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ANALYSIS OF THE EROSION POTENTIAL AND SEDIMENT YIELD USING THE INTERO MODEL IN AN EXPERIMENTAL WATERSHED DOMINATED BY KARST IN BRAZIL

SUMMARY

Soil losses from water erosion jeopardize agricultural sustainability and food security for current and future generations. The research aimed to evaluate the application of the Erosion Potential Method by the Intensity of Erosion and Outflow – IntErO program in a karst watershed in a region with typical savanna climate in the northeast of the State of Goiás, Brazil. Input data were adapted according to the corresponding characteristics of tropical regions. The results indicated that the Extreme watershed has a value of 0.62 in the index (0 to 1) which defined the strength of the intensity of erosion. The river basin belongs to the category 3 of destruction with moderate erosion intensity, which indicates processes of surface erosion in the largest area of the hydrographic basin, and annual soil loss of 480.60 m^3 km^2 yr^{-1}. According to the IntErO model calculations 16% of the eroded material reaches the outflow of the hydrographic basin, and 84% of these sediments are deposited within the Basin, inside the surface and underground caves and galleries of the karst. Calculations by the IntErO model with the Erosion Potential Method in its algorithm proved to be valuable tool in evaluating the production of sediments in tropical soils, especially in evaluating different scenarios after establishing the inputs database for Brazil and will serve as a good starting point for future evaluations.

Key words: Karst Hydrology, Erosion Potential Method, IntErO model, Soil Conservation, Sedimentology.

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INTRODUCTION

Soil is a finite natural resource that takes thousands of years to mature. Its sustainability is essential for the production of food and many other ecosystem goods and services, including climate regulation and nutrient cycling (Greiner *et al.*, 2017). However, with the current developments in erosion, urbanization and climate change, impacts that promote the reduction of its surface layers (more fertile) become a risk for current and future generations (Parsipour *et al.*, 2019; Curovic *et al.*, 2019; Spalevic *et al.*, 2020).

Water erosion is a natural process, subject to intensification according to the uses and managements adopted in agriculture. The process initiated by the impact of the raindrop breaks particles from the structure of the soil's surface layer, causing loss of arable soils and accumulation of sediments in the lower regions (EMBRAPA, 2013).

The erosion rate generally increases when the volume and velocity of surface water runoff occurs on steeper terrain with longer slope length. The adoption of conservation practices that ensure maximum vegetation cover and reduction in slope length, especially on steeper slopes and intensive cultivation, are essential to ensure the agricultural and environmental sustainability of terrestrial ecosystems (FAO, 2015). Hydrographic basins are ideal for evaluating the impacts of the intensification of water erosion processes, as it is a system with open water inlets and outlets for precipitated water, which can be drained or infiltrated. (Dyonisio, 2010).

In karst basins, Palmer (1984) draws attention to the importance of genetic aspects, especially in the hydrological bias, which shape the surface forms (lapias, canyons), the subsoil (porous medium), the vadose zone (free and gravitational flow), and the water table, with emphasis on recharge aspects (autochthonous, allochthonous). In groundwater systems, the transport of autochthonous and allochthonous sediments through conduits can imply high speeds and ascending water table, depending on the width of the underground channels (shape of the conduits), which can promote rapid flooding above the vadose or limited zone in confined flow networks (Caldeira *et al.*, 2019). Among the fine suspended material (silt, clay and sand) the fine sand particles are more easily transported, which explains the presence of sandy sedimentary fans in caves dominated by mud and gravel (Gillieson, 1996).

In this aspect, Karst systems are sensitive to small changes in land use, such as activities that promote soil erosion, siltation of rivers and pollution of the karst aquifer, which must be mitigated in order not to increase the damage caused to karst systems. Thus, the present study aims to quantify and evaluate the application of the indirect model of Intensity of Erosion and Runoff - IntErO (Spalevic, 2011), which uses equations of the Erosion Potential Method of Gavrilovic (1962; 1972, 1988). This model has been applied in basins all over the world: Greece (Efthimiou *et al*, 2016), Iran (Mohammadi *et al*, 2021; Khaledi Darvishan *et al.*, 2019; Gholami *et al.*, 2016; Behzadfar *et al.*, 2014), Morocco (Ouallali *et al.*, 2020; El Mouatassime *et al.*, 2019), Montenegro (Spalevic *et al.*, 2020; Spalevic *et al.*, 2016; Spalevic *et al.*, 2014; Spalevic *et al.*, 2012), Nepal (Chalise *et al.*, 2019) but also in Brazil recently (Sakuno *et al.*, 2020; Tavares *et al.*, 2019; Lense *et al.*, 2019).

