Article

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Estimation of Erosion Rate in a Hydrographic Basin in a Deforestation Area in the Brazilian Amazon, Eastern Mato Grosso

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Abstract: The central region of Brazil, particularly the state of Mato Grosso, has experienced substantial land-cover changes resulting from the conversion of forest areas to soybean and cotton cultivation. This expansion of agricultural land has intensified soil erosion and increased the potential for sediment loss within tropical river basins. This study aims to estimate soil loss in the Curisevo River Basin using the Universal Soil Loss Equation (USLE). The methodology involved developing a spatial database in the QGIS Geographic Information System (GIS), incorporating information on slope, soil characteristics, and land cover within the Curisevo River Basin. Rainfall erosivity was estimated using precipitation data obtained from the National Institute of Meteorology, while soil erodibility was estimated based on soil characteristics and guidelines for the state of Mato Grosso. Land-cover characteristics were derived from remote-sensing imagery, with agricultural land, pasture, and forest areas identified and mapped through spatial analysis. Slope data were obtained from the Shuttle Radar Topography Mission (SRTM) dataset and processed using QGIS to generate the required spatial variables for the USLE model. The Curisevo River Basin covers approximately 1.18 million hectares, and the analysis estimated an annual soil erosion rate of approximately 134,526 t ha^{-1} $year^{-1}$, equivalent to approximately 16 million tonnes of sediment annually. These findings demonstrate the considerable magnitude of soil loss associated with land-cover change and agricultural expansion within the basin. The study also highlights the applicability of GIS-based USLE modelling for quantifying spatial patterns of soil erosion and assessing the effects of climatic, pedological, geomorphological, and land-cover characteristics on erosion processes. The findings are particularly relevant to environmental management in the context of continued deforestation and agricultural expansion in the Amazon region. Excessive soil loss can reduce the availability and productivity of arable land, contribute to agricultural and food-security challenges, and deteriorate water quality through increased sediment delivery to rivers and other aquatic systems. Consequently, spatial assessment of soil erosion can provide valuable evidence for developing appropriate land-management and soil-conservation strategies aimed at reducing erosion, protecting water resources, and promoting sustainable watershed management.

Keyword: Erosion; Estimate; Cartography; Deforest

1.0 Introduction

The phenomenon of soil loss can be quantified through estimates, whose methods were improved from the Universal Soil Loss Equation, developed from the studies of Wischmeier & Smith (1978) from 10,000 data points on soil loss rates in experimental plots in the territory of the United States of America (Laflen & Moldenhauer, 2003). In the United States of America, studies on soil conservation were the result of a severe wind erosion event in 1932, with the creation of a national policy for soil conservation by the Department of Agriculture (Bennett, 1972). Although the intensity of soil loss processes due to water erosion is evident in equatorial and tropical regions, according to Golosov and Walling (2019), only 9% of global estimates of soil losses are from areas of South America and Africa. According to Panagos et al. (2022), as a result of climate change, rainfall erosivity will increase by 27% by 2050. The Amazon Region has annual rainfall above 4,000 mm, and soil losses due to deforestation are worrisome.

The phenomenon of soil erosion needs mapping for geographical relations and better knowledge about the dynamics of processes. Since the development of Geographic Information Systems, spatial data from watersheds has served as parameters for applying the Universal Equation of Soil Losses, mainly through the formation of numerical elevation models. The development of erosive processes in the large hydrographic basins of tropical environments made it propitious to apply this empirical model in river basins to generate databases in Geographic Information Systems (Parveen, Kumar, 2012).

The soil losses in Brazil are estimated at approximately 848 million tonnes per year (Merten, Minella, 2013). The losses of soil at an accelerated pace in the degraded areas of the Western Plateau of São Paulo represent environmental damages, such as silting of watercourses and losses of soil fertility with losses to agricultural practices. Historically, soil losses in Brazil were due to large-scale agricultural practices with coffee and cotton monocultures. Since the 1970s, the central region of Brazil has been deforested for the implementation of soybean and cotton monocultures. The northeastern region of the State of Mato Grosso was deforested in the 2000s due to the expansion of soybean cultivation beyond the axis of the Cuiabá-Santarém highway. In 1961, based on the work of Brazilian Anthropologists Villas-Bôas, the Xingu Indigenous Park was created, with an area of 2.6 million hectares (Barbosa, Araujo, Oliveira, 2022). The deforestation of the Amazon in Brazil is related to the opening of roads and the expansion of agricultural monoculture activities from the Central Region to the north and northwest, being an area with fragile soils and dependent on surface biomass.

