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SOIL LOSS ESTIMATE IN THE CUBATÃO DO NORTE RIVER HYDROGRAPHIC BASIN, NORTHEAST OF SANTA CATARINA, BRAZIL

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ABSTRACT

The main objective of this paper was to apply the Revised Universal Soil Loss Equation (RUSLE) through Geographical Information System (GIS) in the Cubatão do Norte watershed, in Joinville and Garuva municipalities of Santa Catarina State. The map of annual estimated soil loss by water erosion showed minimum erosion rates of 429.28, average of 854.61 and maximum of 1,579.49 t/ha/year. Soil loss due to water erosion in the Cubatão do Norte watershed can be considered low, since 97.58% of the basin area presented none or slight annual average soil loss, ranging from 0 to 10 t/ha/year. Only 1.79% of the watershed has annual moderate soil loss with values ranging from 10.1 to 50 t/ha/year. The high and very high-rate of soil loss with values greater than 50 t/ha/year represents only 0.50% of the watershed studied. The large area covered by native forest was the principal maintenance factor of low erosion rates. The exposed soil and the early stage vegetation, located in medium and high slopes, Argissolo Amarelo (Acrisol) and Cambissolo Háplico (Cambisol), presented the highest rates of soil loss due to water erosion.

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INTRODUCTION

The erosion process has been subject of a major concern in Brazil (Da Cunha et al., 2017) and in the world (Ganasri & Ramesh, 2016), since it is the main cause of soil degradation as a result of its fast processing and because it entails huge damages to the environment, with economic and social consequences. According to Carvalho *et al.* (2014), these processes are natural events on the surface of the earth and are characterized by the fragments of rocks and soils' transportation and disintegration, linked to the physical characteristics of the environment. Therefore, many factors can influence the erosion process, such as the climate, the relief, the soil types, the soil use and occupation, among other factors (Ganasri & Ramesh, 2016). Such processes can be caused or intensified by human activities, resulting in temporary or even permanent imbalances (Eduardo *et al.* 2013).

According to Tomaz (2002), erosion in Brazil reaches an average of 25ton/ha/year; and one of the erosion factors that has contributed the most to the silting of rivers and dams, soil unproductivity, damages to engineering works, reduction of areas for agricultural exploitation, is, undoubtedly, the water erosion accelerated by man through inappropriate soil use and management practices (Angima *et al*., 2003; Aksoy & Kavvas, 2005). Natural factors influencing the erosion process include: the amount and distribution of rainfall, the slopes, the length and shape of the hillsides, the soil chemical and physical properties, the vegetation cover type, and the human action, in the form of soil use and management, which, most times, tend to accelerate the erosion processes (Wishmeier & Smith, 1978; Guerra & Mendonça, 2004). However, it is reasonable to say that two main elements are responsible for triggering the erosion process: the water erosion, as active element, and the soil erodibility, as passive element.

Additionally, the other factors impact either facilitating or hindering the erosion process. Simulation models, such as erosion-prediction mathematical models, are powerful tools in agricultural research and practices, with such models helping to determine, when applied in the field, management and conservation practices that are most appropriate to the different application scenarios (Chaves, 1996). Amorim *et al.* (2010) argues that existing erosion prediction models have been developed and adjusted to mild weather conditions, differing, therefore, from the tropical weather. In this sense, it is extremely important to assess the applicability of these models to Brazilian soil & weather conditions. The areas most susceptible to erosion present greater potential to carry pollutants into the drainage network, such as nutrients, organic materials and pesticides attached to the soil particles, thus deteriorating the quality of water (Cavichiolo*,* 2005).

Galdino *et al.* (2016) certified that the use of the Geographic Information System (GIS) is an important tool to detect changes for land use cover and to apply automatic models for soil loss estimate in complex slopes and hydrographic basins.
One of the most used models around the world for estimating the annual soil loss average is the Universal Soil Loss Equation - USLE), developed as of 1950 by Wishmeier & Smith (1978). USLE consists of an empirical equation that seeks to estimate soil loss in annual rates based on the ratio between the factors: rainfall erodibility, erodibility on the length of hillsides and slope, soil type, soil cover and management practices thereof. USLE, and its successor, the Revised Universal Soil Loss Equation – RUSLE (Renard *et al*., 1997), were designed to calculate the average soil loss in agricultural areas, but in recent years it has been used for other types of erosion, such as forest areas, surface mining, and in hydrographic basin studies. The main purpose of RUSLE is to serve as a systematic guide in soil conservation planning (Renard *et al*., 1997). This purpose of this study is to perform a numeric computational simulation of the erosion processes for calculation of soil loss estimates in Cubatão do Norte River basin, state of Santa Catarina / Brazil, thus contributing to the development of occupation and use-of-space activities, aiming at the conservation of soil and water resources.

MATERIALS AND METHODS

Study Area

The study was carried out in the northeast region of Santa Catarina, covering the municipalities of Joinville and Garuva – totaling an area of 492 km² – and the main river with a length of 88 km. The source of Cubatão do Norte River is located in Serra Queimada, at an altitude of 1,100m and its mouth in the Bay of Babitonga, being the main water supplier of the bay (Figure 1). The weather in the region can be classified according to the Köeppen scale as "moist mesothermal climate without defined dry season (Cfa)", because its geographic location is subject to the entrance of tropical sea masses that, when colliding with the Coastline, result in the so-called orographic frontal precipitation (Pandolfo et al., 2002).

