ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.9, p.655-661, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n9p655-661

Natural erosion potential in the Mato Grosso state, Brazil[1]

Potencial natural de erosão no Estado de Mato Grosso, Brasil

Luis A. Di L. Di Raimo[2], Ricardo S. S. Amorim[3], Eduardo G. Couto[4], Maria O. Hunter[2], Gilmar N. Torres[2], Edwaldo D. Bocuti[2] & Lucas de C. M. da Silva[3*]

[1] Research developed at Universidade Federal de Mato Grosso, Cuiabá, MT, Brazil
[2] Universidade Federal de Mato Grosso/Programa de Pós-Graduação em Agricultural Tropical, Cuiabá, MT, Brazil
[3] Universidade Federal de Viçosa/Departamento de Engenharia Agrícola, Viçosa, MG, Brazil
[4] Universidade Federal de Mato Grosso/Departamento de Solos e Engenharia Rural, Cuiabá, MT, Brazil

HIGHLIGHTS:
The Mato Grosso state predominantly has medium natural erosion potential.
High natural erosion potential was associated with steep slope areas.
Areas with current agricultural use and high natural erosion potential should be monitored.

ABSTRACT: Understanding the susceptibility of soils to erosion is crucial for planning land use towards sustainable agriculture. This study aimed to determine the spatial variability of natural erosion potential for the state of Mato Grosso, an important agricultural center of Brazil. Natural erosion potential was calculated using the Universal Soil Loss Equation, which accounts for erosivity, erodibility, and the topographic factor. For each of these three factors, a map was generated in raster format that was combined into a Geographic Information System and used to create a map of natural erosion potential. This map was then used to separate classes of natural erosion potential for the state of Mato Grosso. The state predominantly has medium levels of natural erosion potential (58.38% in area), followed by high (21.67%) and low (19.57%) levels. Areas of low natural erosion potential are predominantly located in the flatter sections of the state. The topographic factor was strongly correlated with natural erosion potential. It is an important component to support land use planning and soil conservation practices. Regions considered to have high natural erosion potential are most commonly in the northwest (46.69% in area), north (32.7%), and west (30.05%) macro-regions.

Key words: soil conservation, soil loss, erosivity, erodibility, USLE

RESUMO: O entendimento da suscetibilidade de solos à erosão é crucial para o planejamento de uso da terra visando uma agricultura sustentável. O estudo teve como objetivo determinar a variabilidade espacial do potencial natural de erosão para o Estado de Mato Grosso, um importante centro agrícola do Brasil. O potencial natural de erosão foi calculado usando a Equação Universal de Perda de Solo, que considera a erosividade, erodibilidade e o fator topográfico. Para cada um desses três fatores foi criado um mapa em formato raster, que foi combinado em um Sistema de Informação Geográfica e usado para criar o mapa de potencial natural de erosão. O mapa foi, então, utilizado para separar classes do potencial natural de erosão para o Estado de Mato Grosso. O Estado predominantemente apresentou níveis médios de potencial natural de erosão (58,38% da área), seguido por altos (21,67%) e baixos (19,57%) níveis. As áreas de baixo potencial natural de erosão estão predominantemente localizadas nas partes mais planas do Estado. O fator topográfico apresentou forte correlação com o potencial natural de erosão, sendo um importante componente para auxiliar o planejamento do uso da terra e práticas de conservação do solo. Regiões consideradas com maiores potenciais naturais de erosão são mais comuns nas macrorregiões noroeste (46,69% da área), norte (32,7%) e oeste (30,05%).

Palavras-chave: conservação do solo, perda de solo, erosividade, erodibilidade, EUPS

• Ref. 259913 – Received 10 Jan, 2022
* Corresponding author - E-mail: lucas.c.moreira@ufv.br
• Accepted 24 Apr, 2022 • Published 12 May, 2022
Editors: Lauriane Almeida dos Anjos Soares & Carlos Alberto Vieira de Azevedo

Introduction

Natural erosion is a component of processes such as soil genesis and landscape formation. Nevertheless, soil erosion can be accelerated by human activities, leading to several environmental, agricultural, and socioeconomic impacts. Accelerated erosion compromises the sustainability of agricultural activities, given that highly eroded areas may become unusable (Du et al., 2022).

The Universal Soil Loss Equation (USLE), proposed by Wischmeier & Smith (1978), is widely used to predict soil losses by water erosion, considering the following factors: rainfall erosivity (R), soil erodibility (K), topography (LS), soil use and management (C) and soil conservation techniques (P). Within the factors considered in USLE, only C and P include human interventions. Therefore, when R, K, and LS are considered alone, it can be assumed to be the natural erosion potential (NEP) (Silva et al., 2011; Durães & Mello, 2016).

