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Determination of Soil Erodibility by Different Methodologies in the Renato and Caiabi River Sub-Basins in Brazil

Jones Anschau Xavier de Oliveira [1], Frederico Terra de Almeida [2,*], Adilson Pacheco de Souza [2], Rhavel Salviano Dias Paulista [3], Cornélio Alberto Zolin [4] and Aaron Kinyu Hoshide [5,6]

1 Environmental Sciences, Federal University of Mato Grosso, Sinop 78550-728, MT, Brazil; jonesbr14@gmail.com
2 Institute of Agrarian and Environmental Sciences, Federal University of Mato Grosso, Sinop 78550-728, MT, Brazil; pachecoufmt@gmail.com
3 Postgraduate Program in Environmental Physics, Institute of Physics, Federal University of Mato Grosso, 2367, Av. Fernando Corrêa da Costa, Cuiabá 78060-900, MT, Brazil; rhavel.paulista@sou.ufmt.br
4 EMBRAPA Agrossilvipastoril, Brazilian Agricultural Research Corporation, Sinop 78550-970, MT, Brazil; cornelio.zolin@embrapa.br
5 College of Earth, Life, and Health Sciences, The University of Maine, Orono, ME 04469, USA; aaron.hoshide@maine.edu
6 AgriSciences, Federal University of Mato Grosso, Sinop 78555-267, MT, Brazil
* Correspondence: frederico.almeida@ufmt.br or fredterr@gmail.com; Tel.: +55-(66)-99995-1315

Abstract: Mitigating soil erosion's effects have been prioritized since the early 20th century. Rainfall simulators and analytical prediction models are used to determine soil erosion susceptibility. This study used different methodologies to measure soil erodibility in two hydrographic sub-basins, the Renato and Caiabi, in the Middle and Upper Teles Pires River in Mato Grosso state, Brazil. The rainfall simulator showed a higher range of K-factor values for the Renato sub-basin of 0.0009 to 0.0086 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$ and a lower range of K-factor values for the Caiabi sub-basin of 0.0014 to 0.0031 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$. Soil loss equations similarly estimated a higher range of K-factor values for the Renato of 0.0008 to 0.0990 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$ and a lower range of K-factor values for the Caiabi of 0.0014 to 0.0846 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$. There was no significant difference at the 5% level for the K factor determined by the rainfall simulator for both sub-basins. Equations specified in Bouyoucos (1935) and Lombardi Neto and Bertoni (1975) showed significant correlation (5%) for farming systems in the Caiabi sub-basin. Indirect methodologies that performed well for correlation were equations 2 and 3 from Roloff and Denardin (1994), which use iron and aluminum as parameters. Soil erosion was most influenced by physical texture parameters of the region's soil.

Keywords: analytical methods; erodibility; soil erosion; rainfall simulator; Universal Soil Loss Equation

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1. Introduction

Soil erosion can reflect problems of an economic, social, and mainly environmental nature [1]. Soil erosion is also considered to be a factor that triggers concern worldwide due to the historical prevalence of crop production involving plowing, harrowing, cultivation, and other forms of soil disturbance from repeated tillage [2]. Excessive tillage can result in poor agro-environmental management, which can result in greater soil degradation and degeneration [3]. In Latin America, deforestation of native habitats for agriculture and livestock, such as in the Brazilian Amazon, results in high soil erosion due to direct exposure of the soil [4]. In Sub-Saharan Africa, subsistence farming and expansion into pastures also cause severe soil degradation [5,6]. In Europe, the outcomes vary with agricultural practices and soil conservation regulations [7].

Globally, soil erosion rates are variable, ranging from 17 to 40 metric tons (t) hectare (ha)$^{-1}$ year (yr)$^{-1}$ [8]. Similarly in Brazil for plot-scale surface runoff studies involving natural precipitation, soil loss for major annual commodity crop sequences (e.g., cultivated crop, fallow, etc.) ranges from 5 t ha^{-1} yr^{-1} for sugarcane (*Saccharum officinarum*) to 26.7 t ha^{-1} yr^{-1} for peanut (*Arachis hypogaea*) to 50.3 t ha^{-1} yr^{-1} for bare fallow [9]. Undisturbed land cover, such as forests, can have erosion rates below 0.5 t ha^{-1} yr^{-1} [8]. Perennial crops such as pasture in Brazil also have lower erosion rates averaging 6.5 t ha^{-1} yr^{-1} of soil loss measured in plot-scale surface runoff studies [9].

The Universal Soil Loss Equation developed by Wischmeier and Smith [10] became widespread throughout the world. It is an empirical model that seeks to estimate soil loss through mathematical equations. The Universal Soil Loss Equation (USLE) models erosion through explanatory variables of rainfall erosivity (R), erodibility (K), length of slope (L), slope (S), management (C), and conservation practices (P) [11,12].

Erosion models are widely used to estimate soil loss [13]. The assessment of soil erosion in various countries around the world is based on the Universal Soil Loss Equation (USLE), which is widely accepted [14]. For example, the USLE was applied in studies, such as that by Mahamud et al. (2021) [13], to predict soil loss in the Cameron Highlands, Malaysia. It was also used to estimate soil erosion in Tzicatlacoyan, Puebla, Mexico [15], to analyze soil erosion in the Nan River basin, Thailand [16], and for the integrated use of GIS models and USLE in the Hulan River basin, Northeast China [17].

The erodibility (K factor) is complex since it requires the determination of factors such as physical and chemical soil parameters [18] and the configuration of the aptitude that the soil has in tolerating erosive processes [11]. This erodibility can be determined directly or indirectly. To determine the K factor, Marques et al. [4] and Denardin [19] explain that there are three known methodologies: natural rainfall, rainfall simulators, and erodibility estimates through the verification of physical and chemical attributes using prediction equations related to soil variables.

To provide examples of the applicability of the K factor according to the USLE standard worldwide, several studies can be cited. Gupta et al. (2024) [20] conducted a comprehensive analysis of soil erodibility, considering the effects of saturated hydraulic conductivity. Marques et al. (2019) [4] estimated the K factor to assess the average annual soil erosion and sediment production in the Córrego Água Azul basin, located in the central-west region of Brazil. Addis et al. (2015) [5] aimed to estimate the soil erodibility factor (K) using the USLE nomogram and analyze the spatial distribution of the K factor in a watershed in Ethiopia. Additionally, Ojo et al. (2023) [6] investigated the impacts of soil conservation practices on erodibility, with the goal of improving erosion management and agricultural productivity in Ido, Oyo State, southwestern Nigeria.

The use of rainfall simulators is an important tool for obtaining data on erodibility in relatively short periods. It is also a piece of equipment that is commonly used in cultivated areas in order to evaluate the infiltration of water into the soil [21]. Rainfall simulators allow for more rapid data collection of simulated rainfall conditions, which can contribute to more dynamic understanding of elements such as surface runoff, water infiltration, and soil loss [22]. In the Renato and Caiabi River sub-basins in the state of Mato Grosso, Brazil where this study was conducted, rainfall simulation indicates soil erosion is more dependent on the degree of soil disturbance in commodity cropping systems rather than geographic location in the watershed [23].

