Lithic soils in the semi-arid region of Brazil: edaphic characterization and susceptibility to erosion (Postprint)

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Abstract

Soils (Leptosols or Epileptic Regosols) with lithic contact at a depth of 50 cm occupy almost 20% of the Brazilian semi-arid region. These lithic soils are susceptible to erosion due to faster saturation of water-holding capacity during rainfall, which accelerates the beginning of runoff. However, erosion traits of lithic soils in the semi-arid region of Brazil are less studied. The aim of this study was to characterize the soil and landscape attributes in areas with Neossolos Litólicos (Entisols) in the Ca atinga biome to identify region of high susceptibility to erosion. Results showed that the soils were characterized by a sandy texture, soil structure with poor development and low content of organic carbon. These attributes increase susceptibility to erosion and reduce water storage capacity, especially in the states of Ceará and Sergipe. In these states, the content of rock fragments in the soil reaches 790 g/kg. High contents of silt and fine sand, high silt/clay ratio, predominance of Leptosols and strong rainfall erosivity were observed in Piauí and northwestern Ceará. A very high degree of water erosion was observed in the states of Pernambuco and Paraíba. Despite the low degree of erosion observed in the state of Bahia, it is highly susceptible to erosion due to the predominance of very shallow soils, rugged relief and high values of rainfall erosivity. Lower vulnerability was observed in the state of Alagoas because of its more smoothed relief, greater effective soil depth, thicker A horizon of soil and lower rainfall erosivity. In general, the characteristics that intensify the susceptibility to erosion in the Caatinga biome are those soil structures with poor development or without aggregation, low contents of organic carbon, high contents of silt and fine sand, high values of silt/clay ratio and rugged relief in some regions. This study collected information contributing to a better characterization of soils with lithic contact in the semi-arid region of

Brazil. In addition, regions with a higher susceptibility to erosion were identified, revealing insights that could help develop strategies for environmental risk mitigation.

Full Text

Preamble

Lithic soils in the semi-arid region of Brazil: edaphic characterization and susceptibility to erosion

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Abstract: Soils (Leptosols or Epileptic Regosols) with lithic contact at a depth of 50 cm occupy almost 20% of the Brazilian semi-arid region. These lithic soils are susceptible to erosion due to faster saturation of water-holding capacity during rainfall, which accelerates the onset of runoff. However, erosion traits of lithic soils in the semi-arid region of Brazil are understudied. This study characterized soil and landscape attributes in areas with Neossolos Litólicos (Entisols) in the Caatinga biome to identify regions of high erosion susceptibility. Results showed that the soils were characterized by sandy texture, poorly developed soil structure, and low organic carbon content. These attributes increase susceptibility to erosion and reduce water storage capacity, especially in the states of Ceará and Sergipe, where rock fragment content reaches 790 g/kg. High contents of silt and fine sand, high silt/clay ratio, predominance of Leptosols, and strong rainfall erosivity were observed in Piauí and northwestern Ceará. A very high degree of water erosion was observed in Pernambuco and Paraíba. Despite the low degree of erosion observed in Bahia, it is highly susceptible due to predominance of very shallow soils, rugged relief, and high rainfall erosivity. Lower vulnerability was observed in Alagoas because of its smoother relief, greater effective soil depth, thicker A horizon, and lower rainfall erosivity. In general, the characteristics that intensify erosion susceptibility in the Caatinga biome are poorly developed or non-aggregated soil structures, low organic carbon content, high silt and fine sand contents, high silt/clay ratio, and rugged relief in some regions. This study contributes to better characterization of soils with lithic contact in Brazil' s semi-arid region and identifies regions with higher erosion susceptibility, providing insights for environmental risk mitigation strategies.

Keywords: Caatinga biome; drylands; erosive processes; leptosols; soil degradation

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1 Introduction

The arid, semi-arid, and dry sub-humid regions of the world, commonly referred to as drylands, occupy an area of 67$×10^{6}$ km^2, accounting for approximately 45.4% of the world' s total area (Pravalie, 2016). In Brazil, drylands cover approximately 97$×10^{4}$ km^2 of the national territory (Lapola et al., 2014), concentrated primarily in the northeastern region and the northern part of Minas Gerais (IBGE, 2017). This area encompasses 1269 municipalities with a population of approximately 26$×10^{6}$ people, making it the most populous semi-arid region in the world (IBGE, 2011; SUDENE, 2017).