NEP can support decision making processes, mainly regarding land use planning (Silva et al., 2011). Identifying areas more prone to erosion guides public policies towards soil and water conservation (Polidoro et al., 2021) and also guides land adaptation aimed at respecting land use capability (Taveira et al., 2021). Especially in the Mato Grosso state, where agricultural production and deforestation pressure is significant, NEP determination can guide the adoption of cropping systems aimed at combining high yields with erosion mitigation (Silva et al., 2021). Previous studies have calculated NEP within Brazil (e.g., Silva et al., 2011; Cunha et al., 2017). However, there is still a gap in the details for critical areas, such as the Cerrado highlands and Pantanal basin, which are important agricultural areas within the Mato Grosso state.

The Mato Grosso state is a very important agricultural center for Brazil. It leads in the national production of soybean, maize, cotton, and beef. Concurrently, significant land use changes and high rates of deforestation and soil losses have been observed within the state (Barbosa et al., 2018; Zolin et al., 2021), requiring careful attention. In this context, the objective of this study was to determine the spatial variability of natural erosion potential (NEP) for the state of Mato Grosso, Brazil.

Material and Methods

The study was carried out in the state of Mato Grosso, the central western region of Brazil (Figure 1). Mato Grosso has an approximate area of 93 million hectares with a predominant climate classification of Aw (following Köppen). The relief is characterized by large planar surfaces located on plateaus and in Pantanal (Salgado et al., 2015). The main soil classes are Oxisols, Ultisols, or Entisols, which cover most of the state.

The spatial variability of natural erosion potential (NEP) was estimated using the Universal Soil Loss Equation (USLE), shown in Eq. 1, which calculates mean annual soil loss (PS, t ha^{-1} per year) as a function of five factors: rainfall erosivity index (R, MJ mm ha h^{-1} per year), soil erodibility (K, Mg ha h^{-1} ha^{-1} MJ^{-1} mm^{-1}), topographic factor (LS), cropping factor (C), and conservation practice factor (P).

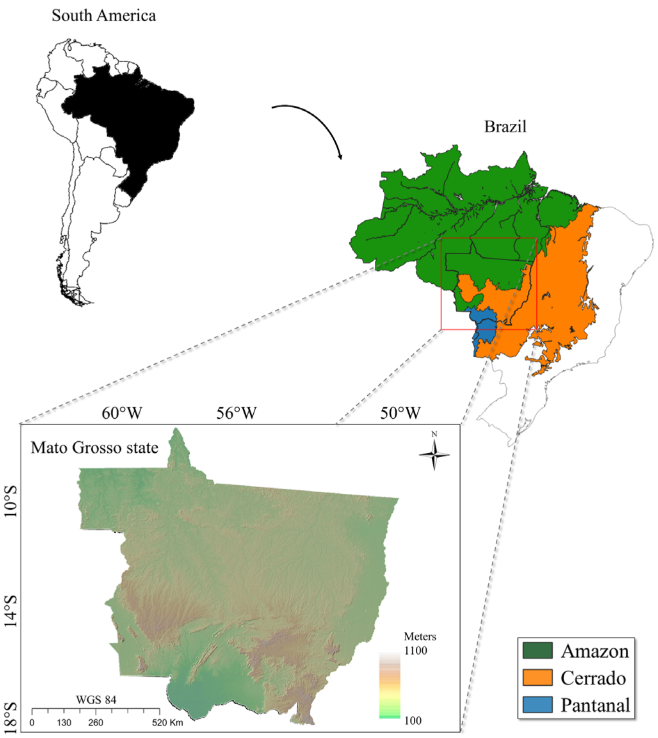

Figure 1. Localization and altimetry of Mato Grosso state, Brazil

$$PS = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

The rainfall erosivity index (R) map used in this study (Figure 2A) was first presented in Di Raimo et al. (2018) and is based on erosivity estimates from 158 pluviometric stations within the Mato Grosso state. These estimates were calculated using the equations proposed by Almeida et al. (2012), and they are based on estimates of the rainfall coefficient (R_c) from 10 pluviographic stations within the state. The selection criteria for the best estimate of R for each of the 158 pluviometric stations was adapted from the methodology described in Oliveira et al. (2012a), accounting for the distance between stations and the correlation between their rainfall characteristics. Data interpolation was performed using geostatistical methods, following the principles of spatial dependence (Di Raimo et al., 2018).

The erodibility (K) map (Figure 2B) was initially presented in Di Raimo et al. (2019), and it is based on 427 soil profiles distributed throughout the state of Mato Grosso. For each soil profile, erodibility was calculated following the equations proposed by Wischmeier & Smith (1978) and Denardin (1990). To determine which equation was best for each soil profile, estimated values were compared with literature values specific to field experiments within the same soil class. Data interpolation was performed using geostatistical methods, following the principles of spatial dependence (Di Raimo et al., 2019).