This region of Mato Grosso state, Brazil is characterized by high to very high rates of soil erosion [24]. The Renato and Caiabi sub-basins, as with other areas in Mato Grosso, saw a shift from native forest and savannah to cultivated crops and extensive pasture over the past 35 years [25]. Compared to native forest/habitat, commodity cropping resulted in physical soil degradation in the Renato sub-basin and crops/pasture reduced soil water conductivity in the Caiabi sub-basin [26]. Both the Renato and Caiabi River sub-basins feed into the Teles Pires River, which eventually feeds into the Amazon River. Increased soil erosion from crops/pasture can contribute to higher sediment loads in the Teles Pires River, particularly during the rainy season from October to March [27].

In Brazil, information about the K factor is considered scarce due to the presence of different types of Brazilian soils. These different types of soils can represent a range of distinct values even within a single soil class [28]. In this context, when dealing with regional/tropical watersheds, the choice of the best model for studying the K factor could lead to consistent results for soil loss prevention [4].

The importance of this research is reflected in the determination of the K factor indirectly for soils in the region, which is crucial for understanding the erosion process and enabling the mitigation of erosive effects for different land uses. This will allow for more effective soil conservation. Additionally, this approach will stimulate reflection on the necessary care in soil management, especially in the context of agribusiness. It will also promote scientific debate and may encourage the development of new studies on other perspectives regarding soil erodibility.

Given the environmental importance of reducing soil erosion in Brazil, it is critical to better validate soil loss equations such as the Universal Soil Loss Equation (USLE) with real-world data. The USLE is best calibrated to region-specific areas [29]. The objectives of this study were to (1) distinguish differences in soil characteristics and to (2) determine the soil erodibility or K factor part of the USLE equation in both cultivated farmland and pasture in two sub-basins located in the Middle and Upper Teles Pires River region, in the northern part of Mato Grosso state, Brazil. Soil erosion data were obtained through direct field observations using a rainfall simulator. Empirical equations were also used to model soil erosion, and these were compared to observed soil erosion during rainfall simulation.

2. Materials and Methods

2.1. Study Area

The study area corresponds to the sub-basins of the Renato River and Caiabi River, which are both sub-basins of the Renato River positioned between the geographic coordinates, longitudes 55°11′47.333″ W and 55°11′31″ W and latitudes 11°3′52.609″ S and 11°22′40.65″ S. The Caiabi River sub-basin is positioned between the coordinates of longitudes 55°27′3.909″ W and 55°20′30.97″ W and latitudes 12°9′2.976″ S and 12°17′55.006″ S. Located between the municipalities of Itaúba and Cláudia is the sub-basin of the Renato River, which is approximately 65 kilometers (km) to the south of the Caiabi River sub-basin, located between the municipalities of Sinop and Vera, Mato Grosso state, Brazil. Figure 1 shows the areas of both sub-basins.

The Renato and Caiabi River sub-basins have areas of 1341 km^2 and 519 km^2, respectively. The Renato sub-basin has soils such as Dystrophic Red Oxisol and Red–Yellow Oxisol Dystrophic. The Caiabi sub-basin is dominated by Dystrophic Red–Yellow Oxisol. These classifications were identified according to the Brazilian Soil Classification System [30]. The experiment was conducted in plots (0.70 m^2) in three areas of both sub-basins: the source, the middle of the basin, and the mouth of the river basin. There were four replicates for each treatment.

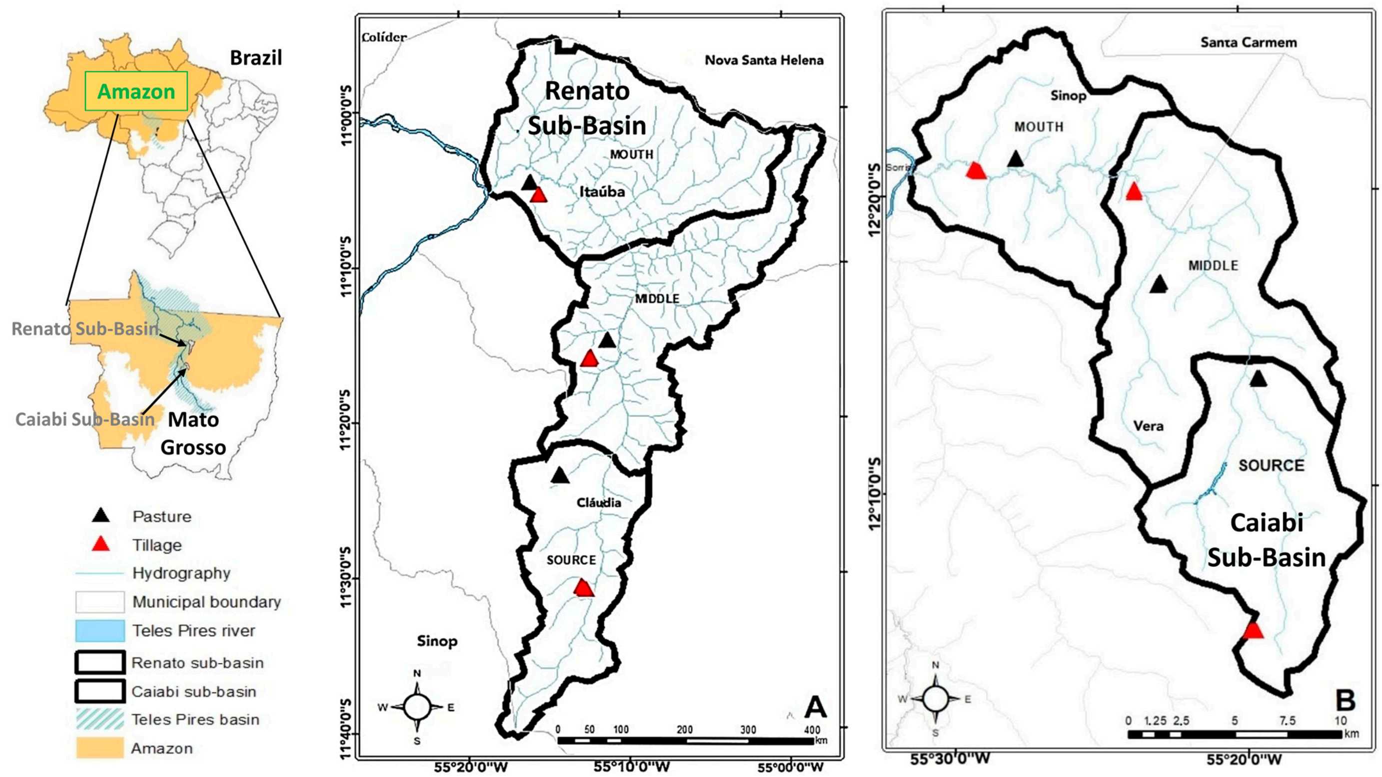

Figure 1. Location of the (**A**) Renato sub-basin, and the (**B**) Caiabi sub-basin in the state of Mato Grosso, Brazil. Sub-basin divisions are by geography (source, middle, and mouth), soil collection points, and the areas under tillage and in pasture. Source: the authors.