Based on the characteristics of the hydrographic basin, the program estimates the production of annual sediments associated with the intensification of water erosion at the basin scale. Such results can be useful as an indication of areas with imminent potential risk of increasing rates of soil loss from arable areas, river siltation and aquifer and surface water pollution.

MATERIAL AND METHODS

Study Area

The karst river basin of the Extrema River has an area of 27.8 km², and a rainfall regime of 1,164 mm yr^{-1}, and is located in the northeast of Goiás State, Midwest Region, Brazil (Figure 1).

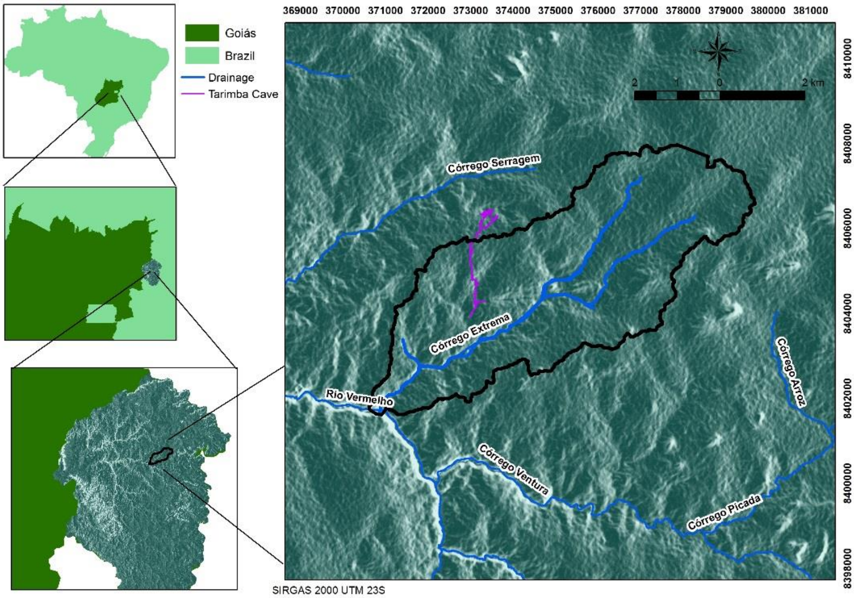

Figure 1: Location of the karstic watershed of the Extrema River with shaded relief effect.

The geomorphology surrounding the Extrema River basin is composed of the Central Chapadão (upper portion), originating from the South American surface that constitutes the Urucuia Group, formed by sandstones that present unconsolidated siliciclastic sediments, and the lower portion (Vão do Paranã) with intercalated pelitic rocks to the carbonates of the Lagoa do Jacaré Formation (Bambuí Group). In the "Lagoa do Jacaré" Formation clastochemical sediments (carbonate rocks) are favorable to karstification.

According to the Köppen-Geiger climatic classification, the climate is type tropical with dry winter (Aw) (Cardoso *et al.*, 2014). Over the past few decades, tropical savannas worldwide have been among the most affected biomes by the suppression of native vegetation. The dry season and the deficiency of phosphorus and other nutrient minerals in the very old soils do not favor forest development, giving rise to landscapes consisting mainly of grasslands with sparse or isolated trees (Walter and Breckle, 1986). Therefore, environmental changes resulting from human activities in these ecosystems pose threats to both biodiversity and climate.

With the increasing exchange of native vegetation for pastures, added to the natural savanna climate, erosion processes are intensified in rainfall events, resulting in surface runoff with a large volume of sediment that is transported to underground channels and galleries in the karst. As it represents the classical dynamics of the fluviocarstic system in the region, the Extrema River whatershed is an area with densification of karstic features that act as recharge areas through wide and distributed fractures and convections in sinks and underground flows.

