

## Assessment of potential surface degradation resulting from erosion processes in environmentally protected area

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Case Study

### Keywords

Erodibility  
Soil loss  
Field tests on erosion  
Geotechnical investigation  
Inderbitzen test

### Abstract

Erosion processes occur in several locations, causing impacts on the environment. This article analyzes the soil erodibility potential of the conservation unit of Timbaúbas municipal natural reserve, located in Juazeiro do Norte, in the southern mesoregion of Ceará, northeastern Brazil. It also addresses geotechnical characterization tests and field tests on erosion. In the field tests on erosion, huge volumes of soil loss were found caused by the action of rainfall and simulated surface flows. The results of the geotechnical investigation revealed silty sand soil, low values resistance parameters, has high erosion potential. The reduced rate of soil vegetation cover associated with the mechanical characteristics of the aggregate increases susceptibility to erosion processes, also intensified by anthropic intervention and construction of buildings on the site, without proper action to discipline the runoff. This work enables us to conclude that natural factors together with unsuifigure anthropic factors have been the causes of erosion of the conservation unit in question.

## 1. Introduction

Although erosion processes are considered natural phenomena, they are now a problem for environmental resources when soil loss rates exceed the natural levels of soil generation (Jorge & Guerra, 2013). In urban areas, one of the main problems related to the increased erosion processes is the possible destruction of community assets, resulting from geohazard events leading to necessary land use planning to prevent such problems (Camapum de Carvalho et al., 2006). The problem is even more severe since erosion processes are not restricted only to where erosion scars exist, but also to where materials are deposited, in some cases, for example, water bodies, possibly causing local siltation and pollution concentration.

Guerra & Hoffmann (2006) discuss studies in several Brazilian locations degraded by several surface erosion types (gullies), mainly caused by deforestation, lack of urban planning, absence of storm water drains and no drainage elements, or by poor design. According to Camapum de Carvalho et al. (2006), some places in Maranhão state evidence severe erosion phenomena, especially ravines in the Bacanga river basin (Coeduc, Batatã, Gapara, Itaquí, Maracanã, Posto, Sacavém, Torre and Vila Maranhão), aggravated by high urbanization rate and the physical, chemical and environmental characteristics of the basin. In

the satellite towns of Ceilândia (DF) and Jardim Ingá (GO), by the end of the 1980s, erosion had destroyed towns and damaged roads.

Soil erosion depends on the active forces of rainfall and slope characteristics, and or by intrinsic factors linked to the soil and vegetation density (Bertoni & Lombardi Neto, 1999). Disordered growth and inappropriate land use are the prime aggravating factors of erosion, major capitals and several other locations in Northeast Brazil, as has been observed in Ceará's hinterland, where erosion processes occur in urban areas, roadsides and legally protected areas (Lafayette, 2006; Meira, 2008; Macedo, 2019). The purpose of this paper is to present a study of the potential soil erodibility of the Timbaúbas Municipal Nature Reserve in Juazeiro do Norte (CE), in support of the area's rehabilitation project.

## 2. Erodibility potential indicator parameters

Field and laboratory testing can be done in order to achieve erodibility potential indicator parameters. Geotechnical characterization testing (soil size analysis, liquid limit, plasticity limit, shear strength, permeability) and other more specific tests (e.g., slaking, crumb, Inderbitzen) could provide information on the hydraulic and mechanical behavior of the soil and, in turn, be directly related to the erodibility potential, making it easier to understand the erosion processes.

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The finer particles (clay) are easily displaced and transported when the cohesive force is overcome. Larger particles (coarse sand, gravel) are more resistant to erosion and tend to accumulate on the surface, due to the relationship with the frictional force. Soils with high silt content generally have high erodibility (Llopis Trilho, 1999). Ramadan (2003) finds that the soils more resistant to erosion have 30%-35% clay in their composition, due to the cohesive nature of the clay and contributing to dispersion resistance.

In the opinion of Bender (1985) the erosion resistance and shear strength depend on the cohesive behavior of the soil. Bastos (1999) states that when the variation in cohesion ( $\Delta c$ ) is more than 85%, obtained from a soil sample in natural moisture in relation to the value of the cohesion obtained in that same sample in the saturated condition, the soil may be considered erodible.