2.0 Study Area

The Curisevo River Basin has an area of 1,182,417 ha, with the main course 240 km long. The Curisevo River, or Coliseum, a tributary of the Xingu River, has as tributaries the Pacuneiro River, Mirassol River, Aulu Stream, and Kevuaieli Stream. The Pacuneiro River has three tributaries: The Piranha, Barreiro, and Xeremece Streams. The map in Figure 1 shows the area of the Curisevo River Basin in Mato Grosso, Brazil.

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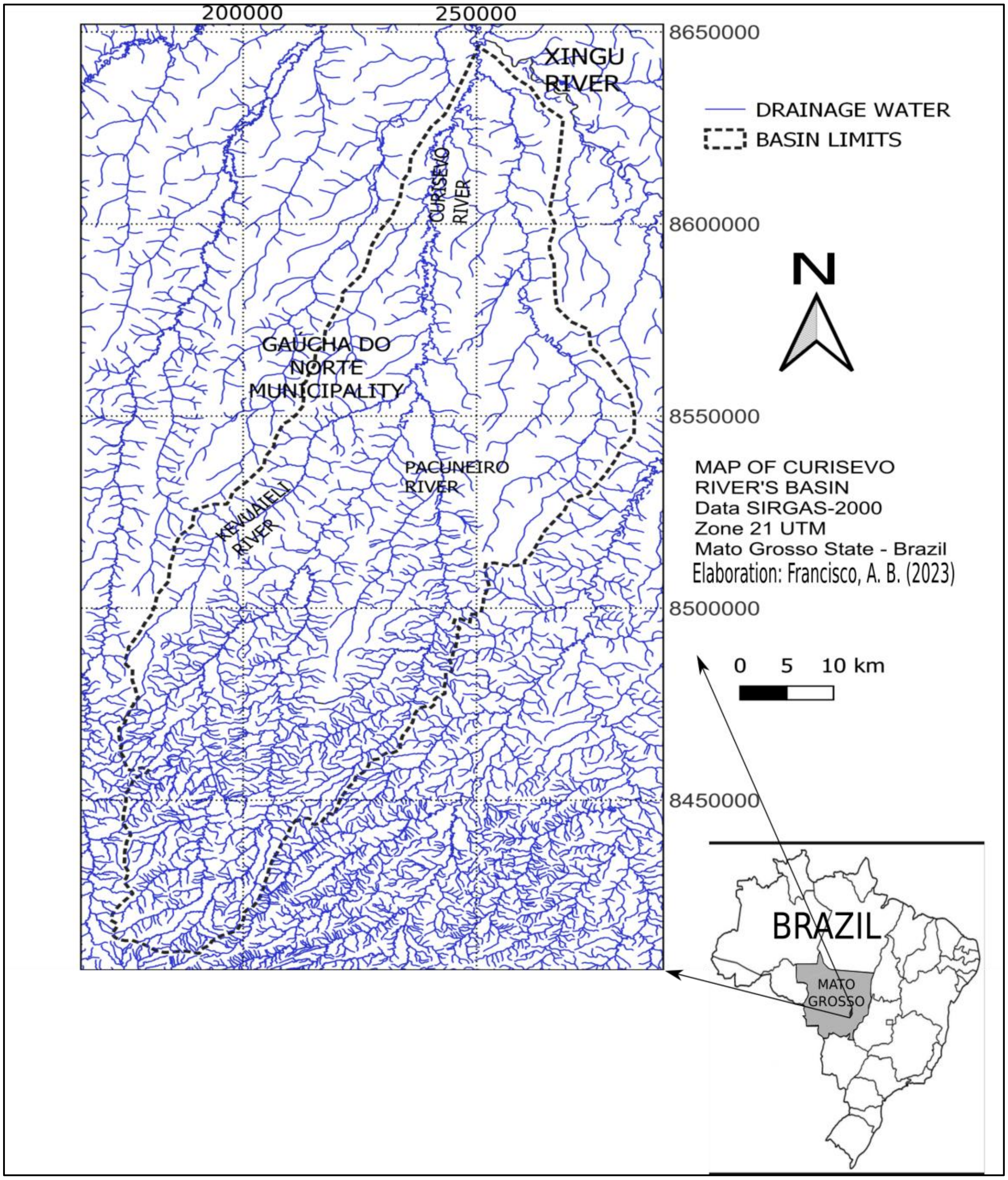

