ESTIMATIVE OF SOIL LOSSES IN THE PARANAPANEMA RIVER BASIN, SOUTHEAST BRAZIL

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Abstract. The Paranapanema River Basin is one of the most important basins in the Centre-South of Brazil, with fertile soils for the practice of agriculture and reservoirs for electricity generation. In the research, the elaboration of a geographic database in the QGIS system was proposed in order to estimate of soil losses using the parameters of the Universal Soil Loss Equation method. Maps corresponding to erosivity, soil types, slopes and land cover in the Paranapanema River Basin were developed in order to define the areas of the plots and generate an average for each factor. Using different tables, averages were obtained by adding the plots of each index to the average from the total area of the watershed. Based on the applied analysis of the Universal Soil Loss Equation, an estimate of 18.13 t/ha/year was obtained, with an estimated sediment production of 302 million tons per year.

1. INTRODUCTION

The phenomenon of soil loss can be quantified through estimates, the methods were improved by the Universal Soil Loss Equation. The latter was developed from the studies of Wischmeier & Smith (1961) using 10,000 data items on soil loss rates in experimental plots on the territory of the United States of America (Laflen & Moldenhauer, 2003). In the USA, studies on soil conservation were the result of 1932's severe wind erosion event, leading to the Department of Agriculture creating a national policy for soil conservation (Bennett, 1972).

Although the intensity of soil loss processes due to water erosion is evident in equatorial and tropical regions, according to Golosov & Walling (2019), only 9% of global estimates of soil losses are from South America and Africa. According to Panagos *et al.* (2022), rainfall erosivity will have increase by 27% by 2050, as a result of climate change.

Soil losses pose a threat to food security and sediments deposition in river plains. The phenomenon of soil loss can occur in areas of preserved forest, but the intensity is many times greater in areas with agricultural crops in soils susceptible to erosion as well as in regions with equatorial climates of heavy rainfall. The erosion of soils caused by agricultural activities represents three times the estimates in relation to natural erosion, reaching 75 billion tons per year (Montgomery, 2007).

In Brazil, soil losses are estimated at approximately 848 million tons per year. The Southeast region of Brazil has the highest rates of soil losses due to dense human occupation and the removal of the vegetation cover. The history of occupation of the Southeast and South regions had be marked by the expansion of coffee crops, including the north of the State of Paraná, between the 1930s and 1970s, with the absence of conservation practices. After the decline of coffee crops, the arable areas were kept only in more fertile soils, such as the nitosol of northern Paraná, with the predominance of the introduction of planted pastures and the action of trampling the herd (Merten & Mirella, 2013).

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The Paranapanema River Basin presents a diversity of natural conditions, with soils highly susceptible to erosive processes, as is the case of Argisols and Cambisols, to very few vulnerable soils such as Nitosols. However, the Paranapanema River Basin has a history of occupation of almost total removal of the original vegetation cover, leaving only the Morro do Diabo state reserve forest, in Teodoro Sampaio and areas of high slopes in the vicinity of Serra do Mar. The northern portion of the Paranapanema River Basin is subject to a large linear erosion, having records of technical and academic works of severe intensities in terms of erosive processes (Tibúrcio, 2021).

The Paranapanema River Basin has an area of more than 10.7 million hectares, distributed between the states of São Paulo and Paraná (Fig. 1). It is one of the main basins of the Paraná River. The economic importance of the territory of the basin is beyond doubt, as it is home to important cities such as Londrina, Maringá, Presidente Prudente, Ponta Grossa, Ourinhos, Itapeva and Itapetininga. Figure 1 shows the location of the Paranapanema River Basin.