The slaking test allows us to observe the stability of an undisturbed soil sample, when immersed in distilled water, estimating the capacity of the water to disperse the soil. Bastos (1999) believes that soils that crumble completely in water are considered highly erodible. However, there is no direct relationship of intermediary and low levels of erodibility with this test.

The crumb test helps classify the reaction of a soil plot in relation to dispersion when immersed in water. The soil may be classified as dispersive (susceptible to erosion) or non-dispersive (possibly erodible or not). The standard ABNT (1996) determines four (4) degrees of dispersibility, as follows: Degree 1 - non-dispersive, where the clod may fracture or crumble, but there is no turbidity; Degree 2 - slightly dispersive, where signs of turbidity are seen in the water; Degree 3 - moderately dispersive, observing turbidity with colloidal particles; and Degree 4 - highly dispersive, with thick turbidity of colloidal particles.

Inderbitzen tests were performed on undisturbed test specimens in order to assess soil mass loss due to surface runoff. The test is performed on an articulated hydraulic ramp, which may have an adjustable slope, fitted with a central orifice in which a soil sample is enclosed (Nagel et al., 2009).

Through testing, quantified hydraulic shear stresses, using hydraulic parameters, can be related to soil loss (per unit area and time). A graph of this relationship can obtain an erodibility rate ( $K$ ) representing a soil loss rate in  $g/cm^2/min/Pa$ . It is also possible to obtain a critical hydraulic shear stress ( $\tau_{crit}$ ), understood as the lowest hydraulic shear stress capable of producing decomposition (Bastos et al., 2017). Bastos (1999) proposes classification of soil erodibility, based on the erodibility rate ( $K$ ) in  $g/cm^2/min/Pa$ , as follows - low erodibility for soils that have  $K < 1 \times 10^{-3}$ ; medium erodibility for  $1 \times 10^{-3} < K < 1 \times 10^{-1}$ , and high erodibility for  $K > 1 \times 10^{-1}$ .

Soil permeability is closely related to its erodibility potential. Water seepage is a problem in soils with low permeability, since the surface or subsurface runoff is greater, as is its erosion potential, due to the direction of particles dragged by the force of the water. On the other hand, highly permeable soils easily suffer leaching processes, losing nutrients to support the vegetation, important for protecting against erosion processes.

An erodibility study in pilot tests is designed to measure the surface runoff and amount of transported soil. It is possible to quantify the soil losses and onsite crumbling rate (Lafayette, 2006; Meira, 2008; Inácio et al., 2007). The relationship between rainfall intensity and soil loss is useful information for decision makers.

### 3. Characteristics of the investigated area

The subject of this paper is the area of Timbaúbas Municipal Nature Reserve, located in the municipality of Juazeiro do Norte (Figure 1). The municipality of Juazeiro

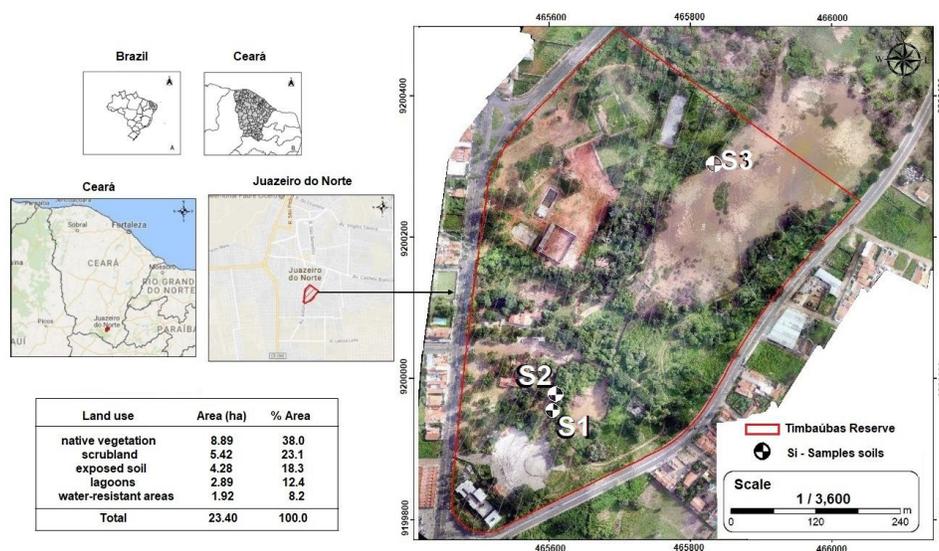


Figure 1. Location of the Timbaúbas municipal nature reserve. Sources: Macedo (2019), IBGE (2010), IPECE (2017).

do Norte, in turn, is located in the southern mesoregion of Ceará, northeastern Brazil, between the coordinates latitude (S) 7°12'47" and longitude (WGr) 39°18'55" covering an area of 248.8 km<sup>2</sup> with a population of 249,939 inhabitants (Ceará Research Institute on Economic Strategy-IPECE, 2017).