The topographic factor (LS) map (Figure 2C) was calculated using Eq. 2, as published by El Jazouli et al. (2017). It is based on calculations of flow accumulation and slope. Flow accumulation is a raster image map of accumulated flow to each pixel from neighbor cells based on the direction of their slope.

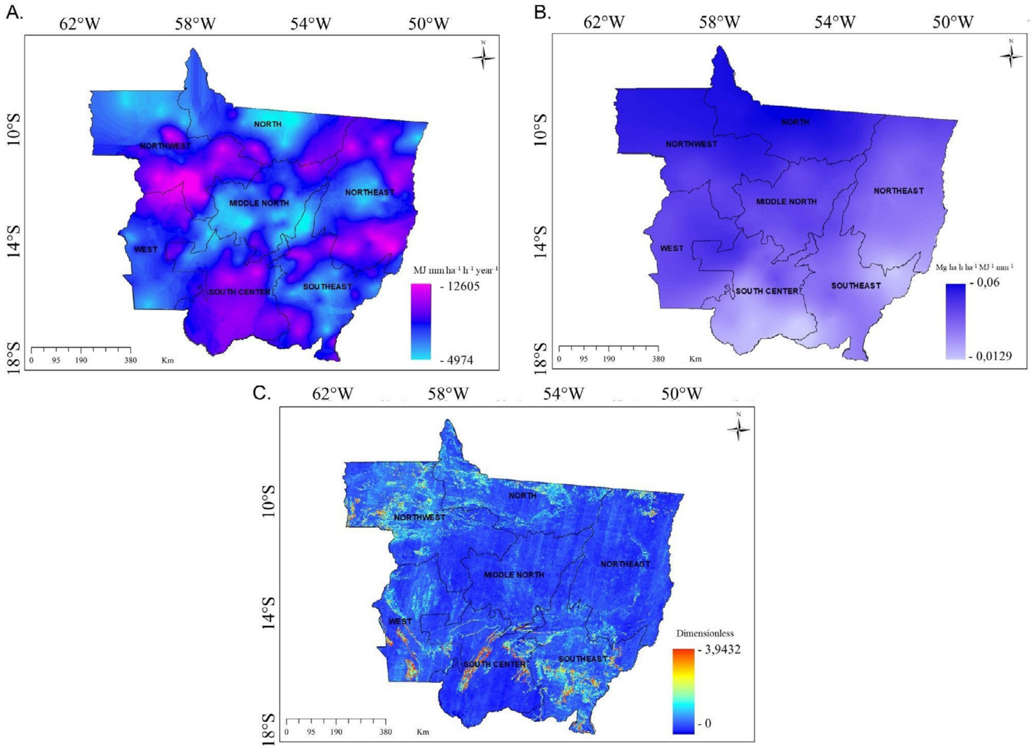

Figure 2. Maps of (A) rainfall erosivity, R, (B) soil erodibility, K, and (C) the topographic factor, LS, for the state of Mato Grosso, Brazil

$$LS = \left(\frac{FA \cdot PS}{22.1}\right)^{0.4} \left(\frac{\sin(s) \cdot 0.01745}{0.09}\right)^{1.4} \tag{2}$$

where:

FA - flow accumulation raster;
PS - pixel size; and,
s - slope.

In this study, unit values of 1 were assigned to parameters C and P, simulating the hypothetical situation of no land cover and no soil conservation practices. The remaining USLE parameters (R, K and LS) were obtained for the entirety of the Mato Grosso state. By applying USLE in this manner, the natural erosion potential (NEP) was estimated for the area of interest.

The NEP map was generated following Eq. 1, as the product of R, K, and LS maps, and the classes were set according to Table 1. To determine the most influential factors at the state and macro-region levels, linear correlations between NEP and R, K, and LS factors were calculated using the “rasterCorrelation” function of the package “SpatialEco” in R (Evans, 2019).

To determine regionally isolated events or critical situations, the state of Mato Grosso was divided into seven macro-regions (northwest, north, northeast, middle north, west, central south, and southeast) as proposed by IMEA (2016). In addition, the main uses and activities developed in each of the macro-regions, also described in IMEA (2016), were considered for characterization of critical areas.

Table 1. Natural erosion potential (NEP) classes, as presented by Cabral et al. (2005)

NEP Class	NEP Range (t ha^{-1} per year)
Low	< 100
Medium	100 > PNE ≤ 200
High	200 > PNE ≤ 600
Very High	> 600

Results and Discussion

Spatial variability of NEP for the Mato Grosso state is presented in Figure 3, and the proportional area by class in Table 2. The majority of Mato Grosso state is classified within the medium class, covering 58.38% of the state. Regions with critical levels of NEP, including the high and very high classes, together account for 22.05% of the state, with 21.67 and 0.38% respectively.

