Revista Brasileira de Geografia Física

Homepage: <https://periodicos.ufpe.br/revistas/rbgfe>

Pedodiversidade e degradação ambiental no baixo curso do rio Acaraú, Ceará, Nordeste do Brasil

Simone Ferreira Diniz¹, Vanda de Claudino-Sales², Jose Falcão Sobrinho³

¹ Professora-doutora do Curso de Geografia e do Mestrado Acadêmico em Geografia da Universidade Estadual Vale do Acaraú. E-mail: dinfersim@hotmail.com. ² Professora-doutora do Mestrado Acadêmico em Geografia da Universidade Estadual Vale do Acaraú. E-mail: vcs@ufc.br. ³ Professor-doutor do Curso de Geografia e do Mestrado Acadêmico em Geografia da Universidade Estadual Vale do Acaraú. E-mail: falcao.sobral@gmail.com.

Artigo recebido em 04/06/2020 e aceito em 03/12/2020

RESUMO

O presente trabalho analisa a pedodiversidade que caracteriza a área do baixo curso do Rio Acaraú, situado no Noroeste do Estado do Ceará, Nordeste do Brasil, a partir da análise de perfis de solo realizados em campo, e da análise granulométrica, química e mineralógica de amostras dos solos em laboratório. Fez-se uma atualização da tipologia dos solos na área de pesquisa, bem como a identificação de características físicas que indicam a ocorrência de processos de degradação ambiental na área. Essas situações resultam do uso inadequado do solo no baixo curso do rio, o qual está acelerando processos de erosão em vários graus, resultando em perdas econômicas e risco de desertificação.

Palavras-chave: Pedodiversidade, Degradação Ambiental, Rio Acaraú, Nordeste do Brasil.

Pedodiversity and environmental degradation in the lower course of Acaraú river, Ceará State, Northeastern Brazil

ABSTRACT

This article analyzes the pedodiversity that characterizes the low course of the Acaraú River, in the northwestern Ceará, northeastern Brazil, from the analysis of soil profiles performed in the fieldwork, and from the chemical, mineralogical and particle size analysis of soil samples in the laboratory. The soil typology update in the research area and physical characteristics indicate the occurrence of environmental degradation processes in the area. These situations result from the improper use of the soil in the low course of the river, which is accelerating erosion processes to various degrees, resulting in economic losses and in the risk of desertification.

Keywords: Pedodiversity; Environmental Degradation; Acaraú River; Northeastern Brazil.

Introduction

The soil is an elementary natural resource and an essential element in ecosystems, and, at the same time, a vital space for human activities (Castro and Cooper, 2019). The soil in the surroundings of river basins is important for both types of spatial contexts (natural and social), considering that river also represents a significant element in ecosystems and human activities. Due to their importance to society, river regions and their respective surrounding soils have suffered modifications throughout history in the search for productive areas for irrigation, urbanization,

electricity production, aquaculture, among other purposes (Janssen et al., 2020).

This situation is an example in the low course of the Acaraú River (northwestern Ceará and northeastern Brazil, figure 1) since the river valley is a significant element of the semiarid environment, the soil being an equally important feature of the landscape. Over the last decades, both of these natural resources have been modified as a result of various forms of use and occupation, thus, transforming the original geographical space and generating new spatial arrangements (Silva et al., 2018).

Figure 1. Location map of the lower course of the Acaraú River (Ceará).

These new spatial arrangements often have high environmental degradation significance. The lack of planning and management of the physical environment by the competent authorities and municipal, state and federal administrators, combined with the complete lack of supervision of private activities, especially in areas of high environmental sensitivity, such as soils and sectors of riparian vegetation in semiarid regions, causes the degradation of surface formations and riverbanks (Falcão-Sobrinho et al., 2017). These situations produce erosion, silting, constant reduction in river flow, unavailability of water in the long term and impacts on adjacent aquifers.

This paper analyses this situation in the low course of the Acaraú River from the point of view of the pedodiversity of the area, which was updated concerning previous classifications, and explores the relationship between land use and the resulting environmental impacts on the whole environment.

Geoenvironmental characterization of the area

The analyzed area covers the municipalities of Santana do Acaraú, Marco, Morrinhos, Bela Cruz and Acaraú, in the lower course of the Acaraú River. The Acaraú River is born in Serra das Matas, in the municipality of

Monsenhor Tabosa, in northwestern Ceará, and pour into the coastline in Acaraú. It is an intermittent river of the type braided that presents exorheic drainage (Colares et al., 2016). It represents one of the main drainage networks of Ceará State and comprises an area of 4,517.5 km² (COGERH, 2019; Stanford et al., 1981). This segment is almost entirely in the context of the semiarid northeastern region, except for the coastal zone, which is subhumid.