According Köppen & Geiger (1928), the region has a semi-arid hot tropical climate, with 925 mm average annual precipitation. The annual average temperature varies between 24°C and 26°C. The wet season is January to May (FUNCEME, 2006).

Timbaúbas municipal natural reserve was created in 1997 in order to “ensure preservation and restoration of the margins of the Rivers Salgadinho and Timbaúbas” (Juazeiro do Norte, 1997). In 2017, the area was classified as a conservation unit and defined as an Integral Protection Area, in order to protect the water table comprising the Salgado river basin (Juazeiro do Norte, 2017). The reserve currently has a total area of 23.40 ha.

The area's predominant soils are alluvial neosols, consisting of coarse and fine sand, mostly quartz, thick well drained and with low natural fertility (FUNCEME, 2012). Costa et al. (2013) studied the hydrosedimentological parameters of the São José catchment area (location of study area) and prepared a GIS-based erosion-prone soil map using the Universal Soil Loss Equation (USLE). They found that the Timbaúbas Municipal Nature Reserve soils with medium to high erodibility potential predominate. This area has laminar erosion shown by exposed tree roots on the surface, and linear erosion in the form of furrows, ravines and gullies.

## 4. Materials and methods

### 4.1 Morphometric characterization and land occupation and use

The morphometric characterization of the microbasin in the study area was done using software QGIS v. 2.14, based on domain images of Google Earth and the Brazilian Institute of Geography and Statistics (IBGE), and an aerial survey using unmanned aerial vehicles (UAV). This work was designed to obtain the following parameters: area, perimeter, length of watercourses, compactness coefficient, shape coefficient, circularity and sinuosity index and drainage density; whose formulations were based in the studies by Villela & Mattos (1975), Cardoso et al. (2006) and Silva Neto et al. (2013). The aerial survey (May 2018) helped toward estimating the areas of vegetation, exposed soil and built up areas.

### 4.2 Methods for geotechnical characterization

#### 4.2.1 Laboratory tests

For geotechnical characterization of the study area, soil mechanics laboratory tests were performed on three samples (Figure 1) collected from different points in the municipal reserve close to an area of severe erosion processes.

The tests were as follows:

- Basic physical characterization tests: Soil grading analysis, by sieving and sedimentation (ABNT, 2016a); specific particle weight based on ABNT (2017) (soil particles passing through the 4.8 mm sieve – Determining the specific density); liquid limit (ABNT, 2016b); plasticity limit (ABNT, 2016c);
- Erosion susceptibility test: Slaking test, Crumb test (ABNT, 1996);
- Inderbitzen tests. The tests were performed in three different surface runoff flows (3.5 L/min, 6 L/min and 7 L/min), when adopting a ramp gradient of 30°, based on the procedures applied by Lafayette (2006). The samples were tested under two initial conditions, starting with natural moisture and then a 24-hour saturated condition. The water flow was measured using Arduino hardware.
- Shear strength tests using a direct shearing press on previously saturated test specimens in natural moisture and previously saturated.

#### 4.2.2 In situ tests

##### 4.2.2.1 Permeability testing

In situ permeability was tested close to the three sampling sites, using the Guelph constant head permeameter. Heads referring to the 5 cm and 10 cm water columns were adopted by monitoring water columns (cm/s) in the *R1* and *R2* tanks, respectively. Hydraulic conductivity saturated on site ( $K_{fs}$ ) was calculated by using Equation 1.

$$K_{fs} = [(0.0041).(x).(R2)] - [(0.0054).(x).(R1)] \quad (1)$$

where:  $K_{fs}$  is the hydraulic conductivity (cm/s);  $x$  is the tank constant, namely 35.22 cm<sup>2</sup> in the case of interconnected tanks; *R1* is the waterfall rate obtained from the first load applied (cm/s); *R2* is the waterfall rate obtained from the second load applied (cm/s).