2.2. Rainfall Simulation to Measure Soil Erosion

Following methods described in detail in Alves et al. [23], the rainfall simulation was conducted under two agricultural systems, one grain crop and the other pasture. Agricultural systems in the Renato River and Caiabi River basins commonly involve soybean (*Glycine max*) followed by corn (*Zea mays*) throughout the year, starting with soybean in October and ending with the corn harvest in June. The pasture evaluated occurs year-round, and the predominant grass cultivated is *Brachiaria brizantha* spp. Because the study took place in a single harvest, the treatments used were soybean (*Glycine max*) and *Brachiaria brizantha* spp. for the Caiabi River basin and corn (*Zea mays*) and *Brachiaria brizantha* spp. for the Renato River basin.

The plots studied were 0.70 meter (m) wide and 1.0 m long (area of 0.70 m^2), and were evaluated at a depth of 0 to 10 centimeters. When bare soil was encountered, the plot was prepared with rakes. The ramps had average slopes in both experimental areas between 3 and 5 degrees. The InfiAsper rainfall simulator used was developed by Sobrinho et al. (2008) [31]. Before the application of the simulated rainfall, all plots received pre-wetting using standard drippers. The device was calibrated before each simulated rainfall in order to maintain constant rainfall, according to the methodology described by Sobrinho et al. in (2003) [32]. The equipment was calibrated to produce rainfall with an intensity of 75 millimeters $hour^{-1}$ (mm h^{-1}), a characteristic of designated precipitation observed over a 10-year period in the region [33].

2.3. Soil Sampling

Deformed and undeformed soil samples were collected in order to measure the following components: soil density (Sd), macroporosity (Ma), microporosity (Mi), total porosity (Tp), hydraulic conductivity through constant load permeameter, particle size analysis, organic matter (Om), particle density (Pd), chemical analysis of iron (Fe), aluminum (Al), and sand sieving. Particle size analysis was conducted by the pipette method with dispersion in water and 1 mol L^{-1} of NaOH. The particle density was determined by the volumetric flask method. All these analyses strictly followed the methodology described by Teixeira et al. [34].

2.4. Calculation of Rainfall Kinetic Energy

To calculate the kinetic energy of simulated rainfall, the methodology adapted from Foster et al. [35] was used. This is described in Equation (1):

$$EC = 0.119 + 0.0873 \log I \quad (1)$$

where EC = the kinetic energy, in megajoules (MJ) $\times$ (hectare)$^{-1}$ and I = the rainfall intensity in mm h^{-1}.

2.5. Calculation of Soil Components

2.5.1. Soil Erosivity Index and Soil Erodibility

To determine the erosivity index ($EI30$) expressed in MJ $\times$ mm $\times$ (ha $\times$ h)$^{-1}$, the maximum water depth that occurred in 30 min was identified. Next, the maximum precipitation intensity was calculated using the equation proposed by Wischmeier in 1959 [36], represented by Equation (2):

$$EI30 = EC \times I30 \quad (2)$$

where $EI30$ = soil erosivity, in MJ mm $\times$ (hectare h)$^{-1}$; EC = the kinetic energy in MJ $\times$ (hectare)$^{-1}$, and $I30$ = the maximum rainfall intensity that occurred in 30 min, measured in mm h^{-1}.

The material containing water and sediment was taken for weighing and dried in an oven at 221 °F for an average period of 24 h to determine the runoff volume and the soil mass.

Soil erodibility can be estimated using Equation (3), using the elements soil loss (A) and the soil erosivity index ($EI30$). The C factors of soil management and P factors of conservation practices were a value of 1, considering the standard plot conditions established by Wischmeier and Smith in 1978 [10]:

$$K = \frac{A}{R} \quad (3)$$

where K is soil erodibility measured in Mg (1 Mg = 1 million grams = 1 metric ton) $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$. A is soil loss in Mg $\times$ (ha $\times$ h)$^{-1}$ and R is rainfall erosivity in MJ $\times$ mm $\times$ (hectare $\times$ h)$^{-1}$.

2.5.2. Equation for Soil Loss

Universal Soil Loss Equation (USLE) standard values for slope length and slope gradient were considered and Equation (4) was used to adjust these to research plots. This adjustment used the equation proposed by Wischmeier and Smith [10]:

$$LS = \left(\frac{L}{22.1}\right) m \times \left(0.065 + 0.0454 + 0.0065 \times S^2\right) \quad (4)$$

where S = land slope in %; L = land length in meters; m = 0.2 for $S \leq 1\%$; m = 0.3 for $3\% \geq S > 1\%$; m = 0.4 for $5\% \geq S > 3\%$; and m= 0.5 for $S > 5\%$. Empirical equations for evaluating the soil erodibility (K) factor of the USLE, expressed as Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$, were tested and the equations used are presented as follows.

2.5.3. Equations Used to Estimate Soil Erodibility

The K factor in the USLE can be calculated using numerous equations. One of these equations is the Bouyoucos 1935 [37] method and is specified as Equation (5):

$$K = \frac{\%\,of\ sand + \%\,of\ silt}{\%\,of\ clay} \times \frac{1}{100} \tag{5}$$

where soil composition is specified as percentages of sand, clay, and silt. The Lima et al. [38] method adapted for Brazilian Latosols by Marques et al. [39] is summarized in Equation (6):

$$K = [1.451 \times 10^{-10} \times (120 - Om) \times Ma^{1.14}] + [0.0043(S - 2)] + [0.0033(P - 2)] \tag{6}$$

where Ma represents the soil texture and expresses the sum of the silt in grams kilogram^{-1} (g kg^{-1}) and very fine sand (g kg^{-1}) contents multiplied by 1000 minus the clay content (g kg^{-1}), where dispersion was conducted in water. Om expresses the organic matter content (g kg^{-1}), S represents the soil structure class, and P expresses the hydraulic permeability. Here S and P are dimensionless factors. The morphological description of the soil was evaluated through field observations and also according to that described by the Office of Planning of the State of Mato Grosso [40]. For the study of the Renato and Caiabi River sub-basins, the soil structure was defined as fine granular assuming use of their code 2.

The Wischmeier et al. 1978 [10] method for soils of the United States of America estimate soil erodibility (K) specified in Equation (7):

$$K = 1.451 \times 10^{-10} \times (120 - Om) \times M^{1.14} + 0.0043(S - 2) + 0.0033(P - 2). \tag{7}$$

This equation has the same parameters as Equation (6); however, M represents the soil texture and expresses the sum of the silt (g kg^{-1}) and very fine sand (g kg^{-1}) contents multiplied by 1000 minus the clay content (g kg^{-1}). Here, dispersion was conducted in sodium hydroxide (NaOH at 1 mol L^{-1}). Structure (S) and permeability (P) were coded as described in Wischmeier et al. in 1971 [41], where S is coded as: very fine granular = 1; fine granular = 2; medium/coarse granular and subangular blocks = 3; and massive laminar = 4. The P is coded as: fast = 1; moderate to fast = 2; moderate = 3; moderate to slow = 4; and slow = 5; and very slow = 6.