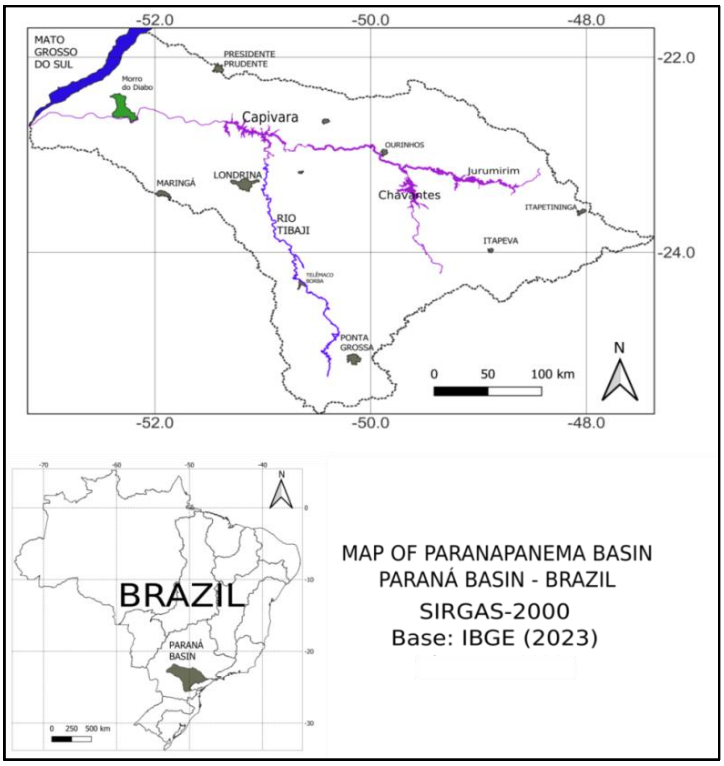

Fig. 1 – Map of Paranapanema's Basin.
Source: Produced by the author (2024).

In addition to the economic activities of food production, such as corn and soybeans in the region of Londrina, the basin has forestry areas used in the pulp industries in the regions of Itapeva and Botucatu, including the production of sugarcane for ethanol in the region of Ourinhos.

The Paranapanema River Basin has large accumulation reservoirs for electricity generation, such as: Capivara, Chavantes, Jurumirim, Taquaruçu and Salto Grande. The development of marginal erosion in the reservoirs can lead to silting, as well as to consequences for the generation of electricity in the Centre-South of the country (Rubio, 2014).

Given these aspects, this study aims to provide an estimate of soil losses through the elaboration of a geographic database for the Paranapanema River Basin, in order to contribute to the production of information that may help present the risks of soil losses for an important territorial segment of Brazil.

2. METHODOLOGY

The methodology was based on the elaboration of a geographic database in the QGIS system, by generating information plans for each factor of the Universal Soil Loss Equation. Each information plan contains the geographic information to be measured by areas, which serves as basis for the analysis and elaboration of the tables regarding the plots. The vectorized information was imported into the geographic database to later be edited for the creation of maps.

In all variables, in order to obtain the factors indices for the Universal Soil Loss Equation, it is necessary to add the values and the ratio of the territorial area in the hydrographic basin.

The estimate of rainfall erosivity was presented based on the data provided by Braido (2015).

The estimation of soil erodibility took into account the parameters presented by Freire *et al.* (1997), Bertol *et al.* (2002) and Bertol *et al.* (2007).

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

When calculating the estimation of the LS factor, taking into account the topographic aspects of the Paranapanema River Basin, the parameters presented by Bertoni & Lombardi (1999) were analysed, was 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 while using high-resolution remote sensing images available in the Google Earth application, whose files on the polygons of the areas were converted into vector format of the shapefile type. They would then be imported into the QGIS database. The indices of each land cover were adopted according to Bertoni & Lombardi (1999).

3. RESULTS

Table 1 contains the estimate of the rainfall erosivity and the average from the areas of the erosivity classes.

Table 1

Rain erosivity factor (R) in Paranapanema River Basin

Class areas (MJ.mm/h/ha/y)	Area (ha)	R (Class x Area)
7,200	4,806,330	34,605.576
7,800	1,860,000	14,508.000
8,400	2,090,140	17,557.176
9,000	1,709,002	15,381.000
9,600	272,075	2,611.920
∑	10,737,547	84,663,672
	Average (R/Area)	7,884.82

Source: Produced by the author (2024).

The result is the erosivity factor for the Paranapanema River Basin whose value is 7,884 MJ.mm/h/ha/year.

Figure 2 shows the geographical distribution of rainfall erosivity in the Paranapanema River Basin.