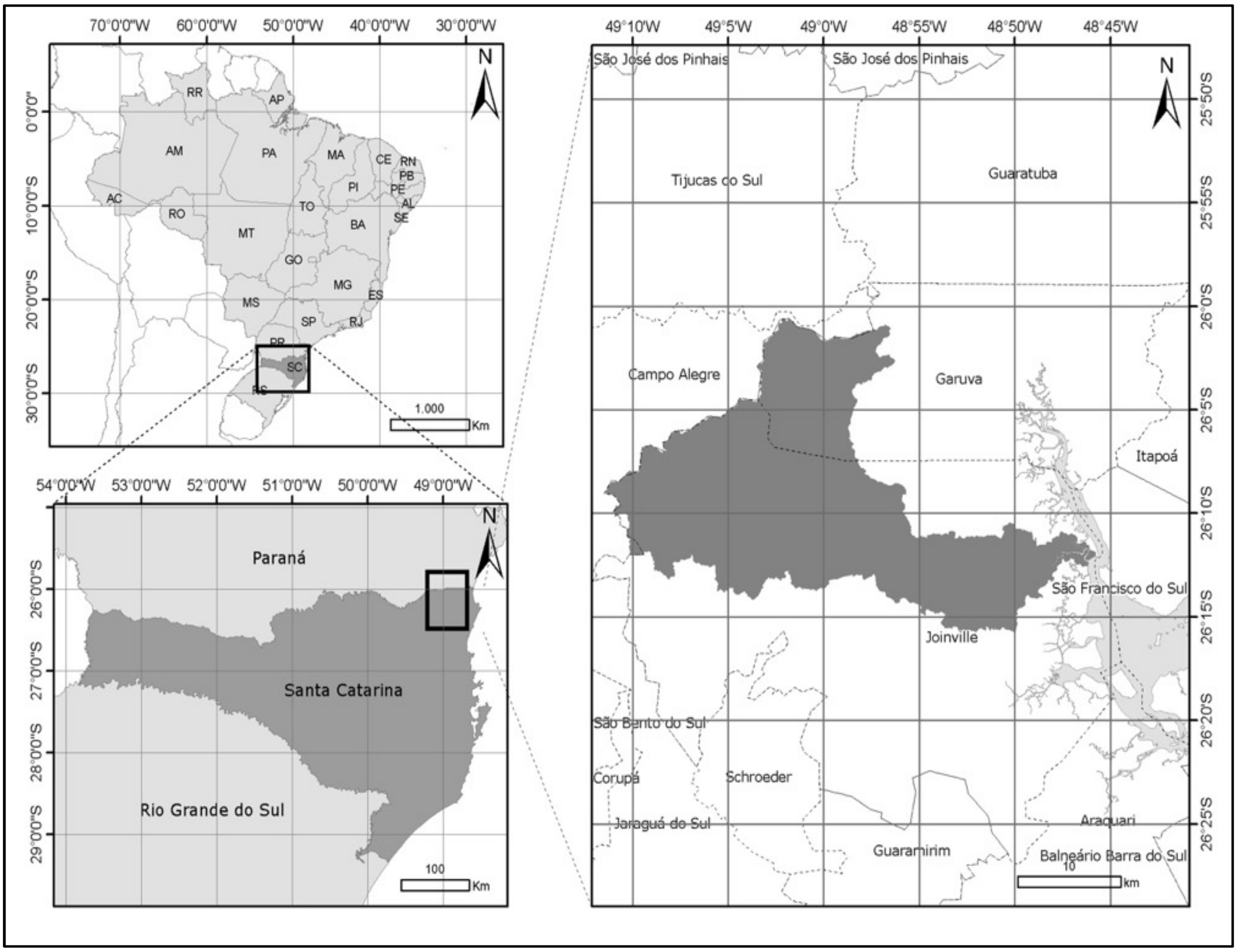

Figure 1. Location of Cubatão do Norte River hydrographic basin.

Table 1. Rainfall data and Calculated factor R-values

Month	Monthly average rainfall (mm)	R = (MJ/ha)*(mm/h)
January	232	104,61
February	242	112,39
March	240	110,81
April	148	48,71
May	124	36,06
June	102	25,87
July	97	23,75
August	106	27,62
September	149	49,27
October	165	58,61
November	159	55,03
December	173	63,52

