Assessment of Soil Losses by Erosion in a Karst Environment in the Cerrado Biome of Brazil

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Abstract

This work aimed to estimate the volume of soil losses due to water erosion in a watershed dominated by karst features, which results in the quantity of sediment directed to the caves in the region. The Corrente river watershed is located in the Northeast region of the State of Goiás, Brazil. Through the Potential Erosion Method (EPM) applied in the Geographic Information System, soil losses were quantified for the year 2021. The estimated average soil loss was 26.41 to/ha/year-1, with a maximum flow of 10,689,083.57 to/year-1 in the watershed outlet. The limits of the catchment, producing sediments to the caves were obtained, which allowed extracting an average estimate of transported sediments in these karst regions.

Résumé

Ce travail visait à estimer le volume des pertes de sol dues à l'érosion hydrique dans un bassin hydrographique dominé par des caractéristiques karstiques, ce qui se traduit par la quantité de sédiments dirigée vers les grottes de la région. Le bassin hydrographique de la rivière Corrente est situé dans la région nord-est de l'État de Goiás, au Brésil. Grâce à la méthode d'érosion potentielle (EPM) appliquée dans le système d'information géographique, les pertes de sol ont été quantifiées pour l'année 2021. La perte de sol moyenne estimée était de 26,41 to/ha/an^{-1}, avec un débit maximum de 10 689 083,57 to/an^{-1} en l'exutoire du bassin versant. A partir des limites des micro-bassins versants, ou zones productrices de sédiments, des zones de convergence vers les grottes ont été obtenues, ce qui a permis d'extraire une estimation moyenne des sédiments transportés dans ces régions karstiques.

Resumo

Esse trabalho visou estimar o volume das perdas de solo por erosão hídrica em uma bacia hidrográfica dominada por feições cársticas, que resulta no quantitativo de sedimentos direcionados para as cavernas da região. A bacia hidrográfica do rio Corrente está localizada na região Nordeste do Estado de Goiás, Brasil. Por meio do Método de Erosão Potencial (EPM) aplicado em Sistema de Informação Geográfica, foram quantificadas as perdas de solo para o ano de 2021. A perda de solo média estimada foi de 26,41 to/ha/year^{-1}, com vazão máxima de 10.689.083,57 to/year^{-1} no exutório da bacia. A partir dos limites das micro-watersheds, ou áreas produtoras de sedimentos, foram obtidas áreas de convergência para as cavernas, que permitiu extrair uma estimativa média de sedimentos transportados nessas regiões cársticas.

1. Introduction

In Brazil, karst makes up between 5 and 7% of the territory, and yet studies on hydrology and karst sedimentology are scarce (KARMANN, 2016). However, the karst evolution processes through superficial and underground flow networks carry relevant information about the type, quantity and quality of the transported material, revealing aspects of the functioning of the karst aquifer in the transport of sediments.

It is known that the degree of development of the karst relief forms varies according to the characteristics of the climate, vegetation and the type of source material. The characteristics of forms, surface and underground, have already been widely elucidated in the literature (PALMER, 1984, JENNINGS, 1985, FORD & WILLIAMS, 2007, HARDT, 2011).

In Brazil, the karst relief gains special importance in the Cerrado biome, where native vegetation is the most affected by suppression among other biomes in Brazil. Allied

to this, the deficiency of phosphorus and other nutrient minerals in some soils does not favor forest development and allows the origin of landscapes consisting mainly of pastures with sparse trees (BRECKLE, 2002). As a result, erosive processes become more and more intensified during rainfall, contributing to a large volume of sediment that is transported to underground channels and karst galleries.

The sources and types of dendritic sediments are varied, as the material is pedogenized on the surface, or alluvial sediments, or epiphreatic mud, or insoluble residues, or suspended solids and organic deposits. Deposition zones are seen in widened fractures, abysses, sinks, internal subsidence, flooded gallery networks and back-flooding (LAUREANO & KARMANN, 2013). These zones of autochthonous and allochthonous sediment transport can imply high speeds and rise of the water table, which can promote rapid flooding above the vadose zone (CALDEIRA et al., 2019). Thus, the preservation of speleological heritage involves the need to delimit the areas that produce sediment, since inadequate land management and the replacement of native vegetation accelerate erosion processes, increasing the amount of sediment in rivers and caves.

Therefore, in order to assess soil loss and sediment production due to water erosion, this study used a watershed dominated by karst features in the Brazilian Cerrado biome, in which an extremely active process of underground karstification and relief dissection occurs. To quantify the sediments directed to the caves, the Potential Erosion Method (EPM) was used, which quantifies the loss of soil by erosion.

2. Materials and methods

The Corrente River watershed (3,824 km2) belongs to the Tocantins River basin, located in the northeast of the State of Goiás, Brazil. The upper portion (Highlands) is formed by sandstones (Urucuia Group) that constitute unconsolidated siliciclastic sediments, while the lower portion (Karst Terrains) has pelitic rocks intercalated with carbonates (Bambuí Group). The area with densification of karstic features acts as recharge areas through fractures and large convections distributed in sinks and underground flows. About 47 cavities with perennial flows were identified (Fig. 1). The climate is tropical with dry winter (Aw), with an average of 1,165 mm/year-1 (CARDOSO et al., 2014).