Figure 1: Basin of Curisevo River

Regarding the pedological cover, in the Curisevo River Basin, there are four types of soils: dystrophic red latosols, alic cambisols, plintossols, quartz sands, and eutrophic haplic glei (Tortorello, Farran, Santos, 1997). The northern part of the Curisevo River basin, about 75% of the area, is located in the municipality of Gaúcha do Norte, in the state of Mato Grosso, and the southern part of the basin is located in the municipality of Paranatinga, in the in the state of Mato Grosso. In the northern part of the Curisevo River Basin, about one-third of the territorial area (the entire northern area) is the conservation unit Xingu Indigenous Park. The southern part of the basin was altered by agricultural and livestock activities. The Curisevo River Basin is located in an area with agribusiness expansion interests and has 394,000 ha of agricultural area, equivalent to 33% of the area.

3.0 Materials and Methodology

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 was entered into the QGIS, version 3.28. From the geographical data in the GIS environment, the areas of soil types and land cover were obtained by visualisation.

For the purpose of analysing precipitation data to estimate rainfall erosivity, data from the Água Boa-Mato Grosso town meteorological station of the National Institute of Meteorology, located about 100 km from the Curisevo River basin, were used. Despite the existence of a meteorological station in Gaúcha do Norte-Mato Grosso town, it remained inoperative for several periods, preventing the

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historical analysis of precipitation rates. In the region of the Curisevo River basin, the average annual rainfall is 1,500 mm. The erosivity of rainfall in the Curisevo River Basin was estimated from the application of the method presented by Wischimeier & Smith (1978).

To estimate soil erodibility, the Pedological Map of the State of Mato Grosso (Tortorello Farran, Santos, 1997) was used, along with soil erodibility indices as presented by Raimo et al. (1999). The land cover was estimated from the vectorization 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 a vector format of the shapefile type to be imported into the QGIS database. The indices of each land cover were adopted according to Bertoni & Lombardi Neto (1999). In the estimation of the LS factor, when considering the topographic aspects of the Curisevo River Basin, the parameters presented by Bertoni and Lombardi Neto (1999) were analyzed, along with the calculation of the average slope in the basin and the ramp length.

4.0 Results

The rainfall erosivity for the Curisevo River basin area was estimated at 9,057.9 KJ.mm/ha/year. The estimation of soil erodibility considers the indices according to each type of soil. Figure 2 shows the map of the soil types in the Curisevo River Basin.