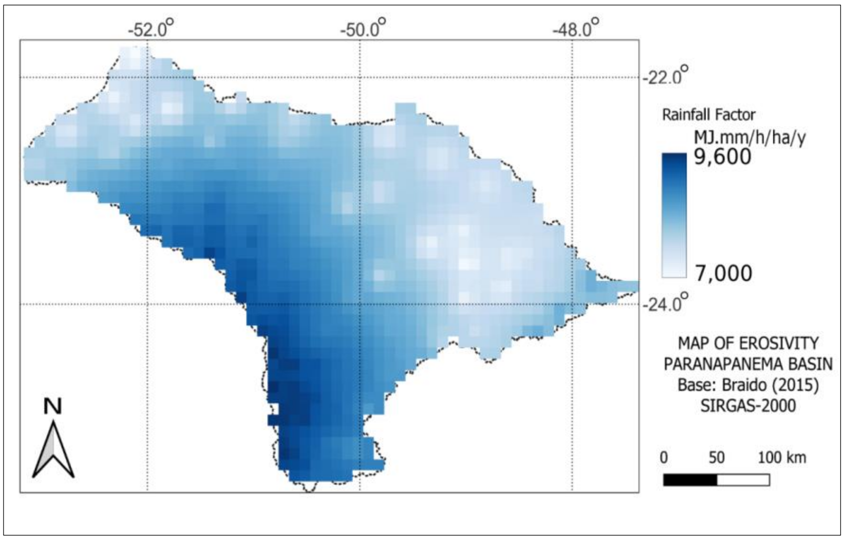

Fig. 2 – Map of erosivity of Paranapanema River Basin.
Source: Produced by the author (2024).

Figure 3 shows the geographical distribution of soils in the Paranapanema River Basin, based on research performed by Oliveira *et al.* (1999) and Larach *et al.* (1984).

The soil erodibility estimate is presented in Table 2, alongside the partial estimates according to soil types, including a synthesis according to the plot average.

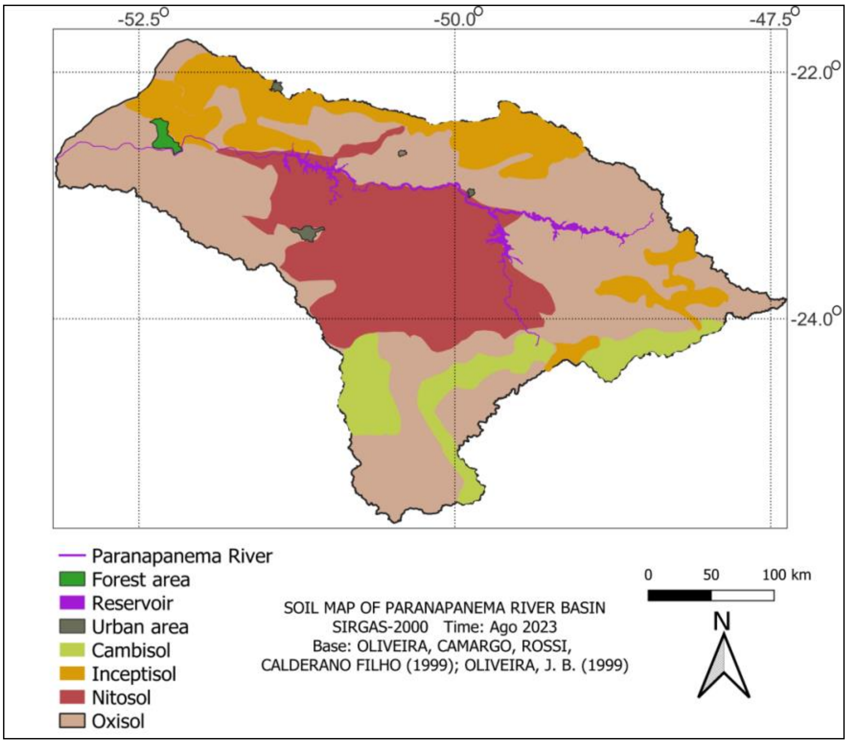

Fig. 3 – Map of Soils of Paranapanema River Basin.
Source: Produced by the author (2024)

Table 2

Factor of erodibility of soil (K) in Paranapanema River Basin

Types of soils	Area (ha)	Index K	K (t/ha/y) (Area x Index)
Inceptsol	1,651,933.3	0.051	84,248.59
Nitosol	2,708,116.2	0.011	29,789.28
Cambisol	909,094.0	0.015	13,636.41
Oxisol	5,468,403.7	0.016	87,494.46
∑	10,737,547		215,168.74
	Average (K/Area)		0.02004

Source: Produced by the author (2024).