Low NEP areas occupy 19.57% of the state. They are concentrated in the middle north, northeast, southeast, and central south macro-regions, matching with the planar regions of Pantanal, the Cuiabá Lowlands, and the plateaus of Parecis and Guimarães (Figure 3). Medium and high NEP areas, with their greater extents, embrace considerable areas of all macro-regions within the state. Areas with very high PNE are concentrated in the northeast, west, and south center macro-regions, occurring according to the high values of the topographic factor (LS) which is attributed to the high slopes present in the contours and escarpments of the Parecis

Table 2. Proportion of Mato Grosso state by natural erosion potential (NEP) class

NEP class (t ha^{-1} per year)	Area (ha)	Percentage	Accumulated percentage
Low	18,219,884.40	19.57	19.57
Medium	54,348,885.20	58.38	77.95
High	20,179,325.10	21.67	99.62
Very High	351,905.30	0.38	100.00
Total	93,100,000	100	-

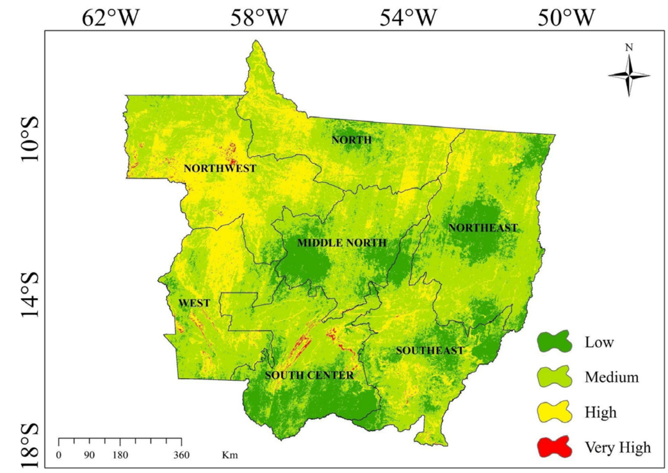

Figure 3. Spatial variability of natural erosion potential (NEP) within the state of Mato Grosso

and Guimarães plateaus, Province Serrana, and Chapada de Dardanelos.

Considering the NEP mapping within Brazil, Silva et al. (2011) found values similar to those presented in this study, with higher levels of NEP concentrated in the northeast and west and lower values in flatter regions. However, despite the similar distribution of values, Silva et al. (2011) found a larger extent of high NEP values as compared to these results. This is due to the lower resolution of maps of R, K, and principally the topographic factor, LS, as shown by Wu et al. (2005).

Linear correlation coefficients between NEP and individual USLE factors (R, K and LS) are in Table 3 at both the state and macro-region levels. Firstly, it is highlighted that only positive correlation values were obtained, since R, K and LS are directly proportional to the NEP values. The correlation between NEP and LS was the strongest for the state of Mato Grosso and for the individual macro-regions. In general, factor K showed low correlation with NEP values, with the exception of the middle north region, likely due to the strong presence of Oxisols which have low erodibility and are strongly associated with gentle slopes.

Within the three factors, R showed the least influence on NEP values. This low correlation can be attributed to the homogeneity of this factor across the state (Figure 2A), when compared to the other USLE factors. Factors K and LS are

Table 3. Linear correlation values, for Mato Grosso state and its macro-regions, between natural erosion potential (NEP) and the contributing factors: erosivity (R), erodibility (K), and the topographic factor (LS)

Region	Correlation of factors		
	NEP × R	NEP × K	NEP × LS
Mato Grosso	0.29	0.24	0.69*
Northwest	0.03	0.27	0.61*
North	0.17	0.43*	0.52*
Northeast	0.24	0.50*	0.59*
Middle North	0.15	0.69*	0.63*
Southeast	0.16	0.34*	0.67*
Central South	0.25	0.05	0.83*
West	0.23	0.32*	0.73*

Correlation

0 0.5 1

* - Significant correlations at $p \leq 0.05$

spatially more heterogeneous (as observed in Figures 2B and C), leading to a stronger influence on the variability of NEP, especially over short distances. Although correlation values between R and NEP are low, the R factor clearly presents a large influence over erosive processes in the state, principally in the west, northeast and north regions, where erosivity values are generally greater than 8000 MJ mm ha^{-1} h^{-1} per year, or highly erosive (Oliveira et al., 2012b). It is noteworthy to state that the homogeneity is compared to other more heterogeneous factors, as high differences in rainfall are recorded within the state. For example, there is more than 2500 mm of annual rainfall in northern Amazon regions and less than 1500 mm of annual rainfall in southern regions of Pantanal and Cerrado biomes.

Figure 4 illustrates the percentage of area occupied within each class of NEP for each macro-region. The pie and bar graphs indicate, respectively, the percentages and frequencies of NPE values in each macro-region. In the northeast and north regions, the predominant classes are medium and high NEP, covering approximately 95% of these regions. High NEP classes account for 46.69 and 32.70% of these regions, respectively.