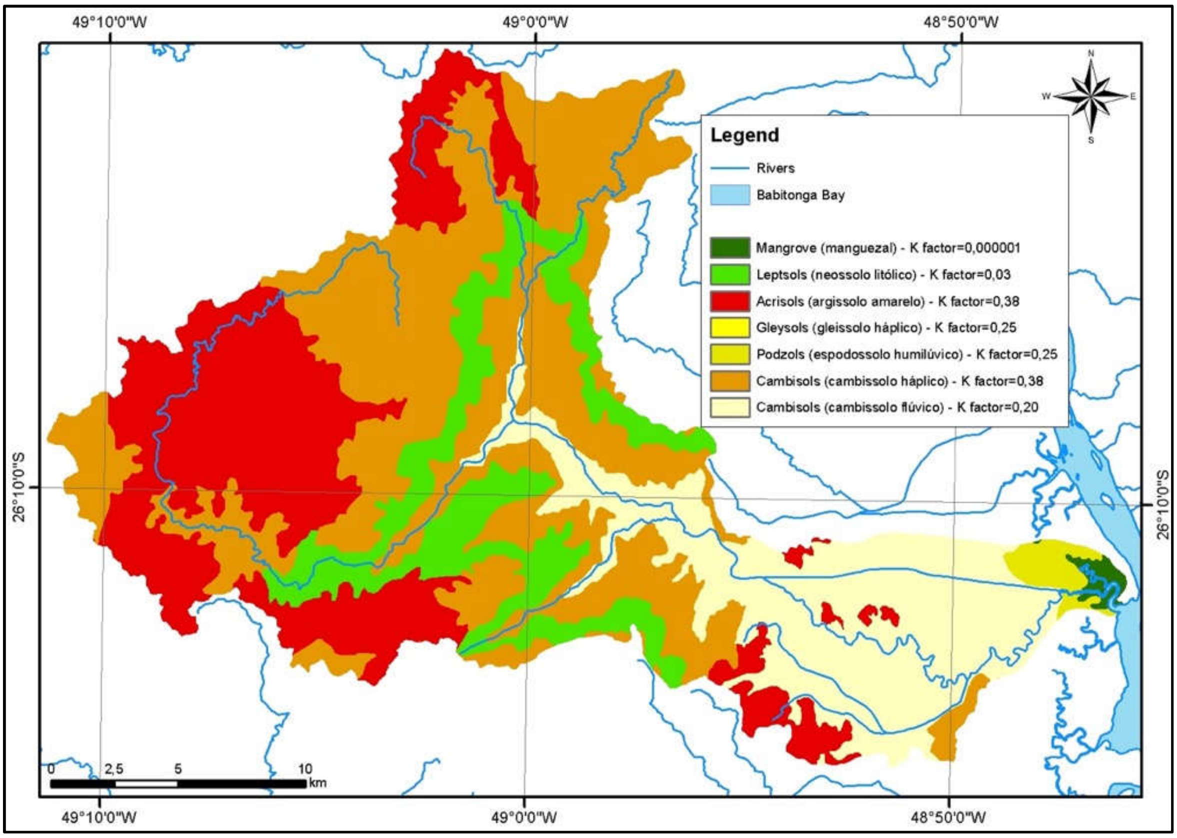

Figure 2. Mapping of Cubatão do Norte River hydrographic basin soils

The hydrographic basin of Cubatão do Norte River covers three geomorphological units: the plateau, the scarpment and the coastal plain. It is possible to find different ecosystems along the route that vary from *campos de altitude*, mixed ombrophylous forests (araucaria forest), dense ombrophylous forest, to restinga vegetation and mangroves that make up the Atlantic Forest biome (Zanotelli et al., 2009). The river basin is further responsible for approximately 70% of the public potable water supply in the municipality of Joinville.

Revised Universal Soil Loss Equation – Rusle

The Universal Soil Loss Equation - USLE (Wischmeier & Smith, 1978) and the revised version thereof, RUSLE, (Renard et al., 1997) were designed to estimate during a period of time the annual soil loss average (A) and involve six erosion factors: A = R*K*L*S*C*P. Where erosion factors are: A = Soil loss (ton/ha/year); R = Rainfall erosion factor (MJ/ha)*(mm/h); K = Soil erodibility factor (ton/ha)*(Mj/ha)*(mm/h); L = Ramp length factor (dimensionless); S = Slope level factor (dimensionless); C = Soil cover and use factor (dimensionless); P = Conservation practices factor (dimensionless).

Rainfall Erosion Factor (R): The rainfall erosion factor (R) is a numerical index representing the rainfall potential to cause erosion in unprotected areas (Bertoni & Lombardi Neto, 1985). The soil loss caused by rainfall in a cultivated area is directly proportional to the result of the rainfall kinetic energy by its maximum intensity in 30 minutes. Such result is named Erosion Index (EI30). The EI30 annual value average of a long period of time (over 20 years) is the value of the rainfall erosion factor (R). The rainfall erosion factor (R), as defined by Bertoni and Lombardi Neto (1985), can be estimated as follows: $EI = 6{,}886 \times (r^2/P)^{0{,}85}$, where EI = erosion index monthly average (MJ.mm/h.ha); r = rainfall monthly average (mm); P = rainfall annual average (mm). Rainfall data were obtained from the Climatological Atlas of the State of Santa Catarina (Pandolfo, 2002) and Mello *et al.* (2015, 2016), and the monthly averages of a period of 20 years were considered.

Soil Erodibility Factor (K): According to Righetto (1998), the soil erodibility factor (K) is the soil loss rate by the rainfall erosion unit for a reference place corresponding to a certain soil. The percentage of sand, silt and organic matter is necessary to find the erodibility value (K). K value represents the soil susceptibility to erosion and the runoff amount. The soil texture, the organic matter, the structure and the permeability determine the erodibility of a particular soil. The determination of the erodibility factor was developed according to Wanielista (1978), while the proportion of clay, silt and sand in the soil composition were obtained from Uberti (2011), and the texture was determined through the texture triangle proposed by the United States Department of Agriculture (USDA, 1975).

