ESTIMATION OF SOIL LOSSES AND SEDIMENT YIELD IN THE XINGU RIVER BASIN, BRAZIL

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ABSTRACT

The soil loss is a phenomenon present in watersheds with surface runoff, especially in equatorial and tropical climates. In the case of the Xingu River Basin, located in the Brazilian Amazon Forest, changes in land cover due to deforestation and the introduction of agriculture in the southern part and cattle ranching in the east have favored the development of processes for soil loss. The Xingu River Basin has approximately 25% of the deforested area with economic activities of agribusiness and mining, in addition to being a region with the implementation of electric power generation plants with the movement of river water. The phenomenon of water erosion needs to be estimated in large river basins, due to the importance of quantifying the impact caused by deforestation. As a methodology, a geographic database was developed for the elaboration of maps of the Xingu River Basin and the production of geographic information on the factors of the revised universal equation of soil losses. It was estimated that 504 tons of soil were lost per year in the Xingu River Basin and 79 million tons of sediments produced that can contribute to siltation, even in the face of the large flow produced by one of the largest rivers in the world.

Keywords: Erosion. Deforest. Equation. Soils

ESTIMATIVA DE PERDAS DE SOLO E PRODUÇÃO DE SEDIMENTOS NA BACIA DO RIO XINGU, BRASIL

RESUMO

A perda de solos é um fenômeno presente em bacias hidrográficas de climas equatorial e tropical. No caso da Bacia do Rio Xingu, localizada na Floresta Amazônica Brasileira, as mudanças na cobertura da terra devido desmatamento e introdução da agricultura e da pecuária na parte sul do território analisado, favoreceram o desenvolvimento de processos erosivos. Aproximadamente 25% da Bacia do Rio Xingu foi desmatada para atividades do agronegócio e mineração, com a implantação de barragens para geração de energia elétrica para aproveitamento do potencial do rio. O fenômeno da erosão hídrica precisa ser pesquisado por estimativas em grandes bacias hidrográficas, pela importância de quantificar o impacto causado pelo desmatamento. Como metodologia, foram elaborados mapas em sistema de informação geográfica da Bacia do Rio Xingu, ao considerar os parâmetros da equação universal de perdas de solo revisada. Foi obtida uma estimativa de 504 toneladas de perdas de solo ao ano e uma produção de 79 milhões de toneladas de sedimentos na Bacia do Rio Xingu, cujo impacto provoca o assoreamento e interfere em larga escala no fluxo de água de um dos maiores rios do mundo.

Palavras-chave: Erosão. Desmatamento. Equação. Solos.

ESTIMATION DES PERTES DE SOL ET DE LA PRODUCTION DE SÉDIMENTS DANS LE BASSIN DU FLEUVE XINGU, BRÉSIL

RÉSUMÉ

La perte de sols est un phénomène présent dans les bassins hydrographiques des climats équatorial et tropical. Dans le cas du bassin du fleuve Xingu, situé dans la forêt amazonienne brésilienne, les changements dans la couverture des terres dus à la déforestation et à l'introduction de l'agriculture et de l'élevage dans la partie sud du territoire analysé ont favorisé le développement de processus érosifs. Environ 25 % du bassin du fleuve Xingu a été déboisé pour des activités d'agrobusiness et d'exploitation minière, avec la mise en place de barrages pour la production d'électricité afin de tirer parti du potentiel du fleuve. Le phénomène de l'érosion hydrique doit être étudié par des estimations dans de grands bassins hydrographiques, en raison de l'importance de quantifier l'impact causé par la déforestation. Comme méthodologie, des cartes ont été élaborées dans un système d'information géographique du bassin du fleuve Xingu, en tenant compte des paramètres de l'équation universelle révisée des pertes de sol. Une estimation de 504 tonnes de pertes de sol par an a été obtenue, ainsi qu'une production de 79 millions de tonnes de sédiments dans le bassin du fleuve Xingu, dont l'impact provoque l'envasement et interfère à grande échelle sur le flux d'eau de l'un des plus grands fleuves du monde.