Elevated values of NEP in the northwest and north regions of Mato Grosso state are due to a combination of high values of R and LS factors, in agreement with the results observed by Durães & Mello (2016) who studied a watershed in the Minas Gerais state, Brazil. Nevertheless, it is noteworthy that LS had the strongest influence on NEP when compared to the R factor, as already discussed and shown in Table 3. The elevated R in these macro-regions occurs due to the frequent and intense convective rains of the Amazon biome and high rainfall indices generated by the marked presence of the continental equatorial mass (Mello et al., 2013). The high values of the topographic factor LS occur due to the steep relief that characterizes these regions (Vieira et al., 2015). According to Rodrigues et al. (2011), LS has a large influence on the definition of highly erodible areas, with both a high and significant influence, which also supports these results. In this study, the spatial correlation between NEP and LS in the northeast and north regions was 0.61 and 0.52, respectively.

Despite large areas with high NEP in the northwestern and northern macro-regions, these areas are not extremely vulnerable to erosive processes because they are predominantly forested or covered with dense savanna or pasture (IMEA, 2016) which provide protection for the soil surface (Rodrigues et al., 2011; Cunha et al., 2017). Regions with forest or dense savanna coverage have low risk of erosion as they are constantly vegetated. In areas used for livestock, as long as they are not degraded, soil erosion is low due to the high density of grass stems and roots which reduce the intensity of floods and increase the resistance of soil particles to the shear stress of water (Bertoni & Lombardi Neto, 2017). However, it is noteworthy that given the elevated levels of NEP in the north and northeast regions, degraded pastures and recently cleared areas for annual crops may show high levels of soil loss (Cunha et al., 2017).

In the middle-north region, medium and low classes of NEP were the most common, with proportions of 60.7 and 31.09%, respectively (Figure 4). The predominance of low erosion susceptibility in the middle-north region is validated by