The native vegetation of the Caatinga biome is classified as savanna-steppe (IBGE, 2012), characterized by substantial floristic and physiognomic spatial variability, with predominance of shrubby, woody, shrub-tree, and xerophilous species (Andrade-Lima, 1981; Araújo et al., 2007). Caatinga vegetation belongs to the global biome of seasonally dry tropical forests and shrubs and is biodiversity-rich, with approximately 3150 catalogued species, of which 23% are endemic (Queiroz et al., 2017). Due to prolonged water deficit in the Caatinga, sparse vegetation cover provides poor soil surface protection. This limited cover, combined with low soil organic matter and short-duration, high-intensity rainfall, makes some areas highly susceptible to water erosion.

The Caatinga is dominated by soils with low pedogenetic development, mostly (19.2%) presenting lithic contact within the first 50 cm depth from the surface (Araújo Filho et al., 2017), classified as Neossolos Litólicos according to the Brazilian Soil Classification System (Santos et al., 2018). Under the World Reference Base (WRB) for soil resources (IUSS Working Group WRB, 2015), these soils are classified as Leptosols when rock occurs within the first 25 cm depth, or as Epileptic Regosols when contact occurs between 25 and 50 cm depths. These shallow soils have important constraints that promote erosive processes: (i) natural impediment to root growth due to the parent rock' s physical barrier, which hinders vegetation development (Kosmas et al., 2000); and (ii) faster saturation of water-holding capacity during rainfall, which accelerates runoff initiation (Pedron et al., 2011).

In addition to sparse vegetation cover and predominance of shallow soils, other common soil attributes that increase vulnerability to degradation include high contents of silt and fine sand (S+FS), high silt/clay ratio (S/C ratio), and low aggregate stability (Vaezi et al., 2008, 2017; Ribeiro et al., 2009; Cantón et al., 2011). Furthermore, different combinations of topographic characteristics (Quan et al., 2020) and rainfall erosivity (Mello et al., 2013; Oliveira et al., 2013; Almagro et al., 2017) can contribute to increased erosion rates. To our knowledge, no research in the literature provides comprehensive spatial information on lithic soils, rainfall erosivity, and landscape features to characterize erosion susceptibility in the Caatinga biome.

Given the high vulnerability of the Caatinga biome, this study aimed to spatially characterize landscape and soil attributes (morphological, physical, and chemical) of Neossolos Litólicos within the Caatinga biome and identify areas with high erosion susceptibility.

2.1 Dataset

We created the dataset based on bibliographical research from exploratory soil surveys conducted in the states of Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Piauí (PI), Maranhão (MA), Alagoas (AL), Sergipe (SE), Bahia (BA), and northern Minas Gerais (MG) (Jacomine et al., 1971, 1972a, b, 1975a, b, 1976, 1979a, b; Jacomine, 1973; 1986a, b). We selected 95 soil profiles within the Caatinga biome [Figure 1: see original paper], all classified as Neossolos Litólicos (Santos et al., 2018). These profiles, besides having lithic contact within the first 50 cm depth, show absence of a subsurface diagnostic horizon, presenting an A-R or A-C-R horizon sequence.

For all studied soil profiles, we obtained landscape information, morphological descriptions, particle-size attributes, and chemical attributes from the aforementioned surveys (Table 1). Soil attributes were evaluated in horizons A and C of each profile (C horizon was not always present). Each horizon was considered as a whole; no specific depths were evaluated and interpolation methods were not applied. Subsequently, we classified the profiles according to WRB (IUSS Working Group WRB, 2015).

[Figure 1: see original paper] Soil samples (a) and profile distribution (b and c) of Neossolos Litólicos in the Caatinga biome. CE, Ceará; RN, Rio Grande do Norte; PB, Paraíba; PE, Pernambuco; PI, Piauí; MA, Maranhão; AL, Alagoas; SE, Sergipe; BA, Bahia; MG, Minas Gerais.

2.2 Spatial Distribution of Soil Attributes

Spatial information on rainfall erosivity in Brazil' s northeast region was compiled from Almagro et al. (2017), representing the most recent and complete estimations available for Brazilian states. Almagro et al. (2017)

used a gridded rainfall dataset with 0.25°$×0.25°*spatialresolutionand*1 − *monthtemporalresolutionbasedonobservedrainfalldatafromapproximately*4000*raingauges*, *providedbydiffe*
h·a), respectively. Methodological details are described in Almagro et al. (2017).