Topographic Factor (LS): The Topographic Factor (LS) combines the hillside average slope (S) with the ramp length (L). The Ramp length factor (L) directly impacts the soil loss, because very longs ramps might result in high-speed flows. LS values have been calculated using the equation proposed by Bertoni & Lombardi Neto (1985): $LS = 0,00984*S^{1,18}*L^{0,63}$, where LS = Topographic factor, S = hillside average slope (%) and L = ramp length (m). For calculating the topographic factor the topographic maps of the Brazilian Institute of Geography and Statistics (IBGE) were used in scale 1:50,000. The digital elevation model (DEM) created was corrected in ArcGIS® 10.1 by using the Fill tool, which caused the sinks to be filled and the peaks removed, thus changing the values of these cells and creating a model hydrologically correct. Subsequently, in ArcGIS® 10.1, the ramp length (L) was calculated by applying the flow accumulation routine by the eight-direction flow method (Jenson & Domingue, 1988) and the slope (S) with percentage calculation.

Conservation Practices and Land Use & Cover Factors (CP): The **land** use and cover factor (C) and conservation practices (P) are treated separately when working with small hydrographic basins and when the agricultural use has great relevance in the occupied area, so that conservation practices influence the rates of soil loss (Eduardo *et al.,* 2013). Factor C expresses the ratio resulting from the soil loss and soil use & cover. Land use and cover data have been obtained from the supervised classification of the LANDSAT TM satellite image, which enabled the identification of ten classes of land use and cover. The values of land use and cover (C) and soil conservation practices (P) have been defined according to Bertoni & Lombardi Neto (1985) and Righetto (1998). All data have been inserted and manipulated in the ArcGIS® 10.1 software, using UTM projection and SIRGAS2000 datum.

RESULTS

Rainfall Erosion Factor (R)

The rainfall data and the erosion indexes (EI) used for Factor R calculation are listed on Table 1. The annual average rainfall in the hydrographic basin was 2.192 mm, and the monthly average rainfall was 161,41 mm. The month with the highest rainfall rate was February, reaching 242 mm, while the month with the lowest rainfall rate was July, with 97 mm. The rainfall erosion value (R) calculated for the place of the study was 716,30 (MJ/ha)*(mm/h). The summer months have an average R-value of 109,27 (MJ/ha)*(mm/h), and the lowest R-values occur in winter, at an average of 33,54 (MJ/ha)*(mm/h).

Soil Erodibility Factor (K)

Soil mapping in the place of the study has identified the occurrence of six soil types, according to the Brazilian Soil Classification System (EMBRAPA, 2006), namely: *Argissolo Amarelo* (Acrisol), *Cambissolo Flúvico* (Cambisol), *Cambissolo Háplico* (Cambisol), *Espodossolo Humilúvico* (Podzol), *Gleissolo Háplico* (Gleysol) and *Neossolo Litólico* (Leptosol). According to the soil mapping (Figure 2), the soils with higher occurrence in the hydrographic basin are the *Cambissolo Háplico* (Cambisol), the *Argissolo Amarelo* (Acrisol) and the *Cambissolo Flúvico* (Cambisol). We found (Table 3) that soil types more susceptible to erosion are the *Argissolo Amarelo* (Acrisol) soil and the *Cambissolo Háplico* (Cambisol) (0,38 ton/ha*Mj/ha*mm/h), with erodibility index approximately 10 times higher than the *Neossolo Litólico* (Leptsol) (0,03 ton/ha*Mj/ha*mm/h). The average soil erodibility value (Factor K) in the hydrographic basin was 0,24 ton/ha*Mj/ha*mm/h.

Topographic Factor (Ls)

Values calculated for LS factor presented values between 0 and 65, which were divided into nine classes, as shown in Figure 3. The topographic factor (LS) value range with the highest occurrence in the hydrographic basin was the class from 0 to 4 , with 88.1% of the basin area. The topographic factor values higher than 8 represent 5.1% of the study area and are concentrated mainly in the areas with the highest slope, located in the scarpment, a region covered with extensive preserved fragments of Atlantic Forest. The topographic factor (LS) average value for the hydrographic basin was only 0.85, and the maximum value was 65, located at isolated points on the scarpment.

Land Cover and Use Factor (C)

The soil cover and use map obtained from the supervised classification of the LANDSAT TM Satellite image indicated that the hydrographic basin has 77.39% of its area covered by atlantic forest, 15.76% occupied by fields, 3.77% occupied by shrub, 1.72% occupied by urbanized area and less than 1% occupied by mangrove, exposed soil, rice cultive/crop and water. Table 4 and Figure 4 show soil cover and use data on the area under study, as well as factor C values. The highest factor C value is associated with the exposed soil (C = 1), and the lowest values occur in floodable soil-use classes, such as water (C = 0) and mangrove (C = 0.000001). The average value of C in the hydrographic basin was 0.1163.

Conservation Practices Factor (P)

For the conservation practices factor (factor P) (Table 4 and Figure 5), the areas covered by atlantic forest, *campos de altitude*, pasture, the exposed soil and the urbanized areas have the same value of P: 1,0. The area covered by shrub has a P value of 0,75, and the rice cultive areas have a value of 0,5. The floodable soil-use classes have the smallest P values, such as mangrove and water, with P=0,000001 and 0, respectively.

Annual Soil Loss Average (A)

The annual soil loss values ranged from 0 to 450 tons/hectare/year, and were divided into 8 classes, as shown in Figure 6 and Table 5.