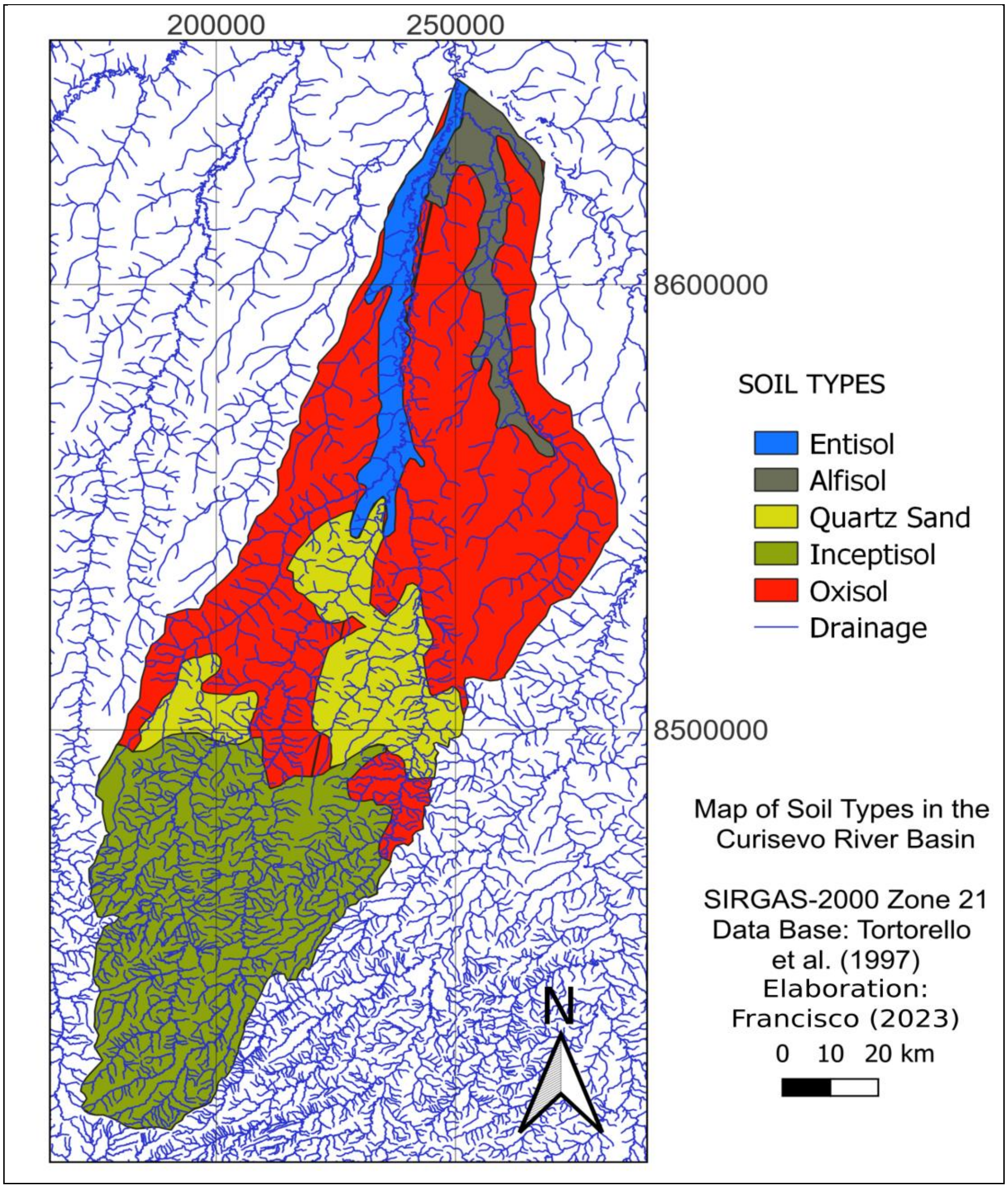

Figure 2: Soil Types in Curisevo River Basin

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The estimate of erodibility of the soils of the Curisevo River Basin from the areas of each soil type is presented in Table 1. The changes in land cover directly influence runoff and the dynamics of water erosion. The map in Figure 3 shows the land cover classes in the Curisevo River Basin.

Table 1: Estimation of erodibility for the Curisevo River's Basin

Soil	Factor K	Area (ha)	Estimated (t/ha/y)
Oxisol	0.09	669,184.06	60,226.5654
Inceptisol	0.31	367,860.94	114,036.8914
Entisol	0.18	59,033.05	10,625.949
Alfisol	0.17	58,017.82	9,863.0294
Quartzer Sand	0.55	28,321.14	15,576.627
	∑	1,182,417	210,329.0622
		Average Index	5.6217

Source: Francisco (2023)