Figure 4 shows the geographical distribution of the slopes in the Paranapanema River Basin

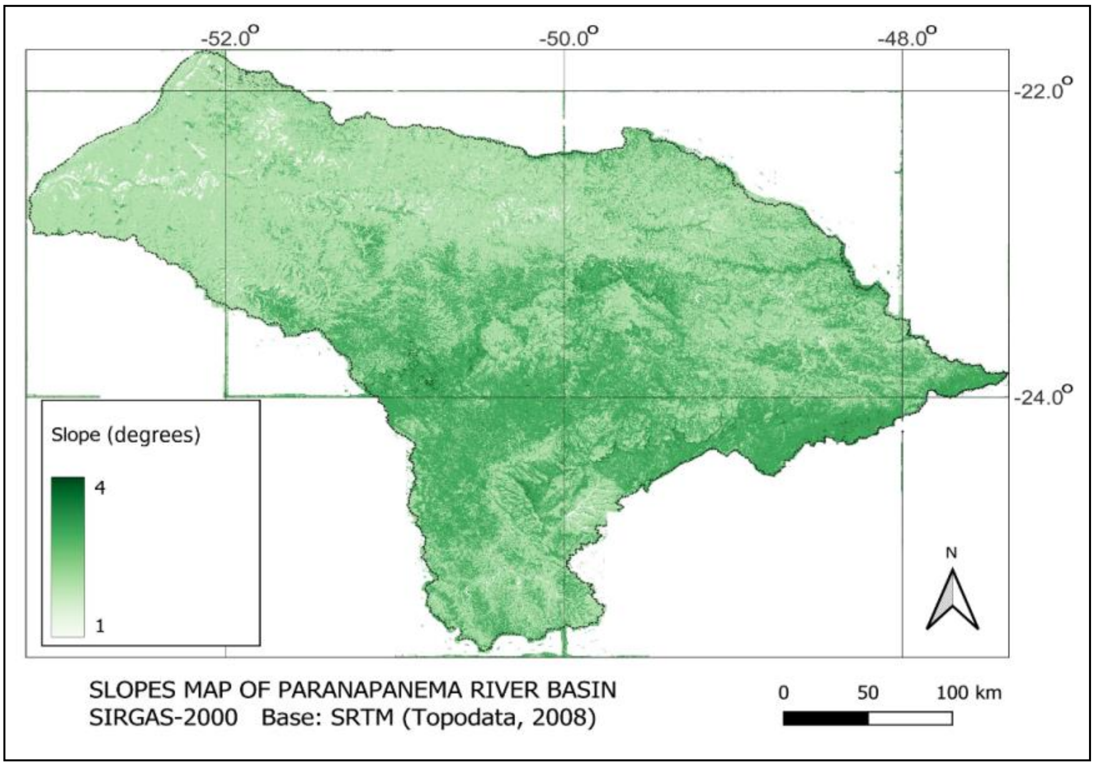

Fig. 4 – Slope Map of Paranapanema River Basin.
Source: Produced by the author (2024).

From the results based on the averages of the soil type plots, the soil erodibility of the Paranapanema River Basin emerges as 0.02 t/ha/year.

If we consider 4.4% as the average slope and 10 meters as the ramp length, the LS factor can be estimated as the following formula:

$$S = 0.00654 \times 0.044^2 + 0.0456 \times 0.044 + 0.065 \quad (1)$$

The index was calculated as having the value of 0.67 when the parameters to estimate the LS factor were applied.

Figure 5 shows the geographical distribution of land cover classes in the Paranapanema River Basin.