Table 3 – Factor K, texture and Soil Class

Soil class (EMBRAPA, 2006)	Soil class WRB/FAO (IUSS, 2015)	Texture	Factor K
Argissolo Amarelo	Acrisols	Clay	0,38
Cambissolo Háplico	Cambisols	Clay-sandy	0,38
Cambissolo Flúvico	Cambisols	Loam	0,20
Espodossolo Humilúvico	Podzols	Sandy-loam	0,25
Neossolo Litólico	Leptsols	Sand	0,03
Gleissolo Háplico	Gleysols	Sandy-loam	0,25

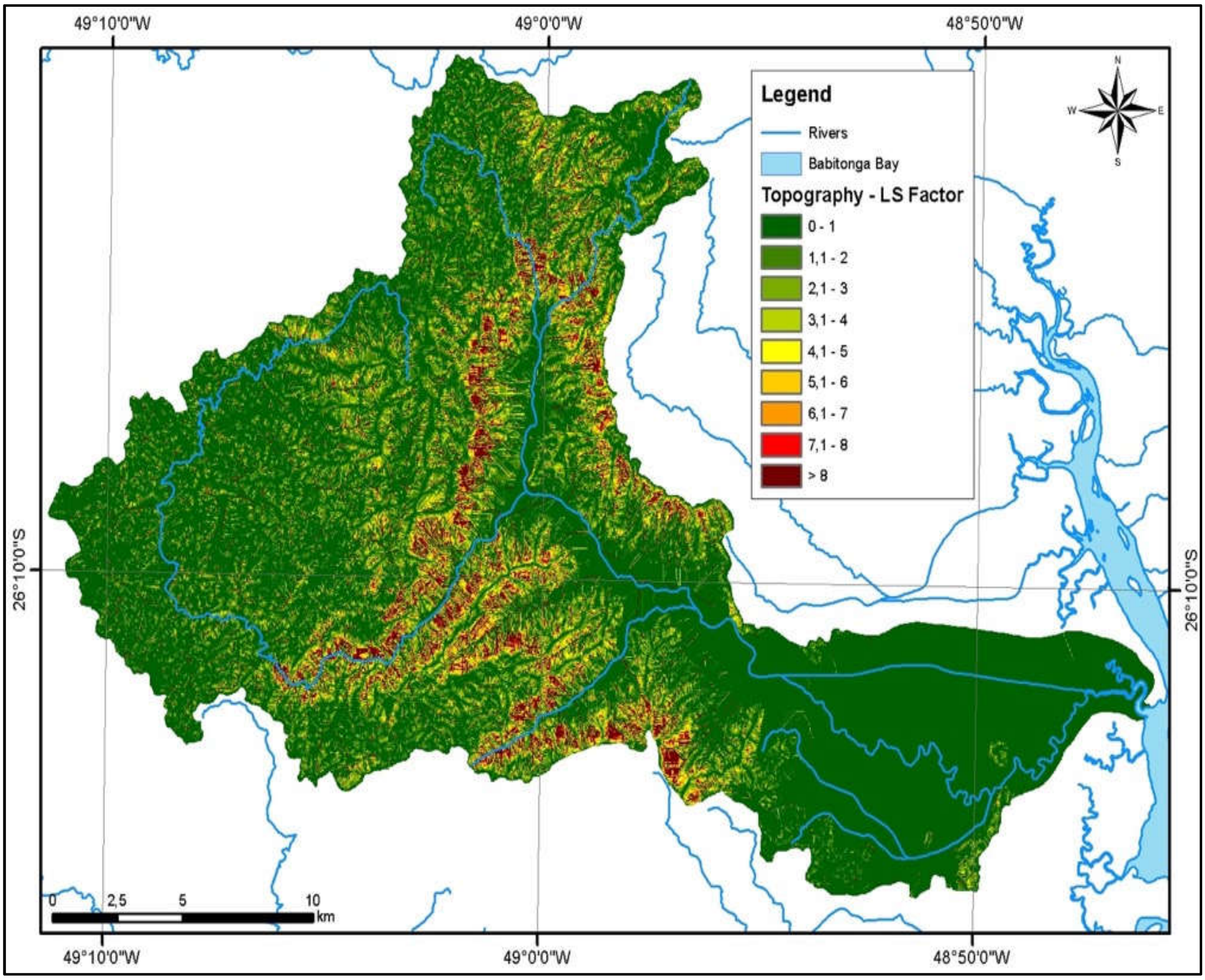

Figure 3: Rio Cubatão do Norte hydrographic basin's LS-factor Map

Taking into consideration the area of occurrence of soil loss classes, we identify that the annual soil loss has a minimum value of 429.28 and a maximum of 1,579.49 tons/ha/year. The annual soil loss average in the hydrographic basin was 854.61 tons/ha/year, with higher values located mainly in the scarpment.

