.org/10.1016/j.catena.2012.08.006.

Robichaud, P. R., Brown, R. E., 2002. Silt Fences: An Economical Technique for Measuring Hillslope Soil Erosion; RMRS-GTR-94; U.S. Department of Agriculture, Forest

Service, Rocky Mountain Research Station: Ft. Collins, CO, USA.

Silva, M. L. N., De Freitas, P. L., Blancaneaux, P., Curi, N., 1997: Índice de erosividade das chuvas da região de Goiânia, GO. *Pesquisa Agropecuária Brasileira*. v.32, n.1, p.977-985. https://acesse.dev/Fb6V7.

Silva, A. S., Rosa, R., 2019: Mapa de capacidade e potencial do uso da terra do município de Catalão (GO). *Caderno de Geografia*, v.29, n.59, p.954-977. https://doi.org/10.5752/P.2318-2962.2019v29n59p954.

Souza at. al., 2020: Reconstructing Three Decades of Land Use and Land Cover Changes in Brazilian Biomes with Landsat Archive and Earth Engine. *Remote Sensing*, v. 12, n. 17, p.1-27. https://doi.org/10.3390/rs12172735.

Steinhoff-Knopp, B., Kuhn, T. K., Burkhard, B., 2021: The impact of soil erosion on soil-related ecosystem services: development and testing a scenario-based assessment approach. *Environmental Monitoring and Assessment*, n.193, v.274, p.1-18. https://doi.org/10.1007/s10661-020-08814-0.

Zhu, X., Yuan, X., Lu, E., Yang, B., Wang, H., Du, H., Singh, A. K., Liu, W., 2023: Soil splash erosion: An overlooked issue for sustainable rubber plantation in the tropical region of China. *International Soil and Water Conservation Research*, v.11, n.1, p.30-42. https://doi.org/10.1016/j.iswcr.2022.05.005.

Wischmeier, W. H., Smith, D. D., 1979. Predicting rainfall erosion losses: a guide to conservation planning. Department of Agriculture, Science and Education Administration: Washington, DC, USA.

Zhao, Y., Zhu, D., Wu, Z., Cao, Z., 2024: Extreme rainfall erosivity: Research advances and future perspectives. *Science of The Total Environment*, v. 917, n.1, p. 1-16. https://doi.org/10.1016/j.scitotenv.2024.170425.

Zolin, C. A., Matos, E. S., Magalhães, C. A. S., Paulino, J., Lal, R., Spera, S. T., Behling, M., 2021: Short-term effect of a crop-livestock-forestry system on soil, water and nutrient loss in the Cerrado Amazon ecotone. *Acta Amazônica*, v.51, n.1, p.102-112. https://doi.org/10.1590/1809-4392202000391.