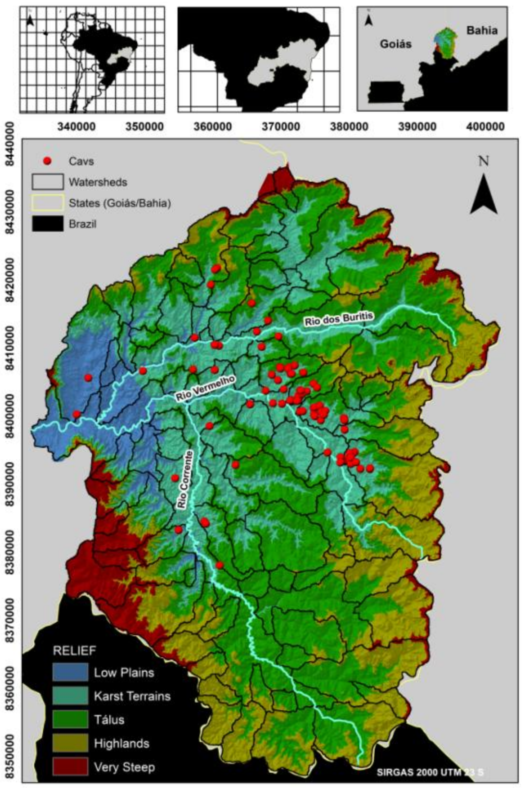

Figure 1: Stream river basin and mappe caves.

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 or collapsed sinks, generating the accumulation of sediments in some caves above the base level.

- Erosion Potential Method (EPM)

The EPM is an empirically-based model that estimates soil loss and the determinants of water erosion intensity, which directly affect soil loss rates at the scale of watersheds, such as soil slope, soil strength, erosive features , land use and management, air temperature and precipitation (GAVRILOVIC, 1988).

Soil loss (Wyr) in the EPM model is estimated by Equation 1.

$$W_{yr} = T * H_{yr} * \varphi * \sqrt[2]{Z^3} \qquad \textbf{Eq. 1}$$

Where: Wyr = total sediment production (m^3 yr^{-1}); T = temperature coefficient (dimensionless); Hyr = mean precipitation (mm $year^{-1}$); π = 3.14; Z = erosion coefficient (dimensionless).

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

$$T = \sqrt[2]{\frac{t_0}{10}} + 0{,}1 \qquad \textbf{Eq. 2}$$

Where: T = temperature coefficient (dimensionless); t_0 = mean air temperature (°C $year^{-1}$).

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

$$Z = Y * X_a * (\varphi + \sqrt[2]{I_{sr}} \qquad \textbf{Eq. 3}$$

Where: Y = soil resistance to water erosion (dimensionless); Xa = land use and management (dimensionless); ϕ = degree of erosion features in the soil (dimensionless); Isr = mean slope of the watershed (%).

The Z coefficient values are classified according to the degree of erosion intensity (Figure 2).

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

Figure 2: The degree of erosion intensity (Z)

In the ENVI 5.3 program, land use and land cover were classified using the OBIA (Object-Based Image Analysis) method. The method is based on the segmentation of matrix images, where samples are defined for training in supervised machine learning, based on the Support Vector

Machine model, a non-probabilistic linear binary algorithm (COHENCA & CARVALHO, 2015). LandSat 8 satellite images (OLI sensor) were used.

Through temporal series of rainfall stations, the average rainfall and temperature of the last 30 years was established, using the inverse distance weighting (IDW) method, which interpolates and gathers the areas of influence of each station from the polygons of Thiessen. Soils were classified based on the Brazilian Soil Classification System (EMBRAPA, 2018). Digital images from the Alos satellite (Palsar sensor) with 12.5 meters of spatial resolution were used for the relief classes. In addition to results obtained in the analyzes published by Nunes (2020).

3. Results

The predominant phytophysiognomy is field/pasture (56.67%), followed by Cerrado (21.40%), dense forest (10.98%), agricultural culture (7.60%), exposed soil (2.83%) and water bodies (0.49%). The dominant soils were Quartzarenic Neosols (38.51%), followed by Red-Yellow Latosols (29.47%), Chernosols (24.46%) and Cambisols (7.54%). The steepest slopes are located near the springs and dissected canyons. However, flat to smooth sloping areas (0-8%) are predominant, with an average slope of 5.6%. The average soil loss for the year 2021 in the Corrente River watershed was 26.41 to/ha/year^{-1}.

Figure 3 highlights the micro-watersheds that act as producers of sediments that converge to the caves. The caves with perennial courses are accumulated in the karst areas of the Vermelho River, more specifically, in the Extrema, Serragem and Ventura micro-watersheds, which contribute to a sediment production in the scale of 33.66, 19.45 and 35.22 to/ ha/year^{-1}, respectively.