##### 4.2.2.2 Erodibility study in pilot tests

Pilot tests were carried out to understand the erosion processes in the form of furrows. In the study area, three pilot tests were performed (pilot tests I, II and III), all close to the Sample 2 site (area with the highest concentration of erosion in furrows). The methodological procedures were based on the studies from Inácio et al. (2007), Meira (2008) and Lafayette (2006). Pilot test I was used in the soil loss study due to the rainfall in April 2018; and Pilot tests II and III (Figure 2) were used for simulated runoffs situated between two erosion furrows, one in soil protected by natural vegetation and plant litter; and the other in unprotected soil. For the pilot tests, the plots were defined by 0.4 m high zinc metal plates, 0.2 m of this being driven into the ground, and rectangular in shape (0.5 m wide x 1.5 m long - Figure 2). Rainfall volumes were obtained from the readings of a rain gauge. Further details can be obtained from studies in Macedo (2019).



**Figure 2.** Pilot tests: II (vegetation), III (without vegetation).

The Rational Method (Equation 2) was applied in order to estimate the test flow, and the rainfall intensity was obtained from Equation 3. The values 28.337; 0.104; 10.845; 0.813 and -2.750 were assigned to the maximum rainfall intensity for empirical parameters  $a$ ,  $b$ ,  $c$ ,  $n$  and  $s$ , respectively, as proposed by Sobrinho et al. (2014). A 50-year return period ( $Tr$ ) was adopted, in these conditions, the calculated flow used in the tests was 1.0 L/min. In order to estimate the soil loss ( $SL$ , in kg/m) and soil dispersion rate ( $D$ , in kg / m<sup>2</sup> x s), Equations 4 and 5 were used, respectively, quoted by Meira (2008) and Inácio et al. (2007).

$$Q = \frac{CIA}{360} \quad (2)$$

where:  $Q$  is the flow (L/s);  $C$  is the runoff coefficient;  $I$  is the rainfall intensity (mm/h);  $A$  is the area (ha).

$$I = \left[ \frac{a(Tr-s)^b}{c^n} \right] \quad (3)$$

where:  $I$  is the rainfall intensity (mm/min);  $Tr$  is the return period (years);  $a$ ,  $b$ ,  $c$ ,  $n$  and  $s$  are the empirical parameters for each location.

$$SL = \frac{\sum(Q.Cs.t)}{Ap} \quad (4)$$

where:  $SL$  is the soil loss (kg/m);  $Q$  is the flow (L/s);  $Cs$  is the concentration of soil (kg/L);  $t$  is the time between collections (min);  $Ap$  is the plot area (m<sup>2</sup>);

$$D = \frac{Mss}{(Ap.Dc)} \quad (5)$$

where:  $D$  is the inter-furrow dispersion rate (kg / m<sup>2</sup>.s);  $Mss$  is the dispersed dry soil mass (kg);

$Ap$  is the plot area (m<sup>2</sup>);  $Dc$  is the collection duration in (s).

## 5. Results and discussion

### 5.1 Morphometric characterization and land occupation and use

The results of the morphometric characterization show that the micro basin is prone to flooding, according to the figures presented in the compactness coefficient ( $kc$ ) of 1.17, shape coefficient ( $kf$ ) 0.62 and circularity index ( $Ic$ ) 0.48, referring to a more circular shape of basin. On the other hand, the shape index suggests a basin prone to average flooding, since the distance of the index figure is one (1) (Magalhães Filho et al., 2013, p. 42). Likely flooding is somehow related to water concentration and, consequently, to the concentration of transported sediments.