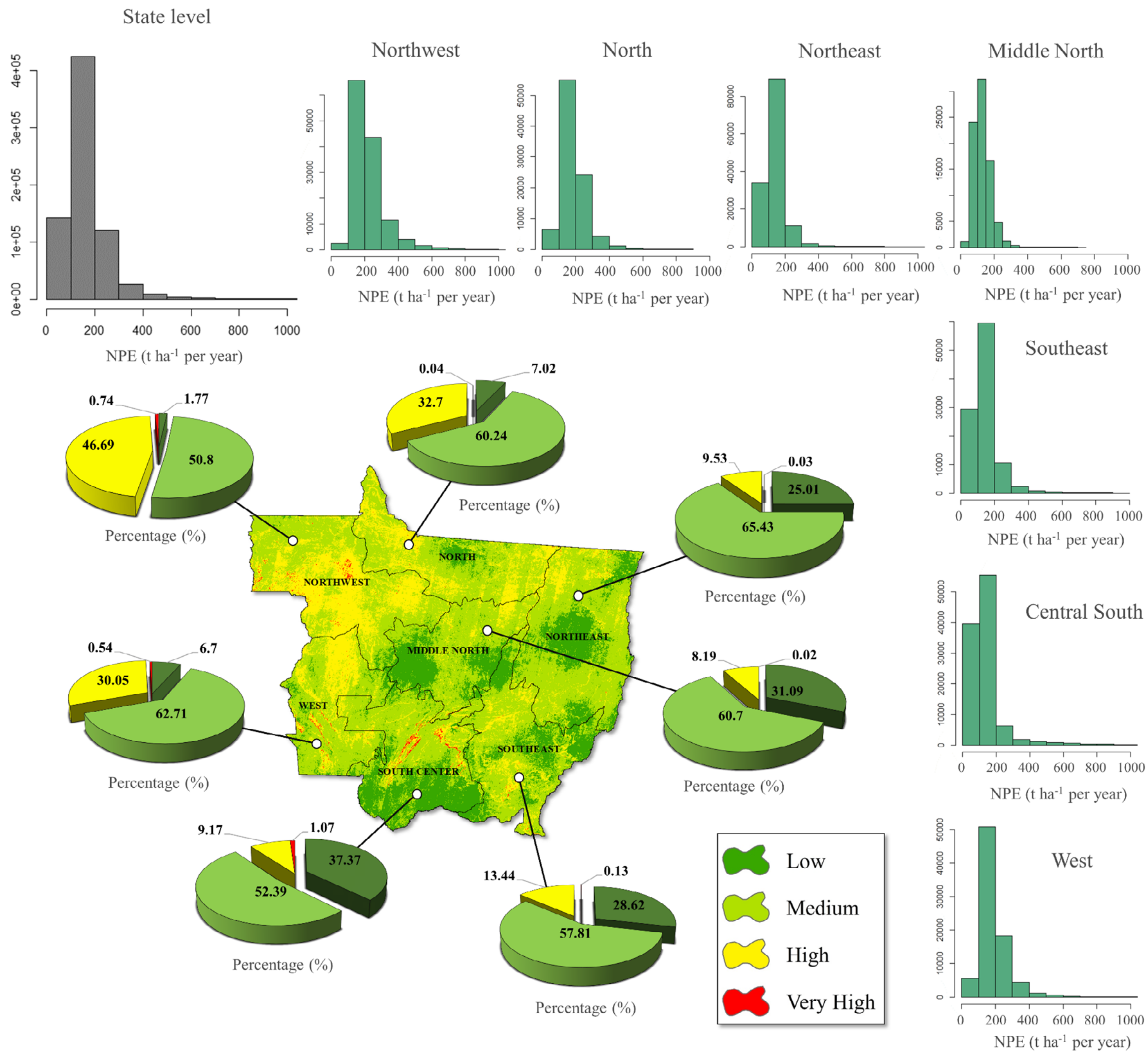

Figure 4. Percentages of Mato Grosso macro-regions occupied by each class and frequency of values of natural erosion potential (NEP)

the study from Zolin et al. (2021), in which the authors found 16 Mg ha^{-1} of soil loss when monitoring bare soil during the rainy season. R values are high in this region, similar to the northeast and north, but the lower NEP compared to those regions is due to low values of LS and K, as shown by the high correlation with these factors in Table 3. The low level of LS in this region is predominantly due to the gentle slopes, whereas the low level of K is due to the Oxisols, which commonly have high permeability and low risk of soil erosion. Also, they are strongly associated to plateau regions (Salgado et al., 2015; Silva et al., 2021).

Although the middle-north region has predominantly low levels of NEP, the concentration of annual crops (IMEA, 2016) requires the implementation of soil conservation activities. According to Peixoto et al. (2020), mechanized processes used for annual crops increase the probability of erosion because they induce soil compaction, surface sealing, and consequently increased runoff. Processes that could minimize erosion, such as minimum tillage, no-tillage, crop rotation, and limiting tillage operations to proper soil moisture conditions, should be recommended for these areas.

The northeast region of the state is marked by different soil uses (IMEA, 2016). In the southern part of this region, annual crops are predominant, while in the east, livestock is more common, and the native forests of the Amazon biome are present in the north. As seen in Figure 3, the areas within this region that intensively used for agriculture are on the south side, within areas with low and medium NEP, similar to those in the middle-north region where conservation techniques are necessary to control erosion.

Similar to the northeast, the southeast region is also characterized by several patterns of land use. The northern part of the region is dominated by annual crops, with medium levels of NEP. In the east, livestock is more common, and in the west, sugarcane. In the center of this region, livestock and agriculture both occur together. Within the southeast macro-region, 60% of its territory was classified as medium NEP. In general, the northern region requires the most attention, due to the strong presence of annual crops.

In the South-Center region, the differences between the north and south potions are visually different (Figure 3). The south side shows predominantly low levels of NEP and is principally devoted to livestock (IMEA, 2016). The confluence of low-risk activities with low levels of NEP characterizes areas with low vulnerability to erosion. In the north side, medium and high classes of NEP are most common, and the region is used for a wide variety of products, including annual crops, sugarcane and livestock (IMEA, 2016). In the case of annual crops, erosion mitigation practices are required, especially in areas with high NEP. In general, areas under sugarcane and pasture are less risky compared to annual crops such as maize and soybeans, as they can produce greater soil cover providing greater protection to soil surface most of the time (Silva et al., 2021; Tabriz et al., 2021). In the off-season cultivation of sugarcane, soil coverage is dependent on the maintenance of plant residues (green cane harvesting techniques). In areas under grass crops, the high biomass production can control erosion and enhance soil functions, depending on crop systems management (Merlo et al., 2022).

Approximately 30% of the west region shows high levels of NEP and is considered at critical risk for erosion (Figure 4). These areas of critical NEP coincide with municipalities recognized as great producers of annual crops (such as Sapezal and Campos de Júlio), and they should be monitored to evaluate the annual soil loss.

Areas with high NEP, including the aforementioned municipalities of Campos de Júlio and Sapezal, have high values for all contributing factors (R, K and LS). For these regions, constant surface cover is recommended throughout the year, e.g., by inclusion of cover crops. This can reduce the erosive action of raindrops directly on the soil surface (Bertoni & Lombardi Neto, 2017). It could also reduce erodibility by allowing the cementation of soil particles which caused by the decomposition of organic matter (Parwada & Van Tol, 2017). Furthermore, the conservation practices can reduce the kinetic energy of surface runoff, due to energy dissipation through the friction between the water and the soil coverage (Bertoni & Lombardi Neto, 2017).

Conclusions

1. The Mato Grosso state is dominated by medium levels of natural erosion potential (58.38%), with low and high NEP areas occupying 19.57 and 21.67% of the state's area, respectively.