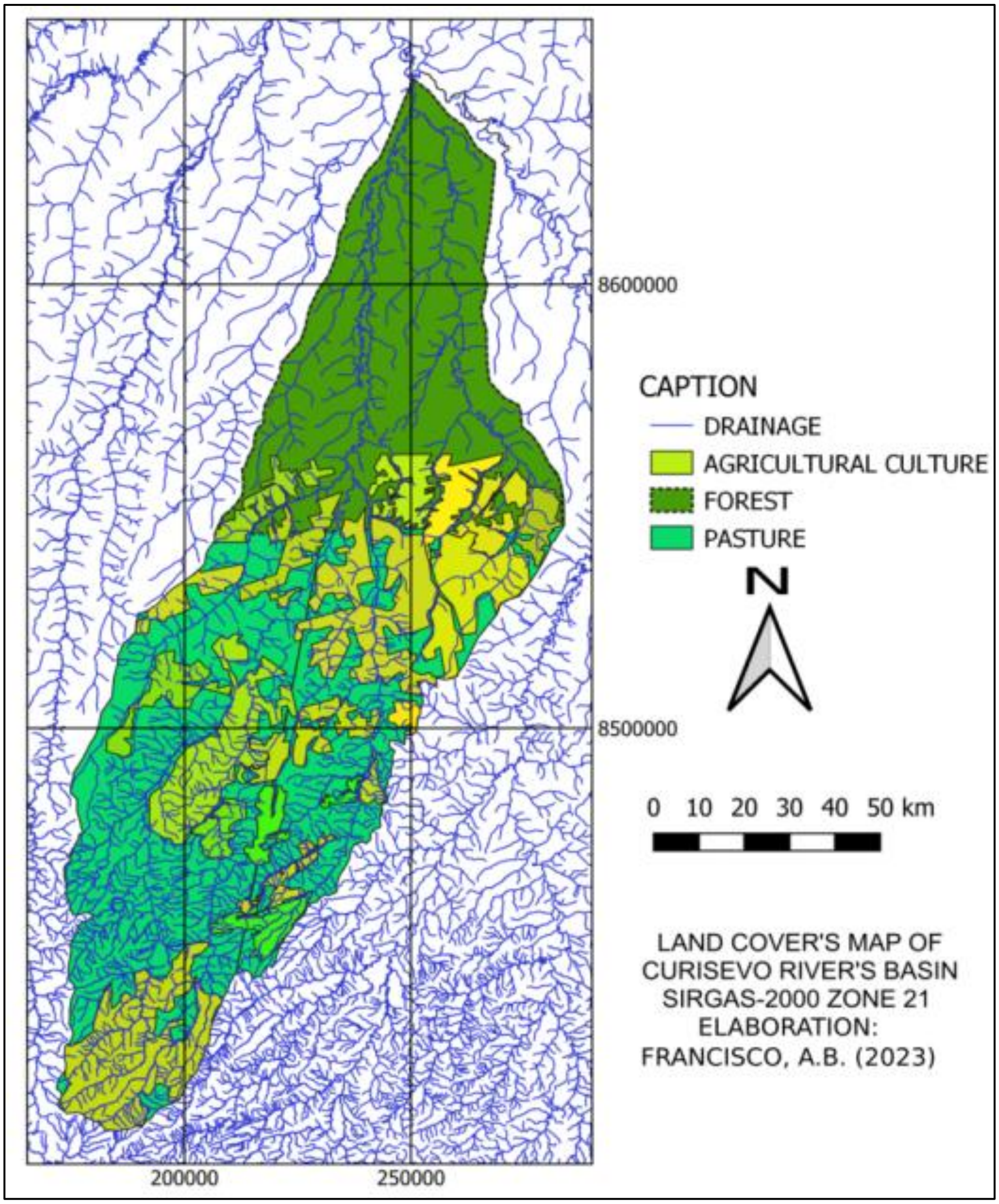

Figure 3: Land Cover in Curisevo River Basin

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The table 2 presents erosion rates according to areas by respective land cover classes. The estimation of the LS factor considers the aspects of slopes and lengths of the slopes of the watershed. The figure 4 shows the map of slopes of the Curisevo River Basin, with a geographical distribution of the average slope of 4%.

Table 2: Estimation of land cover for the Curisevo River basin.

Land cover	Factor C	Area (ha)	Estimated (t/ha/y)
Agriculture	0.1142	394,051	45,000.62
Forest	0.0003	415,102	124.53
Pasture	0.0377	373,264	14,072.05
	∑	1,182,417	59,197,21
		Average Index	19.9742

Source: Francisco (2023)