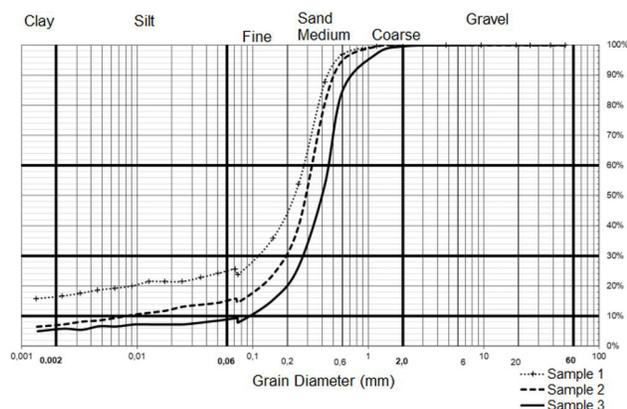
The drainage density was 0.92 km/km<sup>2</sup>, classified as average drainage capacity with few ramifications, according to Strahler (1953). Villela & Mattos (1975) affirm that basins with poor drainage systems vary from 0.1 to 0.5 km/km<sup>2</sup> and well-drained basins vary from at least 3.5 km/km<sup>2</sup>. In light of this, the emphasis is on how important it is to mitigate the severe erosion processes in the area, since they could cause aggradation and contamination of nearby water bodies. The sinuosity of the drainage system was low (0.33), signifying straight channels, that is, channels that encourage greater sediment transport (Antoneli & Thomaz, 2007).

With regard to land occupation and use, it was found that 8.89 ha (38%) are covered with native vegetation, 5.42 ha (23%) with scrubland, and the total value of exposed soil and water-resistant areas is 6.2 ha (26.5%) in addition to the existence of two shallow lagoons.

### 5.2 Results of geotechnical characterization

#### 5.2.1 Laboratory tests

The soil samples from Timbaúbas Nature Reserve revealed predominantly sandy soils with medium particles (53%-65.2%). Figure 3 shows that the materials passing



**Figure 3.** Grading curves of samples.

through the sieve 0.075 mm varied from 10% to 26%. The clay percentages were 16.7%, 8% and 6.8% for Samples 1, 2, and 3, respectively.

The relative particle densities of the soil samples were 2.61 to 2.67. According to Camapum de Carvalho et al. (2015), the values allow to conclude that the sand is predominantly quartz, confirming what was mentioned earlier.

With regard to soil consistency limits, the samples were classified as non liquid and non plastic, allowing classification of the samples in the *SM* (silty sand) group, showing high soil erosion potential (Llopis Trilha, 1999).

In the slaking tests Samples 2 and 3 were found to have disintegrated completely after total immersion (Table 1), indicating the frailty of the material when immersed in water, typical of highly erodible soils (Bastos, 1999). Sample 1, however, remained practically undisturbed throughout the test, associated with the higher concentration of clay content (16.7%) compared to the other samples (8% and 6.8%).

In crumb tests, the lumps of soil were immersed in a vessel with 150 ml of distilled water. One hour later, the sample reactions were observed to attribute the degree

of dispersibility. According to the classification in ABNT NBR 13601/1996, Sample 1 falls into Degree 1 class (non-dispersive), showing to be fractured but with no turbidity in the water; Samples 2 and 3, however, are in the Degree 2 class (slightly dispersive), since the samples are fractured and the water slightly cloudy.

The Inderbitzen tests of the three soil samples, in natural moisture and pre-saturation conditions, showed that the soil mass is mostly lost in the test specimen condition with initial natural moisture. In this condition, the mass losses of the samples varied from  $8.2 \times 10^{-3}$  to  $1.3 \times 10^{-2}$  g/mm<sup>2</sup>. In the saturated soil the mass losses of the samples varied from  $7.8 \times 10^{-3}$  to  $1.1 \times 10^{-2}$  g/mm<sup>2</sup>. Only the saturated Sample 1, tested in the smallest flow (3.5 L/min), showed less mass loss of  $4.3 \times 10^{-3}$  g/mm<sup>2</sup>, after 20 minutes testing - around 50% of the natural soil mass loss ( $8.2 \times 10^{-3}$  g/mm<sup>2</sup>). The mass losses were higher with the increase in runoff flow (Table 2). The results obtained in the study herein are in the same order of magnitude as Fácio's studies (Fácio, 1991) for the locations of Ceilândia I, Sobradinho I and Samambaia, in the Federal District, which present intense erosion processes. From this study, it is found that erosion control interventions must be made before the first rains, when the erosion process would be more severe.

For Bastos (1999), the mass loss is greater in the soil in natural moisture due to the intra-aggregate suction parameter (negative neutral pressure) of non-saturated soils, hampering the water seepage process and, consequently, increasing surface runoff.