Mots-clés: Érosion. Déforestation. Équation. Sols.

INTRODUCTION

Soil erosion is a phenomenon present in hydrographic basins of equatorial climates, with the presence of voluminous precipitation and runoff concentrated in drainages of large territorial areas. Atmospheric conditions in equatorial climates interfere with soil losses, whose climate changes can contribute to risks of greater erosivity intensities (PANAGOS et al., 2022).

The soil loss processes pose a threat to food security and water quality. Approximately 95% of agricultural activities depend on the capacity of soils to produce results in fertility. The consumption of nutrients with the use of fertilizers increases by an average of 2% per year, to correct the losses in soil fertility. As a result of economic activities of land cover change, an annual rate of 43 billion tons of soil lost is estimated (BORELLI et al., 2020).

The context of the Amazon Rainforest, in the case of the north-central region of Brazil, is marked by deforestation with the introduction of agriculture on large farms for the production of grains for the international market and pastures with extensive cattle ranching. In the case of the Xingu River Basin, the existence of indigenous lands delimited for natural conservation units contributed to the preservation of the equatorial forest. However, approximately 25% of the area of the Xingu River Basin has been deforested, which represents changes in the surface runoff of the slopes and areas with the development of erosive processes (RAMALHO et al., 2024).

The hydrographic basins in equatorial climates with high rainfall. When the forms of land cover are altered by deforestation and the implementation of agricultural crops, there is a change in the hydrological cycle, with a relevant increase in surface runoff and soil loss processes (MERSHA et al., 2025).

Soil loss is a phenomenon that causes degradation conditions on the slopes of watersheds, whose dynamics need to be analyzed through data and with the use of field experiments and mapping techniques, according to the territorial area surveyed. At the regional scale of the hydrographic basins, there is the method of estimating soil losses by the universal equation proposed by Wischmeier and Smith (1978), with a review presented by Renard et al. (1997). Factors related to rainfall, soil properties, topography, land cover, and the use of conservation practices are used in the revisions and modifications of the universal equation, but have different parameters altered by the results of the experimental plots in academic research (GWAPEDZA et al., 2021).

As a result of the territorial extension of the analyzed watersheds and advances in remote sensing images, computerized mapping techniques contribute to the analysis of data generation on the factors of the universal soil loss equation (TODISCO et al., 2022).

The Eastern Amazon has areas coveted by Brazilian agribusiness, with the expansion of agricultural activities by soybean monoculture, concentrated in the State of Mato Grosso and areas of influence of mining and hydroelectric activities in the State of Pará, in the north-central region of Brazil. In the case of the Xingu River Basin, the Amazon Rainforest was preserved in the State of Mato Grosso by the existence of the Xingu National Park conservation unit, created from anthropological research work since the 1960s. Practically the entire edge of this Amazon conservation unit was deforested because of the booming agricultural crops in Mato Grosso. The Serra de Carajás is located in the Xingu River Basin, one of the richest mineral provinces in the world, whose mining activities attract populations and secondary activities such as cattle ranching and logging (SANCHES et al., 2020).

The Xingu River Basin represents a territorial unit with an immediate need for nature conservation, given the richness of the biodiversity potential of the Amazon Forest, water resources and mineral resources. Given this scenario, the soil located in the watershed is a very

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important natural resource for territorial integrity, food security and landscape preservation, whose scientific studies contribute to estimating the amount of soil losses.

The Xingu River Basin has a significant environmental importance as it is located in the Amazon Rainforest, with fragile ecosystems and the need for policy attention in the face of the expansion of deforestation and agricultural activities. Figure 1 shows the location of the Xingu River Basin.