Lombardi Neto and Bertoni (1975) [42] outline another method for estimating K based on Middleton 1930 [43] outlined in Equation (8):

$$K = \frac{\%\,clay\ dispersed\ in\ water/\%\,total\ clay}{\%\,clay\ total/\%\,moisture\ equivalent}. \tag{8}$$

Roloff and Denardin 1994 [44] proposed another method for estimating K specified in Equation (9) as:

$$K = (0.0049 \times P) + (3.31 \times 10^{-5} \times Mm^{0.5}) \tag{9}$$

where Mm is the silt content (g kg^{-1}) multiplied by the sum of silt and fine sand (g kg^{-1}) and the particle size analysis disposing of 1 mol L^{-1} of NaOH. Roloff and Denardin [44] used another method for estimating K which requires iron extraction and was developed for soils in the Paraná region shown in Equation (10):

$$K = (9.17 \times 10^{-5} \times Mm^{0.5}) - (5.26 \times 10^{-5} \times Fe) + (1.76 \times 10^{-5} \times FS) \tag{10}$$

where iron (Fe) is related to the Fe_2O_3 content of air-dried fine soil fraction (ADFS) extracted by sulfuric attack, where fine soil (FS) is related to the fine sand content (g kg^{-1}) using 1 mol L^{-1} of NaOH as a dispersant. Finally, Roloff and Denardin [44] use another equation for estimating K which requires aluminum extraction:

$$K = (1.038 \times 10^{-4} \times Mm^{0.5}) - (4.54 \times 10^{-5} \times Al) \tag{11}$$

where *Mm* refers to the silt content (g kg^{-1}) multiplied by the sum of silt and fine sand (g kg^{-1}); *Al* is related to the aluminum oxide (Al_2O_3) content of the ADFS fraction extracted by sulfuric acid with particle size analysis using 1 mol L^{-1} of NaOH as a dispersant.

2.6. Soil Erodibility by Soil Textural Class and Soil Organic Matter Content

Soil erodibility (K) can also vary by the soil type and soil organic matter content. Table 1 presents estimates for K developed by McKague 2023 [45]. Average values of K are specified by different soil texture (e.g., sand, silt, and clay) as well as organic matter content both below and above 2%. These estimates of K were adapted by Lima et al., 2007 [46].

Table 1. Distribution of the predefined values of erodibility in relation to soil textural class and organic matter content based on McKague 2023 [45].

	Soil Erodibility (K) in Mg × h × (MJ × mm)$^{-1}$		
		Organic	**Organic**
Soil Textural Class	**Mean**	**Matter (<2%)**	**Matter (>2%)**
Very clayey	0.022	0.025	0.020
Clayey	0.029	0.032	0.028
Clay loam	0.040	0.043	0.037
Loam	0.040	0.045	0.034
Sandy loam	0.005	0.007	0.005
Sandy	0.003	0.004	0.001
Sandy clay loam	0.026	-	0.026
Sandy loam	0.017	0.018	0.016
Silty loam	0.050	0.054	0.049
Silty clay	0.034	0.036	0.034
Silty clay loam	0.042	0.046	0.040

3. Results

The data were submitted to the non-parametric Kruskal–Wallis 5% probability test and Dwass–Steel–Chritchlow–Fligner post HOC test ($p < 0.05$). These tests were used to verify the differences between sub-basin positions and treatments. Averages were evaluated at the 5% significance level ($p < 0.05$).

We paid attention to possible differences that could be found in both the Renato and Caiabi River basins because they present different land use and occupation times for each sub-basin. These two sub-basins also differ from each other chronologically, as can be observed through satellite images over the years, starting in the 1970s [47]. Table 2 shows the values of the particle size analysis and Table 3 shows the values determined for sand fractionation.

Table 2. Particle size distribution in different treatments of the soils studied along the sub-basins of the Renato and Caiabi rivers, Mato Grosso state, Brazil.

		Sub-Basin	**Renato Sub-Basin (%) [1]**			**Caiabi Sub-Basin (%) [1]**		
Land Use	**Dispersant**	**Region**	**Total Sand**	**Silt**	**Clay**	**Total Sand**	**Silt**	**Clay**
Cultivated	NaOH	Source	75.20 A	8.62 A	16.20 A	42.50 A	29.60 A	27.90 A
		Middle	82.90 B	4.23 A	12.90 A	76.60 B	5.64 B	17.80 B
		Mouth	73.90 A	6.70 A	19.40 B	78.50 B	5.90 B	15.60 B
		CV%	7	56	22	27	87	33
	Water	Source	82.00 A	10.30 A	7.69 A	59.90 A	27.40 A	12.60 A
		Middle	85.80 B	8.52 B	5.70 B	81.30 B	11.60 B	7.15 B
		Mouth	80.70 A	12.60 A	6.70 A	85.00 C	6.84 C	8.14 B
		CV%	3	20	16	15	61	33

Table 2. *Cont.*

Land Use	Dispersant	Sub-Basin Region	Renato Sub-Basin (%) [1] Total Sand	Silt	Clay	Caiabi Sub-Basin (%) [1] Total Sand	Silt	Clay
Pasture	NaOH	Source	80.40 A	3.67 A	15.90 A	49.20 A	14.70 A	36.10 A
		Middle	83.20 A	3.94 A	12.90 A	49.20 A	16.20 A	34.60 A
		Mouth	81.90 A	3.36 A	14.70 A	84.40 B	4.63 B	11.00 B
		CV%	2	29	14	29	51	45
	Water	Source	87.10 A	7.32 A	5.58 A	66.90 A	17.30 A	15.80 A
		Middle	86.60 A	6.93 A	6.43 A	65.40 A	15.90 A	18.70 A
		Mouth	88.40 A	8.02 A	3.57 B	88.40 B	5.94 B	5.66 B
		CV%	2	13	28	15	43	45

[1] Equal capital letters in the column do not differ significantly from each other by the non-parametric Kruskal–Wallis test ($p < 0.05$). CV% = coefficient of variation percentage.

Table 3. Distribution of sand fractionation of the soils studied along the sub-basins of the Renato and Caiabi rivers, Mato Grosso state, Brazil.