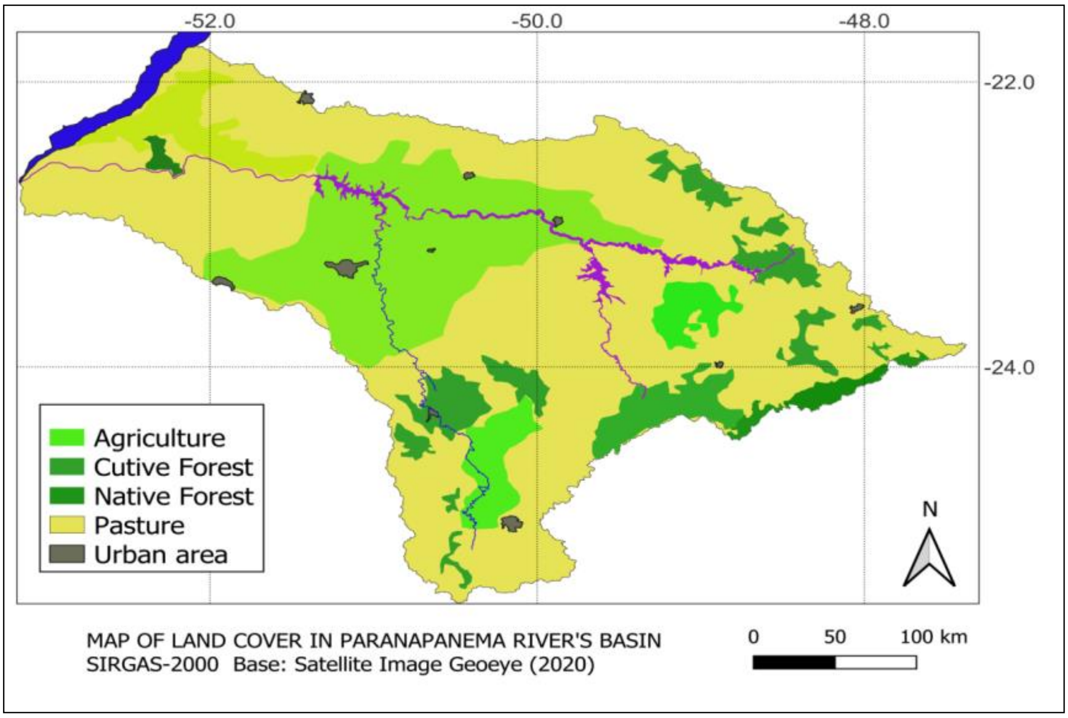

Fig. 5 – Map of Land Cover of Paranapanema River Basin.
Source: Produced by the author (2024).

To obtain the land cover factor (C), the plots of the areas of the land cover classes were calculated according to the Table 3.

Table 3

Factor of land cover (C) in Paranapanema River Basin

Land Cover class	Area (ha)	Index C	C (t/ha/y) (Area x Index)
Agriculture	1,651,933.3	0.11420	340,316.00
Planted forest	2,708,116.2	0.00300	27,605.55
Native forest	909,094.0	0.00003	4.79
Pasture	5,468,403.7	0.37000	2,412,03
∑	10,737,547		2,779,956.33
	Average (C/Area)		0.2589

Source: Produced by the *author* (2024)

The land cover factor for the Paranapanema River Basin was estimated at 0.2589 t/ha/y.

Regarding the factor of conservation practices in the Paranapanema River Basin, approximately 60.7% of the area is made up of pastures land, and about 75% has no conservation practices. In terms of agricultural terrain, which make up about 27.7% of the watershed area, approximately 30% do not have conservation practices. By analysing the territorial areas, we are able to the index of conservation practices index at 0.66.

To conclude, the Universal Soil Loss Equation applied in the Paranapanema River Basin can be expressed as the following formula:

$$A = 7{,}884 \times 0.02 \times 0.67 \times 0.26 \times 0.66 \quad (2)$$

The estimated water erosion rate for the Paranapanema River Basin was 18.13 t/ha/year.

When considering the total area of the Paranapanema River Basin, the soil loss is 194,671,727 tons per year.

When considering that the density average soil in the Paranapanema River Basin is 1.55 t/m^3 (Oliveira, 1994), the estimated sediment production is 302 million tons per year.

4. DISCUSSIONS AND CONCLUSIONS

The Paranapanema River Basin has more than 10 million hectares, a diversity of soils, meteorological and hydrological conditions, including changes in agricultural practices since the beginning of territorial occupation with the planting of coffee in the 1920s. Starting in the 1970s, many pasture areas were replaced by sugarcane plantations and the urban expansion.

In the northern part of the Paranapanema River Basin, despite having lower rainfall with lower erosivity, the erosion processes are more intense. The territorial areas to the north stand out the proximity of the city of Marília, with very sandy soils, as well as the region of the city of Presidente Prudente. In the case of the southern areas of the Paranapanema River Basin, the clayey soils maintain a low erodibility rates, thus registering a lower loss of soil, despite a history of higher rainfall volumes, as is the case of the sub-basin of the Tibagi River, near the city of Londrina.

The Paranapanema River Basin has hydroelectrics, due to the large flow of the plateau rivers. Large areas were flooded to form reservoirs for hydroelectric power plants, leading to biodiversity losses and submerged soils.

When discussing the analysis of the results of the application of the Universal Soil Loss Equation, it is mainly rural erosion that stands out, with the production of sediments that can silt up the reservoirs of hydroelectric plants and generate future problems for the energy matrix as well as losses of resources providing water.

Although the Universal Soil Loss Equation is a method that has been applied since the 1970s, there are few applied research in Geography, whose spatial analyses of geoprocessing contribute to scientific improvement.

The estimation of soil losses entails the geographical analysis of the climatic aspects of the erosivity factor, the pedological aspects of the erodibility factor, the relief conditions of the topographic factor and the land cover changes, which are topic frequently addressed by geographers.