DISCUSSION

Rainfall erosion factor (Factor R) has evidenced that the area where the study take place is very rainy, with averages ranging from 1.600 to over 3.000mm per year, which has generated an erosion factor of 716,30 (MJ/ha)*(mm/h). Guimarães *et al.* (2011), in study at a Cubatão do Norte River sub-hydrographic basin, has identified values ranging from 746,3 to 1186,7 (MJ/ha)*(mm/h), with average value of 940,1 (MJ/ha)*(mm/h). Carvalho *et al.* (2012, 2014). Likewise, Guimarães *et al.* (2001) have also identified higher rainfall erosion factor values during summer months and lower values during winter months. Soils with higher erodibility potential identified in the hydrographic basin were the *Argissolo Amarelo* (Acrisol) and the *Cambissolo Háplico* (Cambisol), with erodibility (Factor K) of 0.38 ton/ha*Mj/ha* mm/h. Guimarães et al. (2011) has identified very similar values for the same soils. Accordingly, the work developed by Uberti (2011), Carvalho et al. (2014) also indicated that the *Argissolo Amarelo* (Acrisol) and the *Cambissolo Háplico* (Cambisol) are soils with high water erodibility potential, including a large presence of scars caused by mass movement. The highest frequency values for the topographic factor (LS Factor) were acceptable, since the areas under study have as predominant relief classes: the heavily undulating relief (23.8%), the mountainous relief (18.6%) and the heavily mountainous relief (26.2%). Silva (2003), in areas with a predominant highly undulating mountainous relief, have identified that 81.9% of the area under study had LS factor values between 0 and 4, a result very similar to the present study. Changes to the soil cover and use values (C) and conservation practice (P) can reduce by over 55% the soil classes erodibility (Eduardo *et al.*, 2013) in temporary crops.

Table 4. Land Cover & Use Classes and values of C & Factor P in Cubatão do Norte River hydrographic basin

Class	Factor C	Factor P	Area (km²)	Area (%)
Atlantic Forest	0,0001	1,0	367,63	74,64
Pasture	0,01	1,0	69,67	14,14
Shrub	0,10	0,75	18,56	3,77
Silviculture	0,05	1,0	13,56	2,75
Urbanized Area	0,03	1,0	8,47	1,72
Campos de altitude	0,01	1,0	8,01	1,62
Mangrove	0,000001	0,000001	2,21	0,45
Exposed Soil	1	1,0	1,72	0,35
Water	0	0	1,74	0,36
Rice Cultivated	0,07	0,50	0,96	0,2

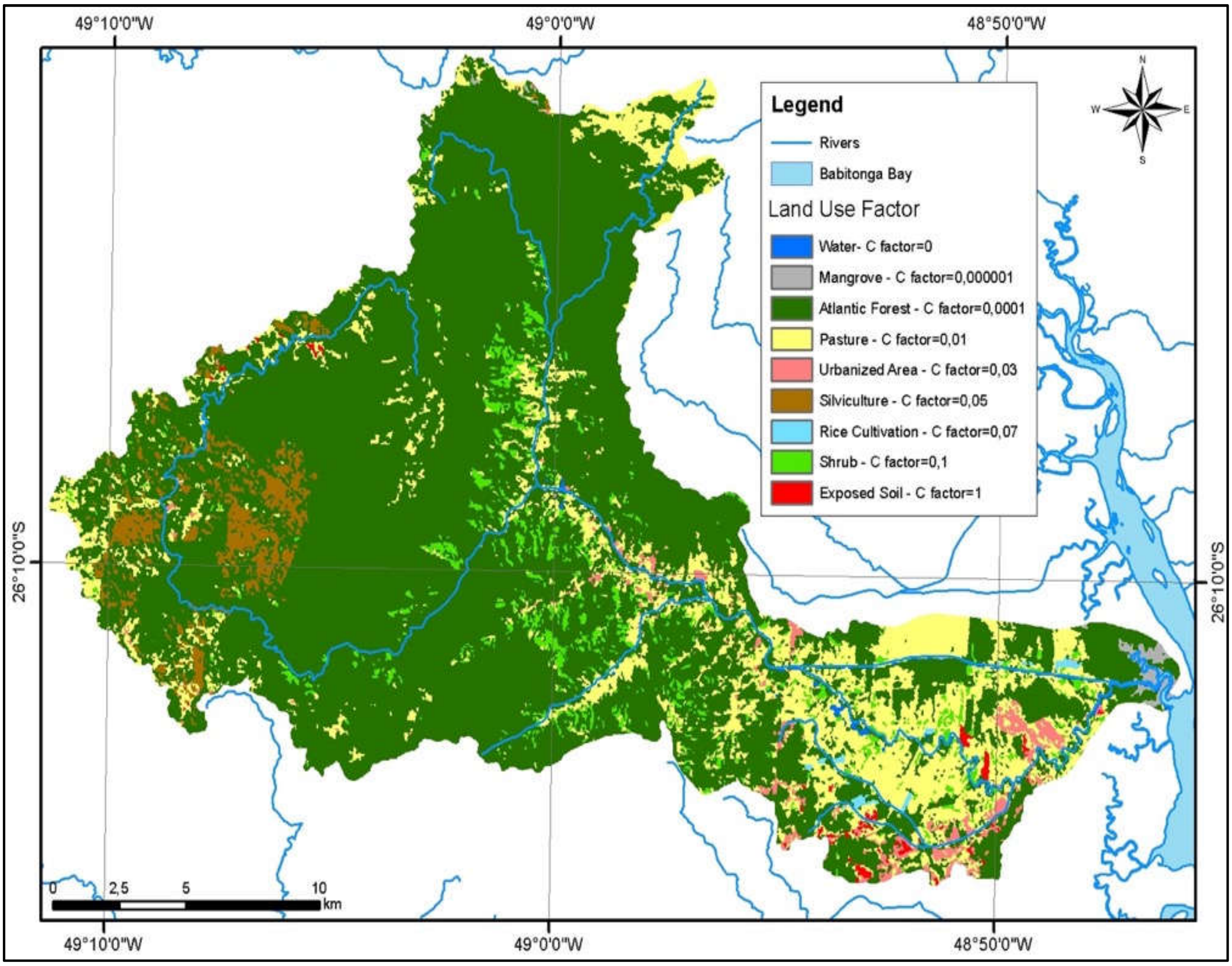

Figure 4. Land Use & Cover Map and Factor C in Cubatão do Norte River hydrographic basin.