In Strahler's (1957) hierarchical classification, the Extrema River configures a first-order level with a pattern of dendritic basin, with quick response to precipitation. At lower altitudes, between the domain of carbonates and siliciclastic sediments, karstic depressions occur with intensified erosive processes, from which there is capture of surface runoff by fractures and/or collapsed sinkholes, generating the accumulation of sediments in some caves above the level of base.

One hypothesis is that upper layers in adjacent caves contribute to the sediment carried by the underground flow in the Extrema cave. Possibly, the main source of sediment production in floods comes from the Tarimba cave (Figure 2), which has thick layers of preserved sedimentary rocks and a permanent flow in its interior. Another hypothesis is that the sediments originate from areas of upstream sinks, with the Tarimba cave acting as an underground stream that transports the sediments.

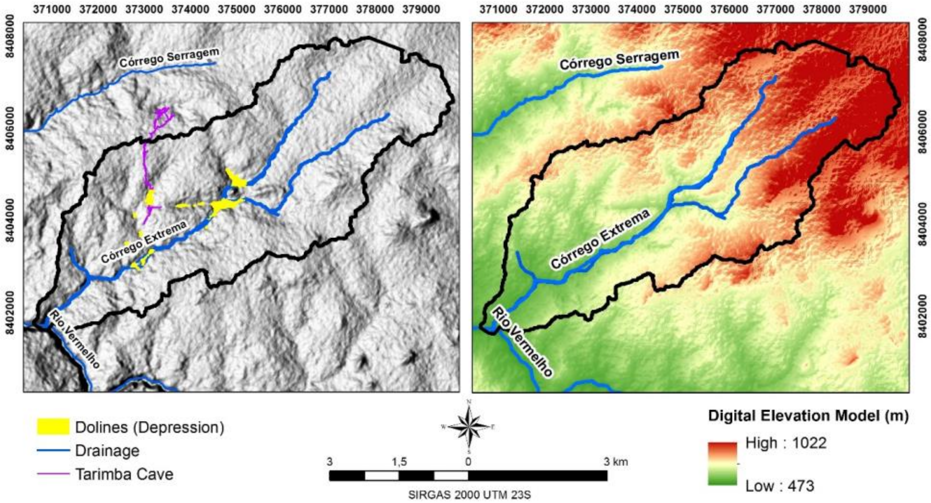

Figure 2: Depressions and connections of underground flows (Tarimba Cave) for the Extreme flow, and digital elevation model (m).

IntErO Model Application and EPM

The Intensity of Erosion and Outflow (IntErO) program package of Spalevic (2011) is based on Erosion Potential Method (EPM) of Gavrilovic (1962; 1972, 1988). The EPM is an empirically-based model that estimates soil loss and water erosion intensity determining factors that directly affect the rates of soil loss from water erosion at the scale of watersheds, such as land slope, soil resistance, field erosion, soil use and management, temperature and precipitation (Gavrilovic, 1988).

The calculations of the EPM model parameters are performed in an automatic form, in the compilation of the input data in the IntErO program. Spalevic (2011) proposed the creation of a database with twenty-six entries, including erosion, geometric, topographical, meteorological data, maximum flow and drainage system characteristics, integrating the EPM model parameters simultaneously (Table 1).

Table 1: Input data for the IntErO in Extrema watershed.

Inputs	**Amount and Unit**
River basin areas (F)	27.80 km²
The length of the watershed (O)	37.09 km
The area of the bigger river basin part (F_v)	14.08 km²
The area of the smaller river basin part (F_m)	13.72 km²
Natural length of the main watercourse (L_v)	7.57 km
Length of the contours/isohyets (L_{iz})	115.34 km
Altitude of the first contour line (h_0)	580 m
Incidence (Up)	100 yr
The lowest river basin elevation (H_{min})	579 m
The highest river basin elevation (H_{max})	854 m
River basin consisted of a very permeable product (f_p)	0.74
A part of the basin consisted of medium permeable rocks (f_{pp})	0.26
A part of the basin with poor water permeability rocks (f_0)	0
A part of the river basin under forests (f_s)	0.30
A part under grass, meadows, pastures, and orchards (f_t)	0.65
A part of the basin under plough-land, and without grass (f_g)	0.05
The length of the main watercourse with tributaries I & II class	9.91 km
The distance between the fountainhead and mouth (L_m)	6.79 km
The volume of the torrent rain (h_b)	50 mm
Average annual air temperature (t_0)	26° C
Average annual precipitation (H_{yr})	1,164 mm