			Renato Sub-Basin (%) [1]					Caiabi Sub-Basin (%) [1]				
Land Use	Disper-sant	Sub-Basin Region	Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand	Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand
Cultivated	NaOH	Source	0.10 A	0.15 A	9.55 A	7.39 A	1.33 A	0.30 A	0.32 A	9.73 A	2.49 A	1.40 A
		Middle	0.13 A	0.16 A	10.80 A	7.67 A	1.73 A	0.07 B	0.12 B	15.14 B	3.90 B	0.97 A
		Mouth	0.14 A	0.13 A	5.92 B	11.31 B	0.61 B	0.08 B	0.15 B	17.93 C	2.37 A	0.61 B
		CV%	71	52	28	28	45	69	62	40	51	45
	Water	Source	0.03 A	0.19 A	8.60 A	9.67 A	1.79 A	0.27 A	0.78 A	7.73 A	3.77 A	2.37 A
		Middle	0.04 A	0.16 A	10.40 A	8.07 A	1.73 A	0.03 B	0.13 B	12.78 A	5.55 B	1.75 A
		Mouth	0.20 B	0.22 A	9.58 A	7.87 A	2.22 A	0.04 B	0.16 B	14.10 C	5.08 B	1.67 A
		CV%	84	55	15	13	17	107	89	25	18	18
Pasture	NaOH	Source	0.03 A	0.08 A	11.99 A	6.31 A	1.65 A	0.08 A	0.24 A	6.95 A	4.47 A	0.79 A
		Middle	0.10 B	0.14 A	11.31 A	7.04 A	1.83 A	0.45 B	0.26 A	8.15 A	3.11 A	0.67 A
		Mouth	0.14 B	0.07 A	16.93 B	2.31 B	0.79 B	0.04 A	0.08 A	19.33 B	1.98 B	0.63 A
		CV%	74	52	21	51	48	104	47	49	69	22
	Water	Source	0.01 A	0.12 A	10.60 A	8.63 A	2.24 A	0.04 A	0.43 A	9.20 A	5.11 A	1.89 A
		Middle	0.03 A	0.10 A	12.90 A	6.94 A	1.67 B	0.09 A	0.61 B	9.25 A	4.83 A	1.41 A
		Mouth	0.16 B	0.07 A	17.80 B	2.98 B	1.05 C	0.10 A	0.16 C	13.10 B	6.53 A	2.20 A
		CV%	103	24	24	40	39	72	56	21	22	25

[1] Equal capital letters in the column do not differ significantly from each other by Kruskal–Wallis non-parametric test ($p < 0.05$). Particle size range (millimeter(s) or mm) for very coarse sand (1 mm), coarse sand (1 to 0.50 mm), medium sand (0.49 to 0.25 mm), fine sand (0.24 to 0.13 mm), and very fine sand (0.12 to 0.06 mm). CV% = coefficient of variation.

The granulometric analysis for the Renato sub-basin (Table 2) demonstrated a higher concentration of sand in the middle of the sub-basin, followed by the source. The same did not occur for the Caiabi sub-basin, where the sand fraction made up a higher proportion of granular composition in the mouth region, followed by the middle part of the sub-basin. The fine sand (FS) and very fine sand (VFS) averaged 7.17 and 4.10 g kg^{-1} and 1.55 and 1.36 g kg^{-1} for Renato and Caiabi, respectively.

Table 4 shows the averages for permeability (cm h^{-1}), particle density (Mg m^{-3}), as well as unitless parameters M (dispersed in NaOH), Ma (dispersed in water), permeability code (P), and structure code. The permeability for Renato and Caiabi averaged 5.41 and 4.41 cm h^{-1}, respectively. The average particle density remained at 2.5 Mg m^{-3} for both pasture and tillage in both sub-basins. Regarding the Ma parameter, there was an increase in its value with the dispersion processed in water. The increase in the Ma parameter in this study confirms the observations made by Lima et al. in 1990 [38] that attribute such an increase to the dispersion conducted in water.

Table 4. Distribution of mean values for permeability, particle density, the M parameter (dispersed in NaOH), the Ma parameter (dispersed in water), permeability code (P), and structure code in the sub-basins of the Renato and Caiabi Rivers, Mato Grosso state, Brazil.

		Renato Sub-Basin (%) [1]						Caiabi Sub-Basin (%) [1]					
Land Use	**Sub-Basin Region**	**Perm-eability (cm h^{-1})**	**Particle Density (Mg m^{-3})**	**M Parameter**	**Ma Parameter**	**P Code**	**Structure Code**	**Perm-Eability (cm h^{-1})**	**Particle Density (Mg m^{-3})**	**M Parameter**	**Ma Para-meter**	**P Code**	**Structure Code**
Cultivated	Source	4.49 A	2.60 A	854.2	1121.3	4	2	5.60 A	2.09 A	2258.9	2604.9	3	2
	Middle	7.01 A	2.67 A	518.4	979.5	3	2	5.26 A	2.47 B	557.0	1244.5	4	2
	Mouth	3.91 A	2.57 A	588.0	1384.5	4	2	6.08 A	2.52 B	550.3	791.6	3	2
	CV%	65	4					19	9				
Pasture	Source	8.56 A	2.58 A	449.7	899.2	3	2	1.55 A	2.42 A	989.3	1618.2	5	2
	Middle	3.25 A	2.55 A	481.6	803.8	4	2	3.16 B	2.31 A	1105.4	1409.8	4	2
	Mouth	5.21 A	2.62 B	354.8	859.3	3	2	4.84 B	2.61 B	467.0	773.9	4	2
	CV%	66	4					13	6				

[1] Equal capital letters in the column do not differ significantly by the non-parametric Kruskal–Wallis test ($p < 0.05$); permeability values obtained through constant load permeameter and P = hydraulic permeability code. CV% = coefficient of variation.

According to Table 5, it was observed that organic matter varied for the two sub-basins. However, the Caiabi sub-basin has a higher percentage of land area devoted to cultivated crops (59.24%) compared to the Renato sub-basin (13.41%), while for a perennial pasture, this was the opposite at 6.26% versus 15.94% [26]. For this scenario, organic matter content is considered one of the main soil stabilization agents [48].

Table 5. Distribution of the average values of the chemical analysis of organic matter, iron, and aluminum of soils sampled in the Renato and Caiabi River sub-basins, Mato Grosso state, Brazil.

		Renato Sub-Basin (%) [1]			Caiabi Sub-Basin (%) [1]		
Land Use	**Sub-Basin Region**	**Organic Matter (dag kg^{-1})**	**Fe_2O_3 (mg dm^{-3})**	**Al_2O_3 (cmolc dm^{-3})**	**Organic Matter (dag kg^{-1})**	**Fe_2O_3 (mg dm^{-3})**	**Al_2O_3 (cmolc dm^{-3})**
Cultivated	Source	2.76 A	47.0 A	0.06 A	5.14 A	26.5 A	0.04 A
	Middle	2.59 A	44.5 A	0.04 B	3.32 B	28.0 A	0.03 A
	Mouth	3.46 A	36.5 B	0.03 B	3.07 B	20.5 A	0.05 A
	CV%	25	16	49	31	22	30
Pasture	Source	1.64 A	63.5 A	0.36 A	3.80 A	75.5 A	0.05 A
	Middle	1.92 A	67.0 A	0.11 A	4.87 B	50.0 B	0.04 A
	Mouth	1.94 A	92.0 A	0.36 A	1.89 C	42.5 B	0.07 A
	CV%	19	25	82	38	26	27

[1] Equal capital letters in the column do not differ significantly from each other by the non-parametric Kruskal–Wallis test ($p < 0.05$). Fe_2O_3 = iron oxide, and Al_2O_3 = aluminum-derived oxide. CV% = coefficient of variation.