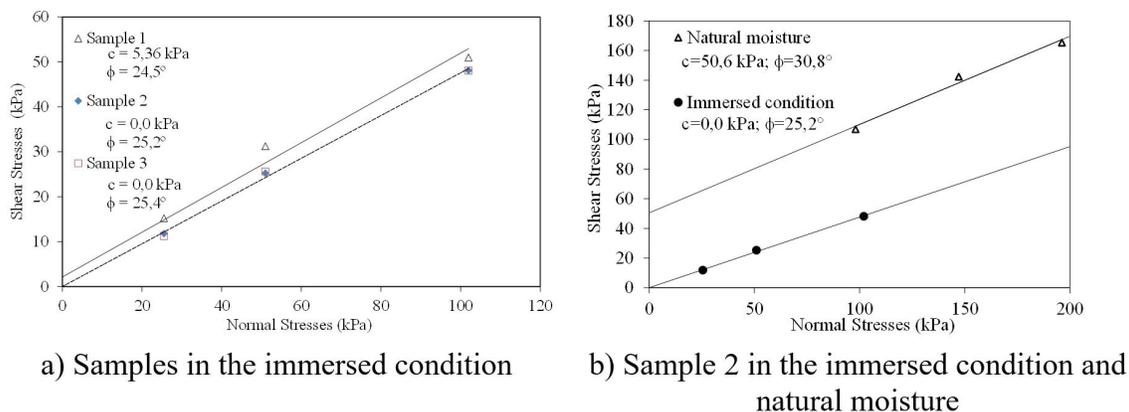
The erodibility rate (*K*) of all three samples in natural moisture, obtained in the Inderbitzen tests, were from 0.105 to 0.108 g/cm<sup>2</sup>/min/Pa, suggesting that they are highly erodible soils. Bastos (1999) believes that the most erodible soils, in the natural moisture condition, have a higher *K* value than 0.1 g/cm<sup>2</sup>/min/Pa.

**Table 1.** Soil behavior in slaking test stages

Water phases in test	Sample 1	Sample 2	Sample 3
Test specimen base	Intact with 80% rise of sample	Intact with full rise of sample	Fracture of sample with full rise
h/3 test specimen	Intact with full rise of sample	Start of dispersion	Advanced dispersion
2h/3 test specimen	Slight dispersion	Dispersion advance	New fractures
Complete immersion of test specimen	Slight dispersion	Formation of a pile of unstructured material (Reduction)	Formation of pile of unstructured material (Reduction)

**Table 2.** Loss of soil mass in the Inderbitzen test

Amostra	Loss of soil mass (x10 <sup>-3</sup> g/mm <sup>2</sup> )					
	Flow of 3.5 L/min		Flow of 6.0 L/min		Flow of 7.0 L/min	
	Natural	Immersed	Natural	Immersed	Natural	Immersed
1	8.2	4.3	11.0	7.8	12.0	8.0
2	9.5	7.8	11.0	8.5	13.0	10.5
3	9.0	8.0	11.7	10.0	12.5	11.0



**Figure 4.** Shear stress x Normal stress. Source: Adapted from Clarindo (2018, *apud* Sobrinha, 2019)

With respect to the shear strength of the soils (Figure 4a), the tests on immersed test specimens provided cohesion intercept low values. Concerning friction angles, the values in the saturated samples are close, with a slight variation (24.5° - 25.4°). In order to evaluate the cohesive behavior for samples in natural and saturated moisture, and their relationship in the erodibility potential, resistance tests were performed in the natural moisture condition of, only in Sample 2, as it has a higher clay content (Figure 4b). For the natural moisture condition, the cohesion was 50.55 kN/m<sup>2</sup>, while in the saturation moisture the cohesion was zero. According to the proposal by Bastos (1999), Sample 2 has high erosion potential ( $\Delta c > 85\%$ ). This fact was confirmed in the study area, where there is a deep erosion scar near the sample extraction site. The friction angle decreased 18% compared to the result obtained in natural moisture (30.8°) with the saturated sample (25.2°). The same behavior is expected in Samples 1 and 3, which have smaller clay contents.