Galdino *et al.* (2016) have indicated that changes to the conservation practices in grazing areas can result in a variation of 709% in erosion rates. Cubatão do Norte River hydrographic basin has no major changes in factors C and P, in view of the great amount of atlantic forest and small agricultural areas. After general analysis of soil loss estimate (Factor A) it was observed that 97,58% of the hydrographic basin of Cubatão do Norte River presented annual soil loss estimate between 0 and 10 t/ha/year, which according to the *Food and Agriculture Organization* (FAO, 1967) represents no soil loss or slight soil loss. The big area of preserved forests played an important role in maintaining these erosion rates low. Most reforestation areas have demonstrated annual soil loss potential within this range. The areas that presented higher soil losses due to water erosion were, mainly, the areas with exposed soil and shrub with steep slope.

The forestry area obtained a low soil loss potential, but it is necessary to evidence that the analysis of soil loss due to water erosion represents a punctual situation. According to Guimarães et al. (2011), in an analysis in forestry areas (silviculture), have indicated that the cutting promoted soil exposure to erosion processes, thus being possible to reach soil loss rates of over 200 t/ha/year, as observed in areas with exposed soil class.

The results of the annual soil loss have indicated that most of the hydrographic basin has a relief characteristic with high slopes and high occurrence of *Argissolo Amarelo* (Acrisol) and *Cambissolo Háplico* (Cambisol), which has high susceptibility to erosion (Uberti, 2011). The predominant soil loss class was from 0 to 1 t/ha/year, covering 449.58 km^2, which is equivalent to 91.86% of the total hydrographic basin area.

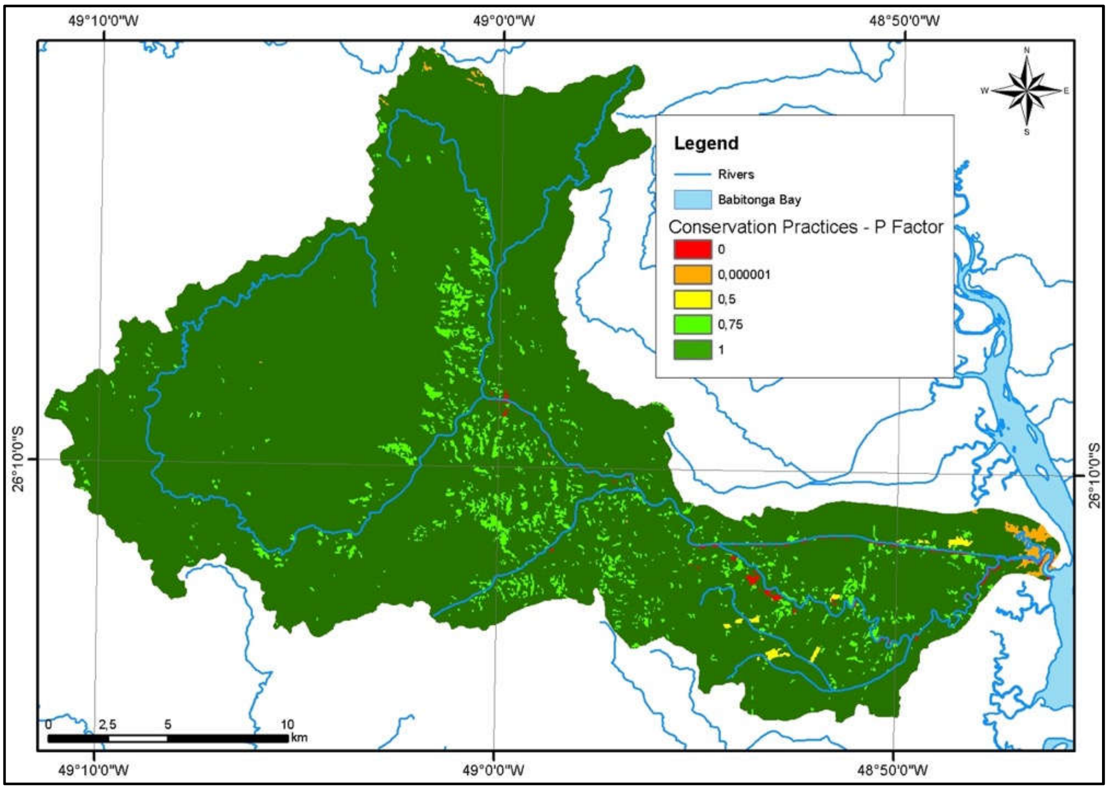

Figure 5: Conservation practices map (factor P) in Cubatão do Norte River hydrographic basin

Table 5: Annual Soil Loss Classes (Factor A)

Soil loss (tons/ha/year)	Area (km^2)	Area (%)	Soil loss classes (FAO, 1967)
0 – 1,0	449,58	91,86	None or slight
1,1 – 3,0	14,62	2,98	None or slight
3,1 – 5,0	6,23	1,27	None or slight
5,1 – 10,0	7,21	1,47	None or slight
10,1 – 20,0	4,94	1,00	Moderate
20,1 – 50,0	3,88	0,79	Moderate
50,1 – 200,0	2,41	0,49	High
> 200,0	0,52	0,10	Very high