Figure 1: Map of Xingu River Basin, Pará and Mato Grosso states, Brazil
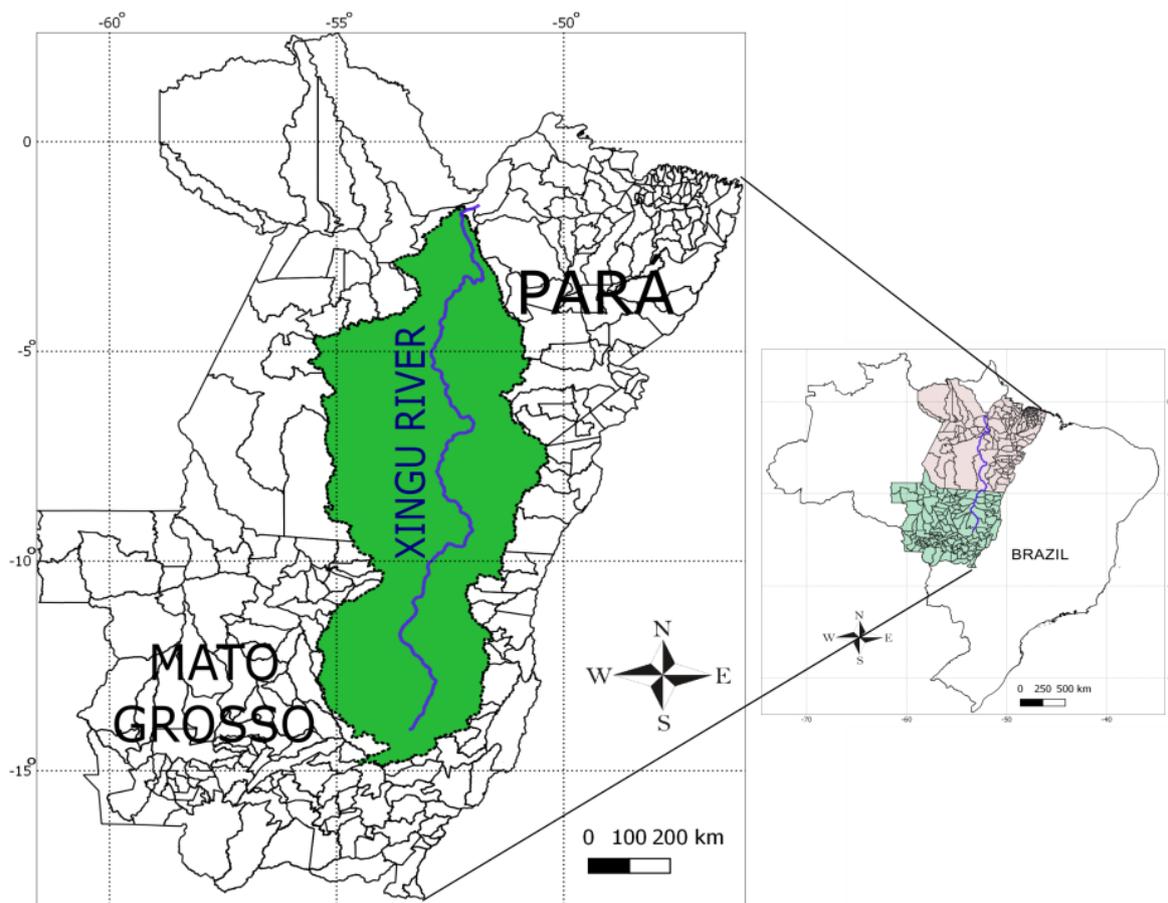
Source: Elaboration by Francisco (2025)

Approximately 25% of the entire territorial extension of the Xingu River Basin has been deforested. The Xingu River Basin has 51 million hectares distributed throughout the eastern Brazilian Amazon, in a region with an equatorial climate with an average annual rainfall of 2,090 mm, with a higher volume of rainfall between the months of June and September, the presence of a lot of humidity throughout the year and average temperatures between 31ºC and 23ºC (RAMALHO et al., 2024).

On the soils of the Xingu River Basin, there is a predominance of distribution of Red Yellow Ultisols in approximately 61% of the territory, with the presence of Red Latosol in 25% of the basin and Yellow Latosol (4%) in the region of the mouth of the Xingu River (Tortorello et al., 1997). In addition to the predominant types, there are Cambisols and Quartz Sand, mainly in the southern portion of the basin, where deforestation is most active (ALMADA et al., 2021).