Chemical evaluation showed that areas under agricultural cultivation had the lowest levels of iron (Fe) and aluminum (Al). Additionally, a decrease in Fe and Al can contribute to the soil leaching process, which can be accelerated by the intensive tillage used in these farming areas. The importance of Fe and Al oxides is linked to their cohesive ability to act as cementing agents, which intensely favors agglutination. These elements are present mainly in soils in tropical climates such as those found in Brazil [49]. Fe and Al oxides are associated with chemical weathering [28], primarily in Oxisols. Such agglutination can reduce the impact of raindrops, hindering the disaggregation of particles through surface runoff [50]. Table 5 presents the chemical values of soil evaluated from both the Renato and Caiabi sub-basins.

The kinetic energy produced for the events ranged from 0.278 to 0.287 MJ hectare^{-1}. The erosivity among all rainfall events obtained minimum of 1065.73 and maximum of 1214.36 MJ $\times$ mm $\times$ (hectare $\times$ h)$^{-1}$ for both sub-basins. Soil loss ranged from 0.178 to 0.813 Mg hectare^{-1} h^{-1}, specifically for the Renato sub-basin and 0.205 to 0.359 Mg ha^{-1} h^{-1} for the Caiabi sub-basin. Table 6 presents other values observed by the rainfall simulator.

Table 6. Distribution of mean values of soil loss, precipitation intensity, length and slope, and erodibility factor (K) in the Renato and Caiabi River sub-basins, Mato Grosso state, Brazil.

		Renato Sub-Basin (%) [1]				Caiabi Sub-Basin (%) [1]			
Land Use	**Sub-Basin Region**	**Soil Loss (Mg ha^{-1} h^{-1})**	**Precipitation Intensity (MJ × mm × (h × ha × year)$^{-1}$)**	**Length and Slope (m)**	**K (Mg × h × (MJ × mm)$^{-1}$)**	**Soil Loss (Mg ha^{-1} h^{-1})**	**Precipitation Intensity (MJ × mm × (h × ha × year)$^{-1}$)**	**Length and Slope (m)**	**K (Mg × h × (MJ × mm)$^{-1}$)**
Cultivated	Source	0.676 A	1174.38 A	0.114 A	0.0052 A	0.306 A	1206.26 A	0.082 A	0.0031 A
	Middle	0.813 A	1137.88 A	0.102 A	0.0086 A	0.275 A	1120.75 A	0.134 B	0.0020 A
	Mouth	0.622 A	1065.73 A	0.102 A	0.0058 A	0.205 A	1145.15 A	0.143 B	0.0012 A
	CV%	63	8	8	76	43	5	29	52
Pasture	Source	0.431 A	1157.06 A	0.143 A	0.0025 A	0.359 A	1141.41 A	0.204 A	0.0017 A
	Middle	0.505 A	1214.36 A	0.163 A	0.0026 A	0.327 A	1154.30 A	0.156 B	0.0016 A
	Mouth	0.178 B	1150.50 A	0.177 A	0.0009 B	0.205 A	1126.98 A	0.137 B	0.0014 A
	CV%	88	4	17	96	63	6	20	57

[1] Equal capital letters in the column do not differ significantly from each other by the non-parametric Kruskal–Wallis test ($p < 0.05$). CV% = coefficient of variation.

The K values ranged from 0.0009 to 0.0086 Mg × h × (MJ × mm)$^{-1}$ for SBR (higher intensity) and 0.0014 to 0.0031 Mg × h × (MJ × mm)$^{-1}$ (lower intensity), the middle of the Renato River sub-basin and the source of the Caiabi River sub-basin being the most susceptible areas. However, the results of the statistical test indicate that there was no significant difference at 5% probability for the analysis of factor K tied to the positions of the sub-basins.

It can be seen that the tillage and pasture systems did not interfere with erodibility. This suggests that the K factor is not altered through the use and management of the soil, but rather with the physical–chemical characteristics of the land. The observed field data using the rainfall simulator and estimated soil erodibility using indirect methodologies such as equations for K factor from the literature were not linked to sediment transfer along the sub-basins. However, these results appear to be connected to the intrinsic characteristics of the soil.

Related to anthropic actions, the factors that draw greater attention to the characteristics of these results may be linked to the intense interventions and movement of agricultural machinery [51], as well as the intense use of tillage in agricultural areas [52]. This includes exposure of soil without vegetation and pastures that were intensely trampled by animals. Both intensive tillage and animal traffic in pastures can accelerate soil erosion and degradation. It is worth noting that erodibility does not depend only on the textural relationship and cohesion between particles, but also on parameters such as soil structure and chemistry [49]. These elements may have influenced the erodibility characteristics in both the Renato and Caiabi River sub-basins.

The Caiabi River sub-basin source showed the lowest density value (1.03 kg dm^{-3}) among both sub-basins, and the highest value of microporosity followed by total porosity were observed for this region of spring whose granulometric condition was classified as clayey. Macroporosity ranged from 0.02 kg dm^{-3} to 0.12 kg dm^{-3} for the Renato sub-basin and 0.02 kg dm^{-3} to 0.14 kg dm^{-3} for the Caiabi sub-basin. Table 7 shows the values for the attributes macroporosity, microporosity, total porosity, soil density, and organic matter throughout both sub-basins.

Table 7. Distribution of mean values for the attributes macroporosity, microporosity, total porosity, and soil density in the Renato and Caiabi River sub-basins, Mato Grosso state, Brazil.

		Renato Sub-Basin (%) [1]				Caiabi Sub-Basin (%) [1]			
Land Use	**Sub-Basin Region**	**Micro-Porosity (m^3 m^{-3})**	**Macro-Porosity (m^3 m^{-3})**	**Total Porosity (m^3 m^{-3})**	**Soil Density (kg dm^{-3})**	**Micro-Porosity (m^3 m^{-3})**	**Macro-Porosity (m^3 m^{-3})**	**Total Porosity (m^3 m^{-3})**	**Soil Density (kg dm^{-3})**
Cultivated	Source	0.27 A	0.09 A	0.36 A	1.57 A	0.43 A	0.08 A	0.52 A	1.03 A
	Middle	0.27 A	0.10 A	0.37 A	1.51 A	0.29 B	0.07 A	0.36 B	1.48 B
	Mouth	0.36 B	0.08 A	0.44 B	1.57 A	0.28 B	0.10 A	0.38 B	1.51 B
	CV%	15	28	10	4	24	47	19	18
Pasture	Source	0.27 A	0.11 A	0.38 A	1.52 A	0.40 A	0.02 A	0.45 A	1.41 A
	Middle	0.35 A	0.02 B	0.37 A	1.59 A	0.37 A	0.05 B	0.48 A	1.30 B
	Mouth	0.26 A	0.12 A	0.38 A	1.74 B	0.24 B	0.14 B	0.50 B	1.59 C
	CV%	17	73	6	8	24	70	9	9

[1] Equal capital letters in the column do not differ significantly by the non-parametric Kruskal–Wallis test ($p < 0.05$). CV% = coefficient of variation.