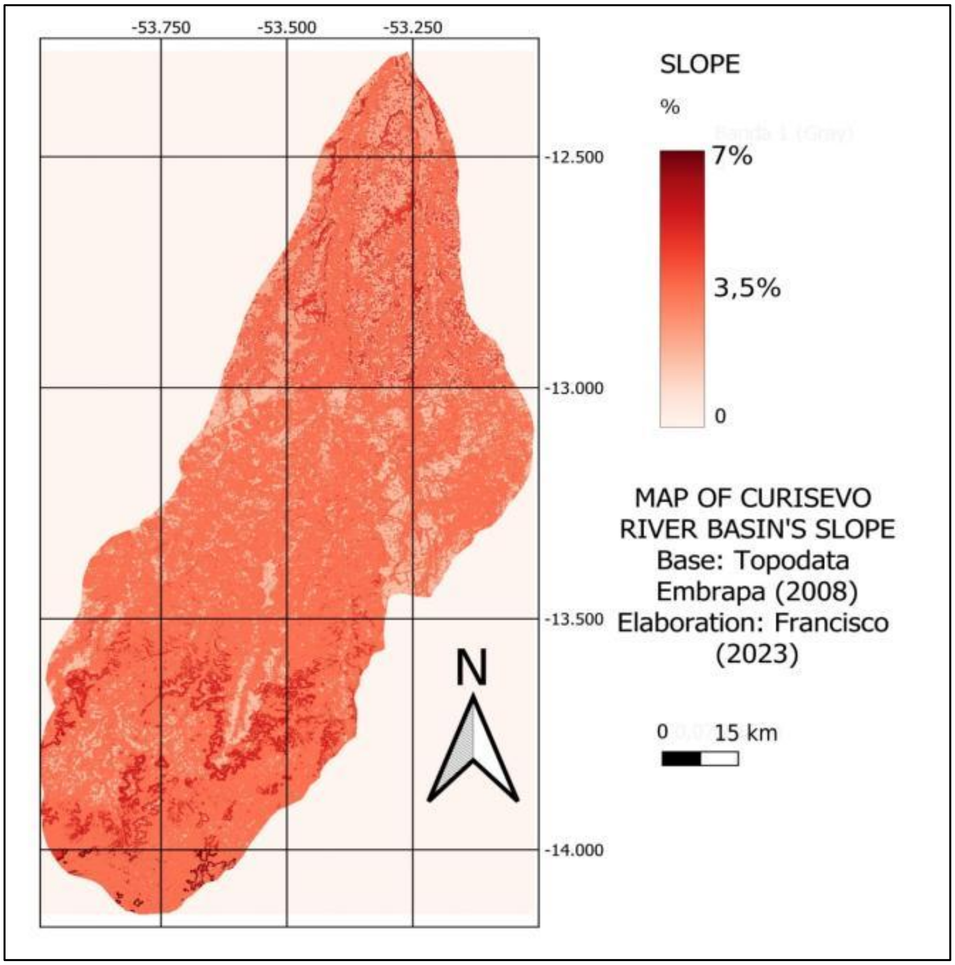

Figure 4: Slope in Curisevo River Basin.

To calculate the mean slope applied to the equation parameter, the expression:

$$S = 0.00654 \times 0.04^2 + 0.0456 \times 0.04 + 0.065 \qquad (1)$$

When applying the parameters to estimate the LS factor, the index 400.8 was calculated. About the conservation practice factor, approximately 66% of the area of the Curisevo River basin has been altered by human action with deforestation, and 33% has pastures without soil conservation practice. In this context, the parameter of 0.33 was adopted, considering the conditions of the absence of conservation practices in 33% of the area of the Curisevo River basin.

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

$$A = 9057 \times 0{,}0056 \times 19{,}9742 \times 400{,}8 \times 0{,}33 \qquad (2)$$

The estimated water erosion rate for the Curisevo River Basin was 134,526 t/ha/year. The sediment production rate in the Curisevo River Basin, according to this estimate, was 16 million metric tonnes of sediment.

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Regarding the data presented, soil losses in the southern part of the watershed are considered worrisome, being the portion with the greatest natural tendency for sediment production. Changes in land cover with deforestation in the 1970s and the introduction of agricultural activities from the 1990s onwards induced accelerated soil loss. The results of a study of tropical areas in South America are important for comparisons with tropical areas in Asia, with large volumes of precipitation and changes caused by human action.

5.0 Conclusions

The Universal Soil Loss Equation has been a method applied for decades, but there is a dearth of research to relate it to geographic science. The estimation of soil losses needs the geographical analysis of climatic aspects in the erosivity factor, pedological aspects in the erodability factor, relief conditions in the topographic factor, and land cover changes, which are frequently addressed by geographers.

The contribution of the research occurs through the cartographic analysis of the influencing factors in soil erosion, using the geographic information system in a database to generate cartographic documents. Cartography, with the existence of a geographic database, contributes to the application of a policy for soil zoning and avoiding deforestation in new areas, in addition to the implementation of conservation practices in the altered areas. In recent years, research on river basins and geoprocessing techniques has become more prevalent in geographical studies. The spatiality of erosive processes involves an understanding of the aspects of hydrographic basins and the transformations that occur in rural landscapes due to changes in agricultural activities. The use of conservation practices for the recovery of areas with degraded soils can contribute to the mappings performed by geographers with support from geographic information systems. The research could advance in the production of land cover maps of different periods and applications of the estimates in studies on surface runoff and water erosion.

As a proposal for further research, the geographic database can be updated, including meteorological data on precipitation in the climate change scenario, for estimates of rainfall erosivity. The research about watersheds is located in an area of agricultural expansion with the existence of indigenous lands and nature conservation units, whose research contributes to the policies of implementation of areas of restriction to the advances of deforestation, with the loss of soils being one of the most important scientific arguments.

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Conflicts of Interest: The author declares no conflict of interest.

Ethics Statement: Ethical approval was not required as the study involved no human participants or identifiable personal data.

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