The Xingu River Basin is distributed as a part of the Serra de Carajás, one of the richest mineral provinces in the world, whose mining activities and implementation of a plant to generate electricity contributed to the flow of migration and population settled in the region.

After the construction of the Tucuruí hydroelectric plant, in Pará, the workers remained in the Marabá region and one of the economic alternatives was the implementation of cattle ranching with deforestation of areas of the Amazon Forest. In the locality of São Félix do Xingu and Ourilândia do Norte, forest conservation units have not been demarcated and are on the borders of indigenous lands, with opening of deforestation fronts and irreversible environmental impacts. Mining activities are present in the Xingu River Basin and have generated contaminants causing serious diseases to native populations with the inclusion of impacts on nature (MOITA et al., 2024).

METHODOLOGY

To present the estimate of soil loss in the Xingu River Basin, the parameters were applied according to the revision of the Universal Soil Loss Equation according to Renard et al. (1997).

The methodology was defined by applying the Universal Soil Loss Equation from a database in a Geographic Information System. The geographic data of the basin were entered into the QGIS. From the geographical data in GIS environment, the areas of soil types and land cover were obtained by visualization.

To estimate soil erodibility, the Pedological Map of the State of Mato Grosso (Tortorello et al., 1997) and were used soil erodibility indices as presented by Raimo et al. (1999).

From the data of the Shuttle Radar Topography Mission with treatment made by the Brazilian Institute of Space Research, a QGIS tool was used to generate the map of slopes.

The estimation of the LS factor, when considering the topographic aspects of the Xingu River Basin, the parameters presented by Bertoni and Lombardi (1999) were analyzed, with the calculation of the average slope in the basin and the ramp length.

The land cover was estimated from the linear design of the areas with high-resolution remote sensing images available in the Google Earth application, whose files of the polygons of the areas were converted into vector format of the shapefile type to be imported into the QGIS database. The indices of each land cover were adopted according to Bertoni and Lombardi (1999).

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RESULTS

The estimated erosivity for the Xingu River Basin, according to data of average rainfall of 1,979 mm, for the locality of Altamira is 11,071 MJ.mm.h/ha/year.

Figure 2 shows the types of soil by geographical distribution.