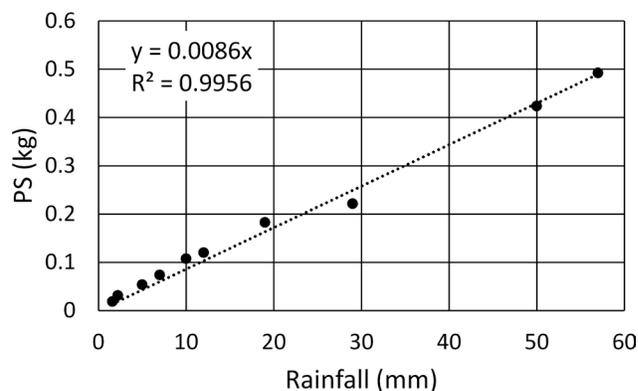
**5.2.2 In situ tests**

*5.2.2.1 Permeability testing*

The Guelph permeameter tests provided permeability coefficient values of 10<sup>-5</sup> m/s, in places near the collection sites of Samples 1 and 3, typical of sandy soils. However, in the vicinity of the Sample 2 site, the permeability coefficient was negative, and may be related to the hydraulic discontinuity in the soil profile or permeability beyond the top limit of the equipment capacity, because roots and ant holes are found around the hole where the test was performed.

*5.2.2.2 Erodibility Study in Pilot tests*

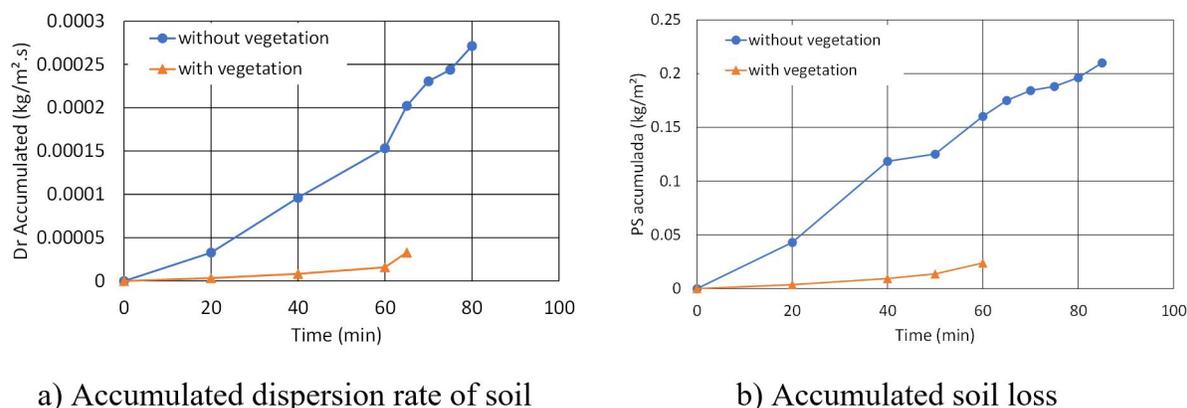
During the experiment, daily rainfall of 7.0 mm (04/14/2018) was able to erode 73.5 g of soil (Pilot test I, Figure 5). On the other hand, 29 mm daily rainfall was logged (04/09/2018) causing 221.37g of soil to be dragged, while heavier rainfall of 50 mm (04/05/2018) eroded 407.9 g of soil. The quantity of soil loss due to natural rainfall provided values that reinforce the alert for the area degraded by erosion will require rehabilitation.



**Figure 5.** Soil loss x rainfall (Pilot test I).

Pilot tests II and III were installed between two erosion furrows in order to estimate the soil mass loss due to surface runoff, over a stretch of land with a gradient of 17%. In Pilot test II (with vegetation), the transported material was first collected an hour and a half after the start of the test, at a measured surface runoff velocity of 0.070 m/s. In Pilot test III (exposed soil), the first collection of the transported material was faster (51 minutes after the start of the test), and the runoff velocity was 0.133 m/s. From the results, a 52.63% drop was observed in the runoff velocity, when the soil is protected by vegetation, implying less pulling power of the runoff and consequently less erosion.