Water erosion, local relief, A horizon thickness, soil depth, soil structure, chemical properties, and physical properties of each soil profile were overlaid with spatial rainfall erosivity information for descriptive analyses. Physical attributes (rock fragment (RF), S+FS, S/C ratio, and coarse sand/fine sand ratio (CS/FS ratio)) and chemical attributes (pH-H_2O, base saturation (V), exchangeable sodium percentage (ESP), and total organic carbon (TOC)) of the A horizon were also spatialized for further descriptive assessment.

Landscape attributes, morphology, particle-size attributes and chemical attributes of the soils

Landscape attribute and morphology | Degree of erosion* | Local relief class | Thickness of surface horizon |
Particle-size attribute | RF (rock fragment; >2 mm, g/kg) | pH (H_2O and KCl) | ADFE (air-dried fine earth, g/kg) |
Total sand (coarse and fine, g/kg) | Degree of structure development | Silt (g/kg) | Effective soil depth |
Clay (g/kg) | S+FS (sum of silt and fine sand, g/kg) | S/C ratio (silt/clay ratio, dimensionless) | Coarse sand/fine sand ratio (dimensionless) |
ΔpH (pH KCl-pH H_2O) | S (sum of bases (Ca^{2+}+Mg^{2+}+K^++Na^+, cmol/kg) | T (effective cation exchange capacity (S+Al^{3+}+H^+, cmol/kg)) | V (base saturation (S/T)$×$100%) |
(exchangeable percentage (Na^+/T)$×$100%) | TOC (total organic carbon, g/kg) | sodium TN (total nitrogen, g/kg) | C/N ratio (dimensionless) |

*Ranging from slight to severe based on quantitative and qualitative field assessments and evidence of surface horizon removal and loss of biological activity.

2.3 Statistical Analysis

We used box plots to summarize the distribution of particle-size and chemical attributes, providing mean values and standard deviations. Cluster analysis identified groups of similar soil physical characteristics based on A horizon physical attributes (RF, air-dried fine earth (ADFE), total sand, coarse sand, fine sand, clay, silt, S+FS, S/C ratio, and CS/FS ratio). Cluster analysis uses Euclidean distance (Eq. 1) as a dissimilarity measure and Ward' s hierarchical technique (Ward, 1963) to form groups, a widely used strategy for grouping soil characteristics and attributes (Bhering et al., 2017; Chaves et al., 2017; Arcoverde et al., 2019; Santos et al., 2020).

$$eD = \sqrt{\sum_{j=1}^{n} (v_{pj} - v_{kj})^2}$$

where eD is the Euclidean distance (dimensionless), and v and v are the variable quantitative characteristics of cooperatives p and k, respectively, of the jth data observed.

Ward' s method is based on the sum of squares between groups and within each group, aiming to obtain maximum similarity within groups and maximum dissimilarity between different groups formed at each clustering stage. Cluster analysis effectively distinguished four similar groups according to pre-established criteria.

3.1 Rainfall Erosivity, Landscape Attributes and Soil Morphology

Figure 2 shows the spatial distribution of rainfall erosivity within the Caatinga biome and compares it with landscape attributes and soil morphology of Neossolos Litólicos profiles. Generally, moderate erosivity predominated with values $\$\ 4000 MJ\cdot mm/(hm^{\{2\}\cdot h\cdot a)(bluish-greenhues)[Figure2a:seeoriginalpaper].Inregionswithyellowish-greenhues,erosivityvar}$ $a)),highlightingstrongclassesobservedmainlyinthecoastalregionofnorthwesternCEandthroughoutmostofP$ $mm/(hm^{\{2\}\cdot h\cdot a),representedbystrongerbluehues)occurredincentralRN,PB,andPE.Incontrast,erosivitywasclassifiedasstrongor}$ h • a)) in southwestern BA and northern MG, PI, and MA.

Neossolos Litólicos were studied under various topographic conditions and distributed across different relief classes [Figure 2c: see original paper]. However, in BA, RN, PB, PE, and northern MG, more rugged reliefs predominated, including wavy and strongly wavy relief classes. Additionally, the most advanced degrees of water erosion (ranging from moderate to severe) [Figure 2b: see original paper] were observed in BA, PE, RN, CE, and central BA, indicating intense surface horizon removal and highly degraded biological function.