2. Areas of low natural erosion potential are predominantly located in the flatter sections of the state.

3. The topographic factor was strongly correlated with NEP and is an important component to support land use planning and soil conservation practices.

4. High levels of natural erosion potential are concentrated in the northwest (46.69% in area), north (32.7%), and west (30.05%) macro-regions.

Acknowledgements

We would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the first author scholarship. The authors declare that there are no conflicts of interest regarding the publication of this paper.

Literature Cited

Almeida, C. O. S.; Amorim, R. S. S.; Eltz, F. L. F.; Couto, E. G.; Jordani, S. A. Erosividade da chuva em municípios do Mato Grosso: distribuição sazonal e correlações com dados pluviométricos. Revista Brasileira de Engenharia Agrícola e Ambiental, v.16, p.142-152, 2012. https://doi.org/10.1590/S1415-43662012000200003

Barbosa, S. G.; Spletozer, A. G.; Roque, M. P. B.; Ferreira Neto, J. A.; Dias, H. C. T.; Ramos, M. P.; Bonilla, M. A. C.; Ribeiro, W. S.; Alcántara-de la Cruz, R.; Zanuncio, J. C. Geotechnology in the analysis of forest fragments in northern Mato Grosso, Brazil. Scientific reports, v.8, p.1-7, 2018. https://doi.org/10.1038/s41598-018-22311-y

Bertoni, J.; Lombardi Neto, F. Conservação do solo. 9.ed. São Paulo: Ícone, 2017. 1450p.

Cabral, J. B. P.; Becegato, V. A.; Scopel, I.; Lopes, R. M. Uso de técnicas de geoprocessamento para mapear o potencial natural de erosão da chuva na bacia hidrográfica do reservatório de Cachoeira Dourada GO/MG. Raega-O Espaço Geográfico em Análise, v.10, p.107-116, 2005. http://dx.doi.org/10.5380/raega.v10i0.4982

Cunha, E. R. da; Bacani, V. M.; Panachuki, E. Modeling soil erosion using RUSLE and GIS in a watershed occupied by rural settlement in the Brazilian Cerrado. Natural Hazards, v.85, p.851-868, 2017. https://doi.org/10.1007/s11069-016-2607-3

Denardin, J. E. Erodibilidade de solo estimada por meio de parâmetros físicos e químicos. Piracicaba: USP-ESALQ, 1990. 81p.

Di Raimo, L. A. D. L.; Amorim, R. S. S.; Couto, E. G.; Nóbrega, R, L, B.; Torres, G. N.; Bocuti, E, D.; Almeida, C, O, S.; Rodrigues, R. V. Spatio-temporal variability of erosivity in Mato Grosso, Brazil. Revista Ambiente & Água, v.13, p.1-14, 2018. https://doi.org/10.4136/ambi-agua.2276

Di Raimo, L. A. D. L.; Amorim, R, S, S.; Torres, G. N.; Bocuti, E. D.; Couto, E. G. Variabilidade espacial da erodibilidade no estado de Mato Grosso, Brasil. Revista de Ciências Agrárias, v.42, p.55-67, 2019. https://doi.org/10.19084/RCA18122

Du, X.; Jian, J.; Du, C.; Stewart, R. D. Conservation management decreases surface runoff and soil erosion. International Soil and Water Conservation Research, v.10, p.188-196, 2022. https://doi.org/10.1016/j.iswcr.2021.08.001

Durães, M. F.; Mello, C. R. de. Distribuição espacial da erosão potencial e atual do solo na Bacia Hidrográfica do Rio Sapucaí, MG. Engenharia Sanitária e Ambiental, v.21, p.677-685, 2016. https://doi.org/10.1590/S1413-41522016121182

El Jazouli, A.; Barakat, A.; Ghafiri, A.; El Moutaki, S.; Ettaqy, A.; Khellouk, R. Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco). Geoscience Letters, v.4, p.1-12, 2017. https://doi.org/10.1186/s40562-017-0091-6

Evans, J. S. spatialEco. R package version 1.2-0, 2019 https://github.com/jeffreyevans/spatialEco

IMEA, Mapa de macrorregiões do IMEA (2016) Available on: <http://www.imea.com.br/upload/publicacoes/arquivos/justificativamapa.pdf>. Accessed on: Oct. 2016.