Figure 2: Map of Soils in Basin of Xingu River
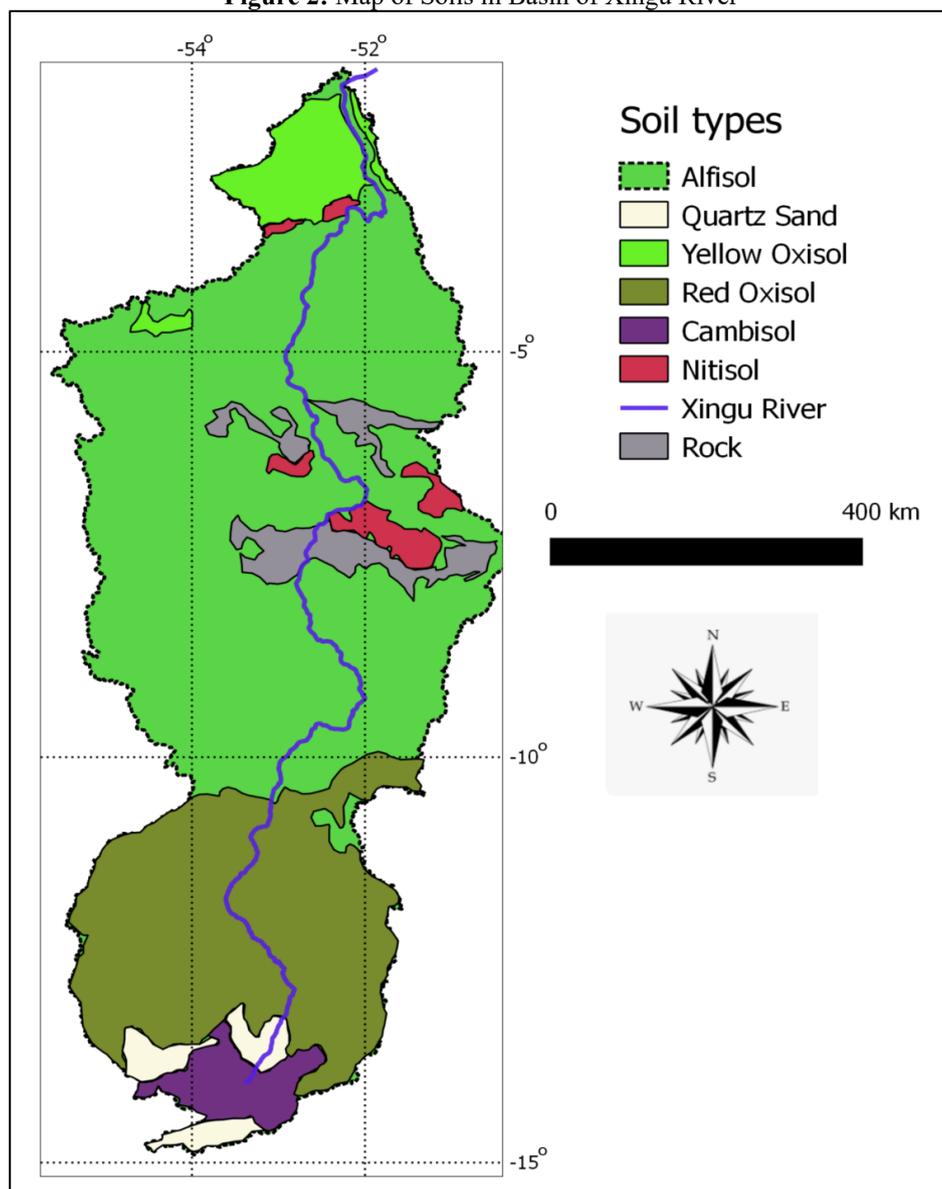
Source: Elaboration by Francisco (2025)

The estimate of erodibility of the soils of the basin from the areas of each soil type is presented in table 1.

Table 1. Estimation of erodibility for the Xingu River's Basin

Soil	Factor K	Area (ha)	Estimated (t/ha/y)
Oxisol	0.09	14,938,952	1,344,505.7
Alfisol	0.31	31,586,261	9,791,740.9
Quartzer Sand	0.55	1,218,722	670,297.1
Cambisol	0.03	1,603,141	32,062.8
Nitisol	0.01	200,675	2,006.8
	Σ	49,547,751	11,840,613.3
		Average Index	0.239

Source: Elaboration by Francisco (2025)