With regard to the dispersion rates given in kg/m<sup>2</sup>.s, and soil losses in kg/m<sup>2</sup>, higher values in the pilot test without vegetation were logged (Figures 6a and 6b). In this pilot test, the dispersion rate was 10 times more than the value obtained in the pilot test with vegetation (Table 3). Inácio et al. (2007) and Meira (2008) also observed this fact. Mannering & Meyer (1963) explain that the vegetation on the ground surface prevents the direct impact of raindrops and dissipates their energy, reducing the dispersion of particles, corroborating the results obtained in this study. The surface soil of the pilot test with vegetation had moisture content of 21.5% in the end, higher than that of the soil in the pilot test



**Figure 6.** Accumulated dispersion rate and accumulated soil loss in the Pilot test.

**Table 3.** Parameters obtained in simulated runoff in Pilot tests

Parameters	Pilot test of soil with no vegetation	Pilot test of soil with vegetation
Gradient	17.25%	17.25%
Initial runoff velocity	0.133 m/s	0.070 m/s
Soil collection duration	51 minutes	1h 30 minutes
Initial soil moisture	9.0%	9.3%
Final soil moisture	14.6%	21.5%
Soil loss (kg/m <sup>2</sup> ) in 1h	0.1603	0.0238

without vegetation (14.6%). These results show that the soil with vegetation cover facilitates the water seepage process, increasing the degree of saturation, reducing the runoff and surface dispersion rate.

The higher dispersion rates in the soil without vegetation may be associated with the higher values of matrix suction of the undiscovered soil, in the as yet unsaturated state, which hinders seepage. When the soil is covered with vegetation, roots can help in seepage. Almeida (2014), in his studies on the influence of suction in the loss of eroded total mass, commented on a direct relationship between the initial soil suction and the eroded mass. This result shows the need to implement rehabilitation projects in the area, considering planting medium-size and small native species, as well as scrubland vegetation.

## 6. Conclusions

Timbaúbas municipal nature reserve presents several factors that contribute to the occurrence of erosion processes. This study addressed the morphometric characteristics that favor the rapid water flow and potential drag on solids. The reduced rate of soil vegetation cover associated with the mechanical characteristics of the aggregate increases susceptibility to erosion processes, also intensified by anthropic intervention, removal of vegetation and construction of buildings on the site, without proper action to discipline the runoff. The exposed soil area and water-resistant areas (6.2 ha) are 26.5% of the Reserve's total area (23.4 ha). The area covered by native vegetation (8.89 ha) represents only 38%. These facts alert to the need to consider the

area's geomorphological, geotechnical and hydrological characteristics, to implement projects to rehabilitate the area degraded by erosion, involving implementation of proper drainage systems; planting native species and other structural and non structural measures. It is the adoption of non-structural measures, such as, for example, educational actions for Reserve users, could contribute to prevent the emergence of new erosion processes in the area.

## Declaration of interest

There is no conflicting interests.

## Authors' contributions

Ana Patricia Nunes Bandeira: investigation, validation, discussion of results, review and approval of the final version of the manuscript. Cícera Camila Alves Macedo: investigation, validation, original draft preparation. Gerbeson Sampaio Clarindo: investigation and validation. Maria Gorethe de Sousa Lima: discussion of results, writing – reviewing. João Barbosa de Souza Neto: investigation, validation, discussion of results, writing - reviewing.

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## List of Symbols

*A* Area

*a, b, c, n, s* Empirical parameters for each location.

*A<sub>p</sub>* plot area

*API* Integral Protection Area

*c* Cohesion intercept

*C* Runoff coefficient

*C<sub>s</sub>* Concentration of soil

*D* Inter-furrow dispersion rate

*D<sub>c</sub>* Collection duration

*GIS* Geographic information systems

*I* Rainfall intensity

*I<sub>c</sub>* Circularity index

*IBGE* Brazilian Institute of Geography and Statistics

*IPECE* Ceará Research Institute on Economic Strategy

*K* Erodibility rate

*k<sub>c</sub>* Compactness coefficient

*k<sub>f</sub>* Shape coefficient

*K<sub>s</sub>* Hydraulic conductivity saturated on site

*M<sub>ss</sub>* Dispersed dry soil mass (kg)

*Q* Flow

*R1* Waterfall rate obtained from the first load applied in the in situ permeability

*R2* Waterfall rate obtained from the second load applied in the in situ permeability

*SL* Soil loss

*SM* Silty sand

*t* Time between collections

*T<sub>r</sub>* Return period

*UAV* Unmanned aerial vehicles

*USLE* Universal Soil Loss Equation

*x* Tank constant

$\Delta c$  Variation in cohesion

$\phi$  Friction angles

$\tau_{crit}$  Critical hydraulic shear stress