Mello, C. R. de; Viola, M. R.; Beskow, S.; Norton, L. D. Multivariate models for annual rainfall erosivity in Brazil. Geoderma, v.202, p.88-102, 2013. https://doi.org/10.1016/j.geoderma.2013.03.009

Merlo, M. N.; Avanzi, J. C.; Silva, L. de C. M da.; Aragão, O. O. da S.; Borghi, E.; Moreira, F. M. de S.; Thebaldi, M. S.; Resende, A. V. de; Silva, M. L. N.; Silva, B. M. Microbiological Properties in Cropping Systems and Their Relationship with Water Erosion in the Brazilian Cerrado. Water, v.14, p.1-15, 2022. https://doi.org/10.3390/w14040614

Oliveira, P. T. S.; Rodrigues, D. B. B.; Alves Sobrinho, T.; Carvalho, D. F. de; Panachuki, E. Spatial variability of the rainfall erosive potential in the State of Mato Grosso do Sul, Brazil. Engenharia Agrícola, v.32, p.69-79, 2012a. https://doi.org/10.1590/S0100-69162012000100008

Oliveira, P. T. S.; Wendland, E.; Nearing, M. A. Rainfall erosivity in Brazil: A review. Catena, v.100, p.139-147, 2012b. https://doi.org/10.1016/j.catena.2012.08.006

Parwada, C.; van Tol, J. Soil properties influencing erodibility of soils in the Ntabelanga area, Eastern Cape Province, South Africa. Acta Agriculturae Scandinavica, Section B, Soil & Plant Science, v.67, p.1-10, 2017. https://doi.org/10.1080/09064710.2016.1220614

Peixoto, D. S.; Silva, L. de C. M. da; Melo, L. B. B. de; Azevedo, R. P.; Araújo, B. C. L.; Carvalho, T. S. de; Moreira, S. G.; Curi, N.; Silva, B. M. Occasional tillage in no-tillage systems: A global meta-analysis. Science of the Total Environment, v.745, p.1-14, 2020. https://doi.org/10.1016/j.scitotenv.2020.140887

Polidoro, J. C.; Freitas, P. L. de; Hernani, L. C.; Anjos, L. H. C. dos; Rodrigues, R. de A. R.; Cesário, F. V.; Andrade, A. G. de; Ribeiro, J. L. Potential impact of plans and policies based on the principles of conservation agriculture on the control of soil erosion in Brazil. Land Degradation & Development, v.32, p.3457-3468, 2021. https://doi.org/10.1002/ldr.3876

Rodrigues, D. B. B.; Alves Sobrinho, T.; Oliveira, P. T. S. de; Panachuki, E. Nova abordagem sobre o modelo Brasileiro de serviços ambientais. Revista Brasileira de Ciência do Solo, v.35, p.1037-1045, 2011. https://doi.org/10.1590/S0100-06832011000300037

Salgado, A. A. R.; Bueno, G. T.; Diniz, A. D.; Marent, B. R. Long-term geomorphological evolution of the Brazilian territory. In: Vieira, B. C.; Salgado, A.; Santos, L. Landscapes and landforms of Brazil. Netherlands: Springer, p.19-31, 2015. https://doi.org/10.1007/978-94-017-8023-0_3

Silva, A. M. da; Watanabe, C. H.; Alvares, C. A. Natural potential for erosion for Brazilian territory. In: Godone, D.; Stanchi, S. (eds.) Soil erosion studies. London: IntechOpen, 2011. p.3-24.

Silva, L. de C. M. da; Avanzi, J. C.; Peixoto, D. S.; Merlo, M. N.; Borghi, E.; Resende, Á. V. de; Acuña-Guzman, S. F.; Silva, B. M. Ecological intensification of cropping systems enhances soil functions, mitigates soil erosion, and promotes crop resilience to dry spells in the Brazilian Cerrado. International Soil and Water Conservation Research, v.9, p.591-604, 2021. https://doi.org/10.1016/j.iswcr.2021.06.006

Tabriz, S. S.; Kader, M. A.; Rokonuzzaman, M.; Hossen, M. S.; Awal, M. A. Prospects and challenges of conservation agriculture in Bangladesh for sustainable sugarcane cultivation. Environment, Development and Sustainability, v.23, p.15667-15694, 2021. https://doi.org/10.1007/s10668-021-01330-2

Taveira, L. R. S.; Weindorf, D. C.; Menezes, M. D. de; Carvalho, T. S. de; Motta, P. E. F. da; Teixeira, A. F. dos S.; Curi, N. Land use capability classification adaptation in low and intermediate technology farming systems: A soil erosion indicator. Soil Use and Management, v.37, p.164-180, 2021. https://doi.org/10.1111/sum.12555

Vieira, B. C.; Salgado, A. A. R.; Santos L. J. C. Brazil: A land of beautiful and undiscovered landscapes. In: Vieira, B. C.; Salgado, A.; Santos, L. Landscapes and landforms of Brazil. Netherlands: Springer, 2015. p.3-7. https://doi.org/10.1007/978-94-017-8023-0_1

Wischmeier, W. H.; Smith, D. D. Predicting rainfall erosion losses: A guide to conservation planning. Washington: United States Department of Agriculture, 1978. 58p.

Wu, S.; Li, J.; Huang, G. An evaluation of grid size uncertainty in empirical soil loss modeling with digital elevation models. Environmental Modeling & Assessment, v.10, p.33-42, 2005. https://doi.org/10.1007/s10666-004-6595-4

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