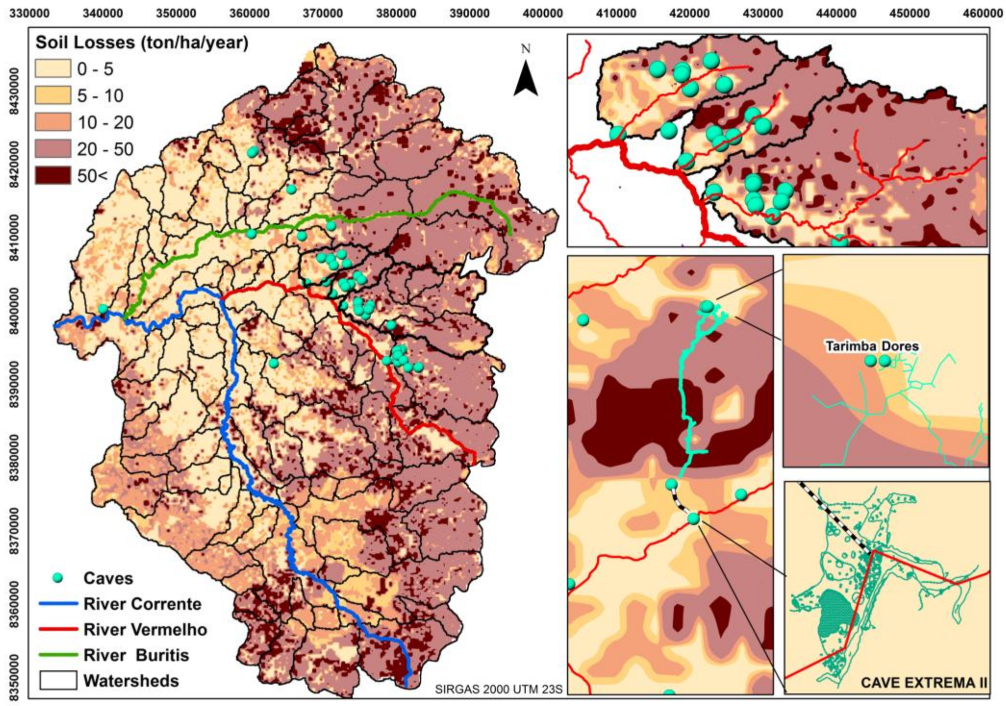

Figure 3 : Soil losses by erosion in the Corrente River watershed and in the karst areas

4. Discussions

In the watershed of the River Corrente, the cretaceous sediments of the Urucuia Group (upper), which would cover the Bambuí Group (lower), are found inside caves, guided by networks of conduits and fractures. The morphology of the transition from sandstones to carbonates occurs through abrupt breaks, in the form of steep slopes, with the presence of erosion in an advanced stage. Part of these structures are related to karstification, which in this situation is expressed externally in the form of sinkholes.

Cave Extrema III, for example, receives volumes of sediment in the scale of 33.12 to/ha/year^{-1}, originating from surface and underground flows associated with sinkholes and adjacent caves, such as coming from the Tarimba cave.

As the study is carried out in a covered karst, the hypothesis is that the underlying karst system works as an inducer of superficial erosion processes, that is, the opening of sinkholes or sinks leads to a rearrangement of the balance profile of rivers and, consequently, expands the erosive capacity of captured surfaces. The absence of conservation practices in land use can increase this process, both with the increase in the sediment load in the suppression of native vegetation, and with the abstraction of water from aquifers, which tends to make karst systems more unstable.

In Figure 4, the estimated values of sediments transported in caves of perennial flows are highlighted, according to the related micro-watershed.

	Micro-Watershed			Soil loss average (to/ ha/ year^{-1})		
	Extrema	**Serragem**	**Ventura**	**Extrema**	**Serragem**	**Ventura**
Caves	Ponte de terra	Meândrica	Cachoeira do Funil	0,38	12,32	0,25
	Extrema I	Lapa I	Corredeiras	0,38	1,33	67,13
	Esperança	Ana Paula I	Pasto	2,28	0,5	56,38
	Extrema II	Judite	Porcos	0,23	0,35	16,14
	Extrema III	Dores	Marimbondos	33,12	2,36	11,88
	Vila Nova	Tarimba	Associação II	0,43	2,36	1,27
		Serragem II	Desgosto		10,49	1,62
		Penhasco			10,34	

Figure 4: Average estimate of sediment transport to the caves.

5. Conclusion

Through the estimation of soil loss in the watershed scale, it was possible to evaluate the spatial dynamics of the sediment producing areas, allowing to highlight the transport potential of these materials in karstic micro-watersheds. From there, such units can be investigated and monitored to better assess the causes and effects that are still little known. The karst region in this research is managed by an important Conservation Unit for the preservation of the region's speleological heritage.

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