The research contributes by providing the cartographic analysis of soil erosion's influencing factors, using geographic information system in a database to generate cartographic documents. Cartography, together with the existence of a geographic database contributes to the application of a policy for soil zoning and for avoiding the deforestation of new areas, in addition to the implementation of conservation practices in the altered areas.

The research may advance in the terms of production of land cover maps for different periods, as well as in terms of the applications of the estimates regarding studies on surface runoff and water erosion.

Soil conservation in the Paranapanema River Basin requires a policy to help temper land use, promote the recovery of deforested areas, the implementation of policies for water resources management units. The loss of soils equates to food and energy insecurity, since soil is a finite natural resource, which requires on hundreds of years to recover and maintain its fertility for the development of life.

REFERENCES

Bennett, H. H. (1972), *Elements of soil conservation*. 2.ed. New York: McGraw Hill Book Company, 165 p.

Bertol, I., Schick, J., Batistela, O., Leite, D., Amaral, A.J. (2002), *Erodibilidade de um Cambissolo húmico alumínico léptico, determinada sob chuva natural entre 1989 e 1998*. Brazilian Journal of Soil Science, **26**(*2*), pp. 465–471.

Bertol, I., Leite, D., Engel, F.L., Cogo, N. P., González, A.P. (2007), *Erodibilidade de um Nitossolo háplico alumínico determinada em condições de campo*. Brazilian Journal of Soil Science, **31**(*5*), pp. 541–549.

Bertoni, J., Lombardi, F. (1999) *Conservação do Solo*. São Paulo: Ícone, 125 p.

Braido, L. M. H. (2015), *Geocomplexo: Interação de elementos naturais e sociais - Produção e expansão da cana-de-açúcar na Bacia do Rio Paranapanema*. Thesis (PhD in Geography), School of Sciences and Technology, São Paulo State University, 182 p.

Freire, O., Godoy, M. C. T. F., Carvalho, W. A. (1992), *Erodibilidade de alguns solos do oeste do Estado de São Paulo*. Journal of Geography, **11**(*1*), pp. 77–87.

Golosov, V., Walling, D. E. (2019), *Erosion and sediment problems*: global hotspots. Paris: UNESCO, 215 p.

Laflen, J. M., Moldenhauer, W. C. (2003), *The Story USLE*: pioneering soil erosion prediction. Beijing: World Association of Soil and Water Conservation, 94 p.

Larach, J. O. I., Cardoso, A., Carvalho, A. P., Hochmuler, D. P., Fasolo, P. J., Rauen, M. J. (1984), *Levantamento e reconhecimento dos solos do Estado do Parana*. Rio de Janeiro: Empresa Brasileira de Pesquisa Agropecuária, Serviço Nacional de Levantamento e Conservação de Solos.

Merten, G. H., Minella, J. P. G. (2013), *The expansion of Brazilian agriculture: soil erosion scenarios*. International Soil and Water Conservation Research, **3**(*1*), pp. 37–48.

Montgomery, D. R. (2007), *Soil erosion and agricultural sustainability.* Proceedings of the National Academy of Sciences of the United States of America, **104**(*33*), pp. 13268–13272.

Oliveira, A. M. S. (1994), *Depósitos tecnogênicos e assoreamento de reservatórios*: exemplo do Reservatório de Capivara, Rio Paranapanema, SP/PR. Tese (Doutorado em Geografia Física), Universidade de São Paulo, Faculdade de Filosofia, Letras e Ciências Humanas, 211f.

Oliveira, J. B., Camargo, M. N., Rossi, M., Calderano, B. (1999), *Soils Map of São Paulo State*: Campinas: Institute Agronomic of Campinas.

Panagos, P., Borrelli, P., Matthews, F., Liakos, L., Bezak, N., Diodato, N., Ballabio, C. (2022), *Global rainfall erosivity projections for 2050 and 2070*. Journal of Hydrology, **610**(*35*), pp. 245–253.

Rúbio, M. F. (2014), *Gênese e dinâmica de erosões em margens de reservatórios*: Pesquisa e desenvolvimento no estudo de caso nas UHEs Chavantes e Rosana (Rio Paranapanema, SP/PR). Thesis (PhD in Physical Geography), São Paulo University.

Tibúrcio, J. A. (2021), *Bacia do Alto Paranapanema*: direitos fundamentais do desenvolvimento sustentável e o controle da erosão do solo. Belo Horizonte: Dialética Books.

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