Soil loss (W_{yr}) in the EPM model is estimated by Equation 1. Its algorithms are incorporated in the IntErO application (Spalevic, 2011), which calculates in an automated way, avoiding errors in manual modeling.

$$W_{yr} = T \cdot H_{yr} \cdot \pi \cdot \sqrt[2]{Z^3} \cdot R_u$$ Equation 1

Where: W_{yr} is total sediment production (m^3 yr^{-1}); T is temperature coefficient (dimensionless); H_{yr} is mean precipitation (mm yr^{-1}); π is the value of 3.14; Z is erosion coefficients (dimensionless); F is watershed area (km^2).

The temperature coefficient (T) is calculated according to Equation 2.

$$T = \sqrt[2]{\frac{t_0}{10}} + 0{,}1$$ Equation 2

Where: T is temperature coefficient (dimensionless); t_0 is average air temperature (°C yr^{-1}).

The erosion coefficient (Z) is obtained by Equation 3:

$$Z = Y \cdot X_a \cdot (\varphi + \sqrt[2]{I_{sr}})$$ Equation 3

Where: Y is soil resistance to water erosion (dimensionless); X_a is land use and management (dimensionless); φ is degree of erosion on the ground (dimensionless); I_{sr} is average slope of the watershed (%).

The values of the Z coefficient classified according to the degree of erosion intensity (Table 2)

Table 2: The degree of erosion intensity (Z)

Categories	Erosion intensity	Erosion Coefficient (Z)	Average of Z
I	Very severe	$Z > 1.0$	$Z = 1.25$
II	Severe	$0.71 < Z < 1.00$	$Z = 0.85$
III	Moderate	$0.41 < Z < 0.70$	$Z = 0.55$
IV	Weak	$0.20 < Z < 0.40$	$Z = 0.30$
V	Very weak	$Z < 0.19$	$Z = 0.10$

RESULTS AND DISCUSSION

Gavrilovic (1972) prepared tables with values that represent the attributes (Y, X_a, φ) needed to calculate the erosion coefficient Z (Dragicevic *et al.*, 2016; 2017). However, the model was initially applied in temperate climate regions, being necessary to adapt the values according to the characteristics of Brazilian tropical soils (Sakuno *et al.*, 2020) (Figure 3).

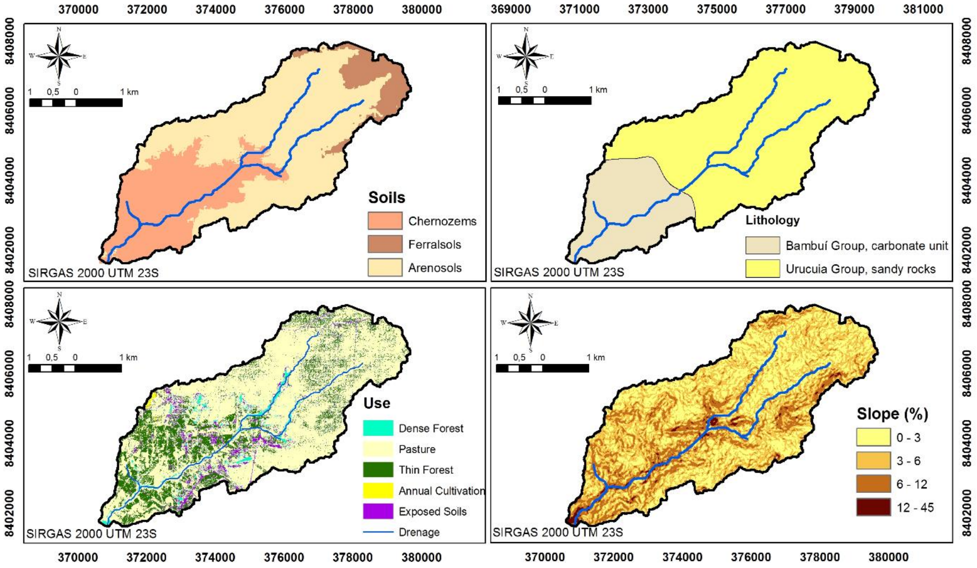

Figure 3: Cartographic base of soils, land use, lithology, and slope of the Extrema River watershed to obtain the Y, X_a and φ factors.