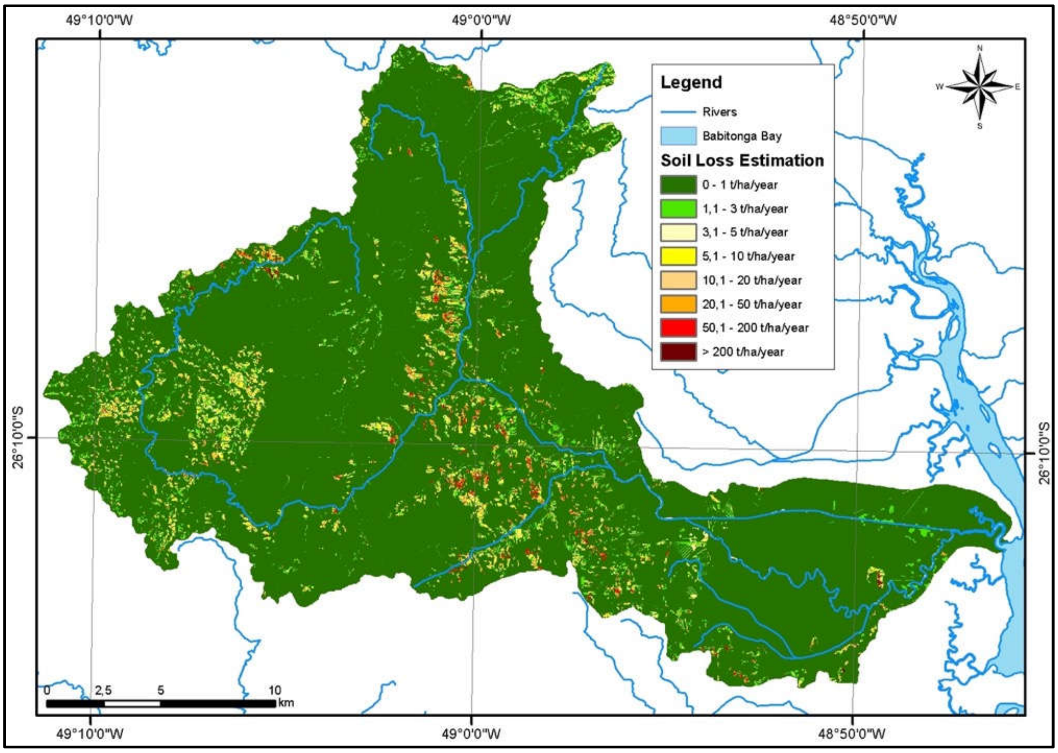

Figure 6. Soil loss estimate map by water erosion in Cubatão do Norte River hydrographic basin.

The area of occurrence of this soil loss class extends basically over the areas covered by atlantic forests, which represent 74.64% and fields/pastures with 14.14%. In this case, the conservation practices and the soil use factor (Factor C and P) was the factor that most contributed to the maintenance of this low index of annual average soil loss (Eduardo *et al.*, 2013; Galdino *et al.* (2016), considering that such class occurs either in *Argissolo Amarelo* (Acrisol) and *Cambissolo Háplico* (Cambisol) or in regions with large slopes.

Three classes with very similar amounts had the second most expressive along the Cubatão do Norte River, with classes ranging from 1.1 to 3 t/ha/year, 3.1 to 5 t/ha/year and 5.1 to 10 t/ha/year. Which comprising 5.72% of the total area of the basin, with predominant soil use by silviculture (forestry), shrub and pasture. The soil loss class from 10,1 to 50 t/ha/year is less expressive (1,79%), in isolated and discontinuous areas, mainly associated to shrub and pasture. The soil loss class from 50,1 to 200 t/ha/year comprises only 0,49% of the hydrographic basin and is directly associated to the exposed soil, *Cambissolo Háplico* (Cambisol) soil type, LS factor above 5 and conservation practices factor between 0.75 and 1. The class above 200 t/ha/year represents only 0,10% of the hydrographic basin. This soil loss class is directly related to the exposed soil and shrub, *Cambissolo Háplico* (Cambisol) soil type, LS factor above 8 and conservation practices factor between 0,75 and 1.

Conclusion

The soil loss due to water erosion at the Cubatão do Norte River hydrographic basin can be considered low, once 97.58% of the basis area represented none or slight annual soil loss, with 0 to 10 t/ha/year. Only 1,79% of the hydrographic basin has moderate annual soil loss, with values ranging from 10,1 to 50 t/ha/year. High and very high soil loss rates, with values higher than 50 t/ha/year represent only 0.50% of the hydrographic basin under study. The exposed soil and shrub regions located in *Cambissolo Háplico* (Cambisol) and *Argissolo Amarelo* (Acrisol) soils, with large ramp lengths and usually with moderate to high slopes, are areas of great risk of soil loss. Under these conditions, the soil loss rates reach values higher than 200 t/ha/year. Therefore, they need special attention with regards to the conservation practices and the monitoring of erosion processes. The application of direct soil loss quantification methods would be extremely important for future works. The field data collection would complement the results obtained in this study and would provide a great advance in the understanding of the erosion processes in the hydrographic basin of the Cubatão do Norte River.

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