Regarding morphological attributes, despite considerable variability among A-horizon thickness classes, horizons between 10 and 20 cm depth predominated [Figure 2d: see original paper]. Most soil profiles had effective depths <34 cm [Figure 2e: see original paper], with the shallowest soils observed mainly in PI, RN, and BA, and to a lesser extent in CE, PE, and SE. Most surface horizons had weakly developed aggregate structures [Figure 2f: see original paper], followed by those without aggregation.

[Figure 2: see original paper] Rainfall erosivity (a), landscape attributes (b and c) and soil morphologies (d-f) of Neossolos Litólicos in the Caatinga biome

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3.2 Spatial Distribution of Particle-Size Attributes

A similar pattern of particle-size attributes was observed in surface and subsurface horizons of the studied soil profiles [FIGURE:3 and FIGURE:4]. Average ADFE and RF values were approximately 750.00 and 250.00 g/kg, respectively. The greatest RF variability occurred in the third and fourth quartiles, especially in surface horizons.

Figure 5 shows the spatial distribution of A horizon particle-size attributes. The highest RF content (reaching 790.00 g/kg) occurred in central CE and SE regions and in some areas of PB, PI, and BA [Figure 5a: see original paper].

[Figure 3: see original paper] Box plot of particle-size attributes (a and b) of A horizon of Neossolos Litólicos in the Caatinga biome. S, silt; FS, fine sand; S/C, silt/clay; CS/FS, coarse sand/fine sand.

[Figure 4: see original paper] Box plot of particle-size attributes (a and b) of C horizon of Neossolos Litólicos in the Caatinga biome. S, silt; FS, fine sand; S/C, silt/clay; CS/FS, coarse sand/fine sand.

Average clay contents were 166.00 and 193.00 g/kg, while average silt contents were 254.00 and 347.00 g/kg in A and C horizons, respectively. These features result in high S/C ratio values, especially in CE, eastern PE, and northern PI, where values can reach 6.25 [Figure 5b: see original paper].

Total sand contents in A and C horizons showed high variance with mean values of 579.00 and 460.00 g/kg, respectively [FIGURE:3 and FIGURE:4]. However, sandy loam textural class predominated, followed by loam class in both horizons [Figure 6: see original paper]. Coarse sand content in surface horizons was slightly higher than fine sand, resulting in CS/FS ratios \$ \$1.2 [Figure 5d: see original paper], though two exceptions with values above 3.2 were observed in BA.

S+FS content, an important characteristic in erosion studies, averaged 542.00 and 561.00 g/kg in A and C horizons, respectively. Many horizons showed values above 640.00 g/kg, especially in SE, PI, and CE [Figure 5b: see original paper].

Figure 7 shows the Euclidean distance dendrogram and four groups based on Ward’ s method. Table 2 shows the average and standard deviation of physical attributes for each group.

Despite high standard deviation, important relationships among A horizon physical attributes can be observed from group mean values. Group 3 showed the highest average RF (273.16 g/kg), highest total sand content (617.37 g/kg), and lowest clay content (129.47 g/kg). Groups 2 and 4 had the highest silt contents (288.22 and 283.75 g/kg, respectively), highest S+FS contents (566.47 and 545.63 g/kg, respectively), and highest S/C ratios (2.42 and 2.23, respectively), while group 1 showed the lowest values for these attributes.

[Figure 5: see original paper] Spatial distribution of particle-size attributes of

A horizon of Neossolos Litólicos in the Caatinga biome. (a), rock fragment; (b), silt+fine sand (FS); (c), S/C, silt/clay; (d), CS/FS, coarse sand/fine sand.

[Figure 6: see original paper] Textural class of A and C horizons of Neossolos Litólicos in the Caatinga biome

[Figure 7: see original paper] Dendrogram plot by hierarchical cluster analysis based on soil physical attributes of A horizon of Neossolos Litólicos in the Caatinga biome

Average and standard deviation (SD) of physical attributes of surface horizons of Neossolos Litólicos for each group formed in cluster analysis and for all surface horizons

<table>
<tr><th>Physical attribute</th><th>Group 1</th><th>Group 2</th><th>Group 3</th><th>Group 4</th><th>All surface horizons</th></tr>
<tr><td>Rock fragment (g/kg)</td><td colspan="5">221.03$±200.18|215.29±174.72|273.16±215.90|200.63±153.69|225.75±192.78||<i>Air−driedfineearth(g/kg)</i>|778.97±200.18|784.71±174.72|726.84±215.90|799.38±153.69|774.25± <i>FS(g/kg)</i>|535.88±129.40|566.47±146.71|539.47±77.78|545.63±162.52|542.08±129.13||<i>S/C</i></td></tr>
</table>

Note: S, silt; FS, fine sand; S/C, silt/clay; CS/FS, coarse sand/fine sand. Mean±SD.