The estimation of the LS factor considers the aspects of slopes and lengths of the slopes of the watershed. About the Xingu River's Basin the topography conditions show data considering the average slope at 5.5% and ramp length at 9,000 meters, the LS factor can be estimated at the expression:
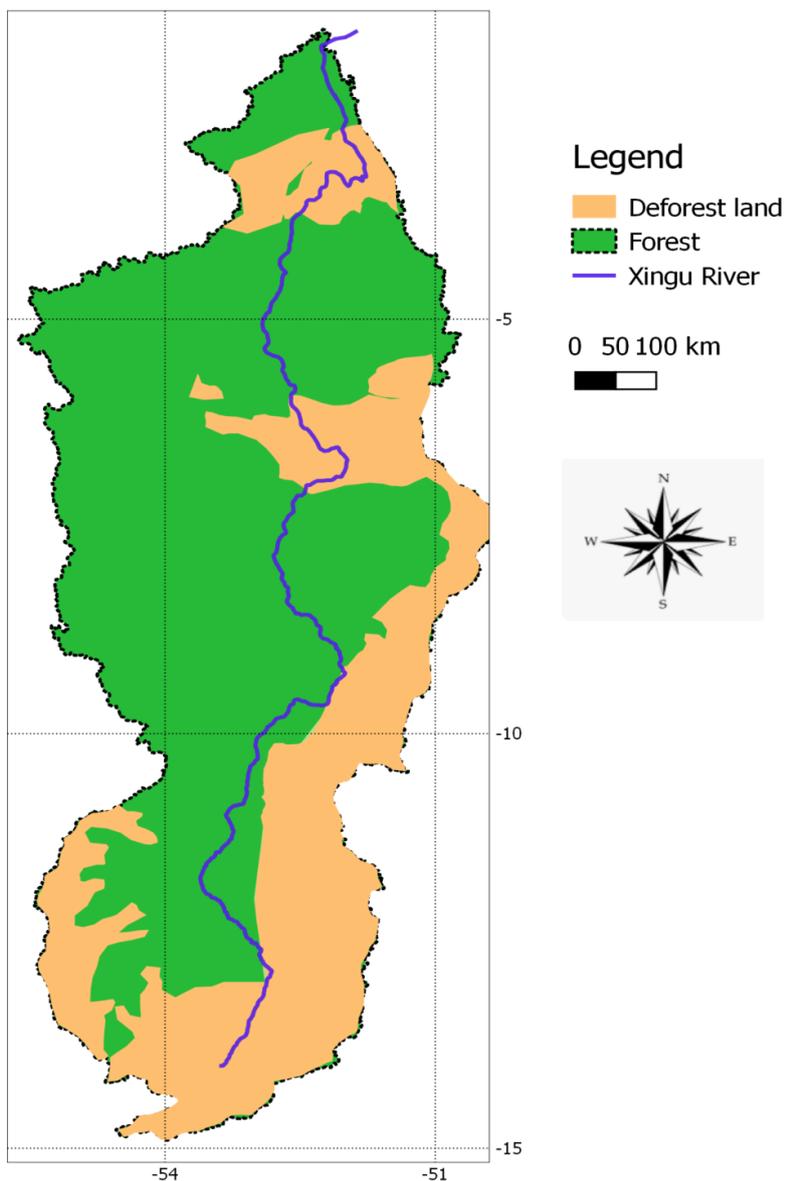
$$S = 0.00654 \times 0.055^2 + 0.0456 \times 0.055 + 0.065 \qquad (1)$$

When applied to the parameters to estimate the LS factor, the index 607.75 was calculated.
The changes in land cover directly influence runoff and the dynamics of water erosion.
Figure 3 shows the land cover classes in the Xingu River's Basin.

Figure 3: Map of Land Cover in Basin of Xingu River

Source: Elaboration by Francisco (2025)

The table 2 presents erosion rates according to areas by respective land cover classes.

Table 2. Estimation of land cover for the Xingu River's Basin

Land cover	Factor C	Area (ha)	Estimated (t/ha/y)
Agriculture	0.1142	4,227,334.3	482,761.6
Forest	0.0003	39,015,022	11,704.5
Pasture	0.0377	8,454,668.6	318,741.0
Σ		51,825,126	813,207.1
	Average Index		15.691

Source: Elaboration by Francisco (2025)

As a result of human action having modified approximately 25% of the territory with deforestation and the predominance of pastures in approximately 70% of the area altered by agricultural activities, in the factor of conservation practices the index of 0.2 was estimated for the application of the equation.

In summary, the Universal Soil Loss Equation applied in the Xingu River Basin obtained the following expression:

$$A = 11,071 \times 0.239 \times 607.75 \times 15.691 \times 0.2 \quad (2)$$

The estimated water erosion rate for the Xingu River Basin was 504.65 t/ha/year.

The sediment production rate in the Xingu River Basin, from this estimate, was 79 million tons of sediments.

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CONCLUSIONS

Water erosion needs to be researched with geographic information, with the production of cartographic documents and geographic data can be used to produce estimates. In the case analyzed, the basin located in the Amazon Rainforest has changes in land cover due to deforestation and consequently changes in runoff and hydrological regime.

The Universal Soil Loss Equation is a method with empirical data on watershed conditions and can be applied with the use of geographic information systems.

Soil erosion is a phenomenon with dynamics to be understood through the production of geographic information, since in a watershed there are local particularities in the face of factors that induce soil loss.

The equatorial regions need scientific research to analyze the impacts caused by deforestation and create arguments for public policies for land management.

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