Table 8 presents the erodibility results and Table 9 presents the values of the correlation performed through the items observed by the use of the rain simulator and estimated through the indirect methodologies. Regarding the estimation models, the results point to intensity in the distribution of K values. For RSB the indirect models presented range from 0.0008 to 0.0990 Mg × h × (MJ × mm)$^{-1}$ (greater intensity) and for SBC ranges from 0.0014 to 0.0846 Mg × h × (MJ × mm)$^{-1}$ (less intensity). Although this range was considered small. In general, the equations that presented alpha (0.05) significance level were the equations of Bouyoucos [37] and Lombardi Neto and Bertoni [42]. However, these correlations presented were negative, leading values in opposite directions for cultivated areas in the Caiabi sub-basin. Moderate and positive correlation was observed with values between 0.469 and 0.660, where the pasture of the Renato sub-basin presented the greatest number of contrasts with moderate correlation.

Table 8. Distribution of erodibility values (K factor) estimated by indirect methodologies along the Renato and Caiabi River sub-basins, Mato Grosso state, Brazil.

	Source Used for Soil Erodibility Value	**Renato Sub-Basin (Mg × h × (MJ × mm)$^{-1}$) [1]**				**Caiabi Sub-Basin (Mg × h × (MJ × mm)$^{-1}$) [1]**			
Land Use	**(K Factor)**	**Source**	**Middle**	**Mouth**	**CV%**	**Source**	**Middle**	**Mouth**	**CV%**
Cultivated	Boyoucos (1935) [37]	0.0528 Aa	0.0681 Aa	0.0427 Ba	25	0.0282 Aa	0.0464 Ba	0.0541 Bb	31
	Lima et al. (1990) [38]	0.0102 Ab	0.0076 Ab	0.0122 Ab	32	0.0173 Aa	0.0088 Ab	0.0067 Ab	50
	Lombardi Neto and Bertoni (1975) [42]	0.0811 Aa	0.0942 Aa	0.0480 Ba	38	0.0381 Aa	0.0574 Ba	0.0846 Ba	39
	Roloff and Denardin (1994) [44]	0.0188 Ab	0.0162 Ab	0.0199 Ab	21	0.0194 Aa	0.0162 Ab	0.0174 Ab	19
	Roloff and Denardin (1994) [44]	0.0073 Ab	0.0024 Ab	0.0056 Bb	85	0.0436 Ab	0.0029 Bb	0.0023 Bb	126
	Roloff and Denardin (1994) [44]	0.0083 Ab	0.0027 Bb	0.0063 Ab	85	0.0493 Ab	0.0033 Bb	0.0026 Bb	126
	McKague (2023) [45]	0.0160 Ab	0.0110 Ab	0.0210 Ab	38	0.0355 Aa	0.0160 Ab	0.0165 Bb	42
	Wischmeier and Smith (1978) [10]	0.0083 Ab	0.0041 Ab	0.0077 Ab	48	0.0150 Aa	0.0040 Bb	0.0050 Bb	68
Pasture	Boyoucos (1935) [37]	0.0539 Aa	0.0679 Aa	0.0587 Aa	16	0.0178 Aa	0.0190 Aa	0.0835 Ba	84
	Lima et al. (1990) [38]	0.0083 Ab	0.0090 Ab	0.0086 Ab	24	0.0154 Aa	0.0111 Ba	0.0080 Cb	29
	Lombardi Neto and Bertoni (1975) [42]	0.0573 Aa	0.0990 Ba	0.0449 Aa	40	0.0294 Aa	0.0365 Bb	0.1260 Ca	76
	Roloff and Denardin (1994) [44]	0.0174 Ab	0.0198 Ab	0.0185 Ab	16	0.0226 Aa	0.0202 Aa	0.0186 Ba	13
	Roloff and Denardin (1994) [44]	0.0019 Ab	0.0017 Ab	0.0008 Ab	52	0.0137 Aa	0.0158 Aa	0.0014 Bb	79

Table 8. *Cont.*

	Source Used for Soil Erodibility Value	Renato Sub-Basin (Mg × h × (MJ × mm)$^{-1}$) [1]				Caiabi Sub-Basin (Mg × h × (MJ × mm)$^{-1}$) [1]			
Land Use	**(K Factor)**	**Source**	**Middle**	**Mouth**	**CV%**	**Source**	**Middle**	**Mouth**	**CV%**
	Roloff and Denardin (1994) [44]	0.0021 Ab	0.0020 Ab	0.0009 Ab	52	0.0155 Aa	0.0179 Aa	0.0016 Bb	79
	McKague (2023) [45]	0.0175 Ab	0.0083 Bb	0.0143 Ab	41	0.0287 Aa	0.0260 Aa	0.0093 Bb	46
	Wischmeier and Smith (1978) [10]	0.0046 Ab	0.0065 Ab	0.0047 Ab	40	0.0109 Aa	0.0092 Aa	0.0056 Bb	32

[1] Same capital letters in the row do not differ significantly from each other by the non-parametric Kruskal–Wallis test ($p < 0.05$). Same lower-case letters in the column do not differ significantly from each other by the non-parametric Kruskal–Wallis test ($p < 0.05$). CV% = coefficient of variation.

Table 9. Correlation between direct soil erodibility values measured using a rainfall simulator and indirect values estimated from K factor equations from the literature in the Renato and Caiabi River sub-basins, Mato Grosso state, Brazil.

Source Used for Soil	Correlation Coefficients			
Erodibility Value	**Renato Sub-Basin** [1]		**Caiabi Sub-Basin** [1]	
(K Factor)	**Cultivated**	**Pasture**	**Cultivated**	**Pasture**
Boyoucos (1935) [37]	0.245	0.322	−0.660 *	0.042
Lima et al. (1990) [38]	−0.126	0.322	0.497	0.154
Lombardi Neto and Bertoni (1975) [42]	0.210	0.483	−0.587 *	0.147
Roloff and Denardin (1994) [44]	−0.126	0.559	0.021	0.147
Roloff and Denardin (1994) [44]	−0.469	0.510	0.287	0.231
Roloff and Denardin (1994) [44]	−0.469	0.510	0.287	0.231
McKague (2023) [45]	−0.484	−0.451	0.486	0.165
Wischmeier and Smith (1978) [10]	−0.035	0.441	0.217	0.224

[1] Values in bold and asterisk * are different from 0 at a significance level of alpha = 0.05 (5%). Significantly higher averages were identified at the source of the Caiabi River sub-basin compared to other regions, especially in cultivated and pasture areas. Overall, for the Renato sub-basin, there were little statistically significant differences in the averages from one area of the sub-basin compared to another. These statistically significant differences can be found in cultivated areas at the mouth of the sub-basin.

4. Discussion

4.1. Comparisons and Contrasts to Prior Studies

When evaluating the equation of Bouyoucos 1935 [37], it was found that this model presented a significant difference (5%) in relation to the other indirect methodologies evaluated for most of the cultivated and pasture areas in both the Renato and Caiabi River sub-basins. High values were also observed by da Rocha Lima et al., 2021 [53] who detected erodibility for a dark red Oxisol at 0.0790 Mg × h × (MJ × mm)$^{-1}$ and for a dystrophic purple Oxisol at 0.0290 Mg × h × (MJ × mm)$^{-1}$. The same can be verified in the model proposed by Lombardi Neto and Bertoni 1975 [42], which also presented a significant difference (5%) and the explanation may be related to the smaller number of parameters associated with this model.