3.3 Spatial Distribution of Chemical Attributes

Chemical attributes of studied soils generally did not impede plant development, with prevailing eutrophic character (V>50%). Mean pH values were 5.8 and 5.5 in A and C horizons, respectively, and soils were predominantly eutrophic despite considerable V value variability [FIGURE:8 and FIGURE:9]. BA showed the lowest V values (<20%), attributable to its acidic character (pH<5.0) [FIGURE:10a and b]. Generally, Al^{3+}, H^+, and ESP values were low [FIGURE:8 and FIGURE:9]. Despite large variance and locally high ESP values [Figure 10c: see original paper], the average was only 2%.

[Figure 8: see original paper] Box plot of chemical attributes of A horizon of Neossolos Litólicos in the Caatinga biome. ΔpH = pH-KCl-pH-H_2O; S, sum of bases; T, effective cation exchange capacity; TOC, total organic carbon; TN, total nitrogen; V, base saturation; ESP, exchangeable sodium percentage.

[Figure 9: see original paper] Box plot of chemical attributes of C horizon of Neossolos Litólicos in the Caatinga biome. ΔpH = pH-KCl-pH-H_2O; S, sum of bases; T, effective cation exchange capacity; TOC, total organic carbon; TN, total nitrogen; V, base saturation; ESP, exchangeable sodium percentage.

TOC content in the A horizon was low [Figure 8c: see original paper], averaging 11.20 g/kg. Despite TOC data variability, the median was 9.00 g/kg, explaining the predominance of soils with TOC content lower than 10.00 g/kg, particularly in CE, RN, AL, and PB [Figure 10d: see original paper].

[Figure 10: see original paper] Spatial distribution of chemical attributes of A horizon of Neossolos Litólicos in the Caatinga biome. (a), pH-H_2O; (b), V, base saturation; (c), ESP, exchangeable sodium percentage; (d), SOC, soil organic carbon.

3.4 Soil Classification

Regarding profile classification according to WRB (IUSS Working Group WRB, 2015), Leptosols predominated, with smaller effective depths in BA, PI, and RN [Figure 11: see original paper]. In contrast, Epileptic Regosols occurred more frequently in PB and AL. In other states, both soil groups had similar proportions.

[Figure 11: see original paper] Soil classification result according to World Reference Base for soil resources

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4 Discussion

The small effective depth that restricts water circulation to the first centimeters of the profile is probably the main factor contributing to erosive processes in Neossolos Litólicos. Our results show that several other factors can intensify erosive processes in these Caatinga biome soils, including soil structure development, particle-size attributes (RF, S+FS, and S/C ratio), topographic attributes, surface horizon thickness, effective soil depth, and rainfall erosivity across different Brazilian states.

The predominance of poorly developed or apedic soil structures, as observed in this study, increases susceptibility to erosion due to low stability (Rabot et al., 2018). Several factors may contribute to this low structural stability. An important factor is the limited number of cementing agents, reflected in (i) predominance of sandy loam texture and (ii) reduced organic carbon content (Six et al., 2002; Wachendorf et al., 2014; Vaezi et al., 2018). Deforestation-related factors should also be considered. Pinheiro Junior et al. (2019) studied deforestation effects on sandy soil morphology in the Caatinga biome and found significant land-use change effects on this attribute. In semi-arid regions, low aggregate stability is considered one of the main factors responsible for high soil erodibility (Vaezi et al., 2008, 2017).

Beyond greater erosion susceptibility, lower structural stability results in reduced water-holding capacity due to small intra-aggregate pore volume (Pachepsky and Rawls, 2003; Rabot et al., 2018). This characteristic, combined with sandy texture, small effective depth, and regional climatic conditions, intensifies water deficit, making vegetation establishment even more difficult. Additionally, the large RF amount observed especially in CE and SE further reduces water-holding capacity. Cluster analysis showed that soil profiles with the highest RF amounts also had higher total sand content and lower clay content.