The coefficients of the river basin form (A), average river basin width (B) and watershed development (m) were calculated to be 0.95, 9.32 km, and 0.41, respectively. The value of peak discharge, with a return interval of 100 years (Q_{100}) and for a land use setup of 2021 resulted to 38.94 $m^3 s^{-1.}$

The drainage density of the study river basin (G) we calculated as 0.36, what indicates that there is a low density of the hydrographic network. The factor G is an important affecting the flood hydrograph and erosion process. The index of average decline to be 8.30% shown that in the studied watershed mild slopes prevail. The Z coefficient value of 0.626 indicates that the river basin belongs to destruction category III. The resistance to the erosion process is medium, where the surface erosion is predominant.

The production of erosion material (W yr^{-1}) in the Extrema watershed was calculated to be 81,927.2284 m^3 yr^{-1} and the coefficient of the deposit retention (Ru) resulted in 0.163. This means that 16% of the total eroded material reaches the exit point, while the remaining 84% é deposited in irregularities of the relief inside the watershed, in the hydrological drainage system, caves and underground galleries. Calculated real soil losses per year per square kilometer for the river basin amounts to 480.60 m^3 km^2 yr^{-1}, corresponds to the results obtained in 2021.The detailed report for the hydro morphological parameters is shown in Table 3.

Table 3: Outputs data for the IntErO in Extrema watershed.

Outputs		Amount and Unit
Coefficient of the river basin form	A	0.95
Coefficient of the watershed development	m	0.41
Average river basin width	B	9.32 km
(A)symmetry of the river basin	a	0.03
Density of the river network of the basin	G	0.36
Coefficient of the river basin tortuousness	K	1.12
Average river basin altitude	H_{sr}	634.36 m
Average elevation difference of the river basin	D	55.36 m
Average river basin decline	I_{sr}	8.30 %
The height of the local erosion base of the river basin	H_{leb}	275.00 m
Coefficient of the erosion energy of the river basin's relief	E_r	38.12
Coefficient of the region's permeability	S_1	0.48
Coefficient of the vegetation cover	S_2	0.75
Analytical presentation of the water retention in inflow	W	0.6537 m^{-3}
Energetic potential of water flow during torrent rains	$(2gDF)^{1/2}$	173.76 m km s^{-1}
Maximal outflow from the river basin	Q_{100}	38.94 $m^3\ s^{-1}$
Temperature coefficient of the region	T	1.64
Coefficient of the river basin erosion	Z	0.626
Production of erosion material in the river basin	W yr^{-1}	81,927.2284 $m^3\ yr^{-1}$
Coefficient of the sediment retention	Ru	0,163
Real soil losses	G yr^{-1}	13,360.31 $m^3\ yr^{-1}$
Real soil losses per km^2	G $yr^{-1}\ km^2$	480.60 $m^3\ km^2\ yr^{-1}$

CONCLUSIONS

In the last three decades, the forest area has decreased with the replacement of native vegetation for the production of pastures in the northeast region of Goiás State, Brazil. This change in land cover increases the risks to water erosion, especially in sensitive areas of karstic watersheds. The accumulation of the annual production of sediments is demonstrated through deposits inside the caves of the watersheds in the region. Studies on the origin and fate of these sediments must be carefully monitored to understand the hydrosedimentological behavior of karst systems in tropical climates. This study analyzed some factors and processes that are associated with soil losses and the production of sediments by water erosion, serving as an important indicator of areas at risk of accelerated erosion, and must be constantly evaluated and monitored. The application of the IntErO model demonstrated that the removal of sediments by water erosion in the Extreme River watershed belongs to the 3rd category of destruction (Z = 0.62), which is classified as medium degree. Finally, it is important to emphasize that climate change can increase soil erosion and sediment production processes in extreme rainfall events, which are increasingly common in tropical regions, which requires such processes to be evaluated annually. It is strongly recommended that this approach be considered when planning public monitoring policies.

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