Analyzing the other equations, there was no significant difference in the means between the methodologies evaluated. The model adapted by Lima et al. in 1990 [38] pointed to an increase in erodibility values compared to the Wischmeier and Smith 1978 [10] method. The interpretation for this can be addressed by Lima et al. [38], who discuss that the clay element when flocculated resembles the performance of silt and very fine sand for Latosols. The Wischmeier and Smith [10] model had higher values for the K factor observed in the source region in the Caiabi sub-basin. However, the highest susceptibility in the Renato sub-basin occurred in the source area of the sub-basin for cultivated areas and in the middle part of the sub-basin for pasture.

Generally, Oxisols are known for having low silt contents and structurally have granular characteristics. This contributes to a greater flow of hydraulic conductivity in the soil. Therefore, the estimation of erodibility through methodologies that focus on parameters such as conductivity and percentages of silt in its composition can reduce the values of K factor when analyzed in Oxisols [38].

Godoi et al. [18] explain an analysis for results with low values estimated by the Wischmeier and Smith [10] model. This can be explained as a function of fixed values in the structure code because indexed values can contribute to uncertainties in the erodibility results. On the other hand, there is insufficient measurable data for this attribute, which contributes to assumptions of soil structure.

The model developed by McKague 2023 [45] obtained moderate correlation for most of the systems with the exception of the pastureland of the Caiabi sub-basin. Here, there was weak correlation (0.165). The models proposed by Roloff and Denardin [44] had one of the best correlations among all the methodologies, especially for models 2 and 3, which had iron and aluminum being intrinsically linked to weathered Oxisols [54]. Methodologies 2 and 3 from Roloff and Denardin [44] had moderate correlation for most of the systems of the sub-basins.

According to Godoi et al. [18], Oxisols present less susceptibility to erosion than other soils. However, this soil type becomes much more susceptible when exposed to intensive agricultural land use. The same observation applies in the context of both sub-basins of the study, especially in relation to the soil in the Caiabi River sub-basin. The Caiabi has areas that were deforested much longer ago for agricultural production compared to the Renato sub-basin.

From the perspective of the correlation between direct and indirect methods, Silva et al. [55] concluded that when determining the erodibility of latosols in the Cerrado, indirect methods may not provide statistically accurate estimates when compared to the direct method to calculate the absolute value of the erodibility factor. However, in the study of the Renato and Caiabi Rivers sub-basin, equations 2 and 3 by Roloff and Denardin [44], which use elements such as iron and aluminum as parameters, showed reasonable to moderate correlations, especially as they are latosols.

Di Raimo et al. (2019) [50] studied various soils from the state of Mato Grosso using indirect methodologies for determining erodibility. The authors employed the equations of Wischmeier and Smith (1978) [10] and Denardin (1990) [19]. They determined an erodibility range for the oxisols in the region from 0.0019 to 0.0340 $Mg \times h \times MJ^{-1} \times mm^{-1}$.

Marques et al. [4], using indirect methodologies, determined erodibility values of 0.0080 and 0.0060 $Mg \times h \times MJ^{-1} \times mm^{-1}$ for Typic Eutrophic Red Latosol (LVe) and Typic Dystrophic Red Latosol (LVd), respectively. Using a rainfall simulator, they found concentrations of 0.0030 and 0.0020 $Mg \times h \times MJ^{-1} \times mm^{-1}$ for LVe and LVd, respectively. These values are similar to the results we obtained using a rainfall simulator for the Renato and Caiabi river sub-basins.

4.2. Implications of Research

The identification of soil erodibility in cultivated and pasture areas in the Renato and Caiabi Rivers sub-basins contributes to a better understanding of the factors that influence erosion in these specific ecosystems. Understanding the mechanisms related to erodibility makes it possible to mitigate the complex effects of erosion [24]. In the most varied uses and occupations, soil management policies can promote the effective use of new conservation mechanisms. In this sense, the analysis of erodibility in different scenarios aims to detect characteristics intrinsic to the soil, which may vary over time or due to agricultural activities, without forgetting that the soil can be modified mainly by compaction processes, agricultural mechanization, and trampling by cattle.

The research conducted in this study has substantial social implications, especially for rural communities. Preventing soil degradation allows communities to maintain the productivity of their land, supporting livelihoods and preventing potential risks of economic losses due to poor soil health. In addition, effective land management is critical for environmental sustainability, which results in benefits for society at large in terms of preserving ecosystems and natural resources.

Frequently tested methodologies can provide improvements in the phases of soil erodibility determination. This can lead to better soil management practices, increasing crop yields, and ensuring food security. Another important point is that the correct adjustment of parameters for specific soil prediction models directly results in adequate performance of the tested model and the reliability of the data obtained. Magalhães et al. [56], used a soil and water prediction model (GeoWEPP) to evaluate sediment production in different land uses and considered it extremely important to observe the geographic conditions of the environment to be tested. This study emphasized that it is essential to correctly insert data according to geographic and environmental characteristics [56]. Our results can be used to update 14 other erosion/sediment transport models in addition to USLE and GeoWEPP [57]. Our results can also help validate machine learning techniques that were developed to globally map the K factor for soils [58].

The appropriate selection of techniques compatible with soil availability and variability in specific environmental conditions not only refines existing theoretical frameworks on the topic, but also suggests a more focused approach to modeling soil erosion, emphasizing the need for adaptable and sensitive methodologies to the environment. Throughout our study, however, it was observed that the models proposed by Lombardi Neto and Bertoni [42], in addition to geographic information and inclusion of a smaller number of parameters could result in significantly different erodibility estimates if a smaller number of parameters is included. This suggests the need to generate new models that integrate a greater number of appropriate criteria. Composing mixed models that combine multiple approaches can provide a more accurate and comprehensive assessment of soil erodibility.

5. Conclusions

Experiments with a rainfall simulator indicated higher values and also variation in the K factor for the Renato sub-basin ranging from 0.0009 to 0.0086 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$ and lower values and also variation for the Caiabi sub-basin at 0.0014 to 0.0031 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$. Indirect methodologies also estimated a higher K factor for the Renato River sub-basin at 0.0008 to 0.0990 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$ and lower for the Caiabi River sub-basin at 0.0014 to 0.0846 Mg $\times$ h $\times$ (MJ $\times$ mm)$^{-1}$. There was no significant difference at the 5% level of the K factor determined by the rainfall simulator for both sub-basins. The equations of Bouyoucos (1935) [37] and Lombardi Neto and Bertoni (1975) [42] presented significant (5%) correlation for cultivated soils surveyed in the Caiabi River sub-basin. The indirect methodologies that obtained reasonable correlation and that showed the best performance were equations 2 and 3 from Roloff and Denardin (1994) [44] that use iron and aluminum as parameters. The elements that most influenced soil erodibility were the physical textures of the soil. This study aims to open new studies for future investigations on the subject, keeping in mind the focus on new methods of corroboration in various scenarios, such as different soil categories, different climatic conditions, and the most varied use and occupation of land. Furthermore, the insertion of improved technologies, such as remote sensing and geoprocessing, could increase the precision of erosion and erodibility estimates and become more developed, reliable, and applicable anywhere.

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