S+FS content, which contributes to high erodibility, was elevated in PI, northwestern CE, and some SE regions. Several studies indicate that particle-size characteristics are key factors in soil erodibility evaluation (Dimoyiannis et al., 1998; Fraser, 1999; Parysow et al., 2003; Pérez-Rodríguez et al., 2007; Vaezi et al., 2016). These studies reported strong correlation ($r>0.90$) between erodibility and S+FS content (Duiker et al., 2001). Soils with high S+FS values have aggregates with low structural stability (Mbagwu et al., 1993; Miqueloni and Bueno, 2011), contributing to greater erosion susceptibility. Additionally, these particles are the first to be eroded during intense rain (Quan et al., 2020). This is particularly relevant in PI and northwestern CE, which have high rainfall erosivity and predominance of shallower soils (Leptosols). In these regions, high S/C ratio values, often observed in desertification hotspots in the Caatinga biome (Ribeiro et al., 2009), hinder formation of stable, larger aggregates (Vaezi et al., 2018). According to cluster analysis, soils with higher silt contents also have higher S+FS content and S/C ratio (average >2.0), contributing to greater erosion susceptibility.

The higher occurrence of Leptosols (shallower soils) in PE, RN, BA, and some SE regions is associated with more rugged topography. Ruggedness intensifies material removal, conditioning soil to constant rejuvenation (Valtera et al., 2015; Lybrand and Rasmussen, 2018). In these states, advanced erosion degree appears directly related to topographic attributes, as observed in semi-arid regions of Spain (Cantón et al., 2011) and Iran (Moghadam et al., 2015). In western PB, despite predominance of smooth wavy relief, variation in erosion degree from moderate to severe may be associated with land-use changes (Cantón et al., 2011) and smaller A horizon thickness (Pinheiro Junior et al., 2019) observed in PE and RN.

In BA, despite predominance of erosion-facilitating factors (wavy, strongly wavy relief, and Leptosols), many sites showed lower erosion degrees (slight to moderate), perhaps due to relative humidity in BA. Although sparse vegetation cover predominates in the Caatinga biome, some slightly wetter areas favor dry forest formation with denser cover (Moro et al., 2016; Oliveira et al., 2019). In these areas, soil is better protected against direct rainfall impact, reducing erosion degree even on steep slopes. Dry forest cover could thus be responsible for lower erosion degrees in BA. However, BA and northern MG had the highest rainfall erosivity and high soil erosion susceptibility, highlighting the need for environmental risk-mitigation strategies. Given high environmental vulnerability, anthropogenic activities such as land-use changes and soil management can intensify soil erosion (Wei et al., 2007; Vasquez-Mendez et al., 2011; Moghadam et al., 2015; Oliveira Filho et al., 2019). Nevertheless, erosive process dynamics depend on complex interactions among rainfall, soil, vegetation, topography, and hydrological processes (Ludwig et al., 2005; Moghadam et al., 2015).

At the other extreme, lower vulnerability was observed in AL due to a combination of factors reducing erosion susceptibility: (i) predominance of smoother relief; (ii) soils with greater effective depth (Epileptic Regosols); (iii) thicker A horizons (20–40 cm depth); and (iv) lower rainfall erosivity.

5 Conclusions

This study improved characterization of soils with lithic contact in Brazil' s semi-arid regions and identified regions with higher erosion susceptibility and the factors influencing this process.

Characteristics intensifying erosion susceptibility in the Caatinga biome include poorly developed or non-aggregated soil structures, low organic carbon content, high silt and fine sand contents, high silt/clay ratio, and rugged relief in some regions. In PI and northwestern CE, erosion susceptibility was intensified by a combination of high silt and fine sand values, high silt/clay ratio, high rainfall erosivity, and Leptosol predominance. In PE and PB, an extremely advanced degree of water erosion occurred.

In BA, although many factors contributed to high erosion susceptibility, low water erosion degree was observed, possibly associated with denser vegetation cover. Future research evaluating land-use change and vegetation cover indices in the Caatinga biome is important to broaden understanding of erosive processes in Neossolos Litólicos and management strategies that can mitigate or intensify these processes. This study provides insights to help stakeholders (consultants, researchers, public and private companies, and policymakers) identify opportunities for developing environmental risk mitigation strategies.

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