The semiarid climate is the principal conditioning factor of environmental dynamics in the region. High temperatures, usually between 25°C and 29°C, result in evapotranspiration rates of over 1,000 mm per year (Mesquita et al., 2016). The rain occurs in a very irregular way, with torrential character in the first half of the year, controlled by the oscillations of the Intertropical Convergence Zone (ITCZ) (FUNCEME, 2019). The precipitation rate is in the order of 600 to 800 mm per year in the innermost segments of the research area, and 1000 mm in the coastal zones. In both sectors, the dry season lasts up to nine months (ANA, 2020; Zanela, 2005).

In the most continental regions of the research area, there are rocks of the Precambrian crystalline basement that characterizes most of the lands in Ceará, members of the Granja complex (Paleoproterozoic: 2.2 billion years), formed by

orthogneiss, gneiss, migmatite and quartzite (CPRM, 2019). Sedimentary rocks are common in the low course of the river, all of them gathered in the Barreiras Formation during the Miocene and Pleistocene epochs. The sediments of the Barreiras Formation are made by clays and sands, with little or no lithification, with reddish, cream or yellowish coloration, sometimes mottled and with ferruginous cement (e.g. Morais et al., 2019). The grain size varies from thin to medium, containing interceptions of conglomerate levels consisting of rounded to smoothly rounded quartz pebbles and quartzite, besides other rocks with indistinct stratification (Ximenes Neto et al., 2018). The presence of dispersed and isolated spots of the Barreiras Formation in the basement area possibly indicates that its spatial dimension was larger before (Brandão and Freitas, 2014).

Near the coastline, quaternary sand and marine terrace cover the Barreiras Formation (Maia et al., 2018). The set (pediplain, tableland and marine terrace) is cut by the course of the river, whose valley has quaternary alluvium made of low-permeable clayey sediments. The sandy sediments constitute the principal aquifer of the Acaraú River valley, but with a low water potential because they represent a sedimentary cover of small thickness (IPECE, 2010).

From the geomorphological point of view, it is verified the existence of (1) planation surface in the segments of occurrence of the crystalline rocks, here called “Sertaneja Surface”, which corresponds to the crystalline pediplain classically called “Sertaneja Depression” (Ab'Saber, 1969; Peulvast and Claudino-Sales, 2004) (recent works have been changing the term “depression” for “surface” in order to better characterize the topographic position and the geomorphological connotation of this relief feature, since it is not a real depression, and as indicated by Claudino-Sales (2016); (2) tableland features, corresponding to the so-called coastal zones, almost occupy the areas of

occurrence of the Barreiras Formation, stretching from close to the coastline to about 80 km within the continent (Brandão e Freitas, 2014); (3) alluvial plain, characterized by the occurrence of quaternary alluvium and river flow, which acts by dissecting the pediplain and the coastal zones, generating tabuliform interfluvial tableland in the latter domain (e.g. Melo et al., 2005); (4) fluvial-marine plain in the sectors of the alluvial plain in contact with marine water, where tides penetrate (Diniz et al., 2008; Claudino-Sales, 1993); and (5) coastal zone, with occurrence of coastal dunes (mobile, fixed and paleodune), marine terrace and beaches. The dunes form almost continuous strands, covering a line around 2.5 km wide (Diniz et al., 2008). In the area as a whole, the altitude varies between 200 m (Surface Sertaneja) and 5 m (coastline). Figure 2 represents this set of natural features.

A large part of the area corresponds to the caatinga domain (Fernandes and Bezerra, 1990). The caatinga, a Brazilian biome, is predominantly deciduous, which develops on a shallow and almost always stony soil, with extreme water deficiency during most of the year; the main species is the Brazilian Peppertree (*Schinus terebinthifolius*) and Braúna (*Melanoxylon brauna*) (Fernandes, 1990).

Besides caatinga, there are three other types of vegetation in the research area: (1) the riparian forest that occurs in the floodplain and is characterized by the presence of Carnaúba Palm (*Copernicia prunifera*), (2) the tableland forest that covers the coastal tableland, which is typical of the transition area between the sertão and the sea, with the occurrence of plant species of the caatinga and the coastal zone, such as Murici (*Byrsonima crassifolia*) and (3) the paludose forest (mangrove forest), where red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*) occur mainly (Moro et al., 2015; Figueiredo, 1997).

Figure 2– Geomorphological sketch of the low course of Acaraú River. The location and sequence of the analyzed profiles are indicated by the numbers. Source: Superfície Sertaneja: Planation Surface Sertaneja; Tabuleiros: low tablelands; Planície flúvio-marinha: fluvial-marine plain; Planície fluvial: fluvial plain; Zona litorânea (campos de dunas, terraços marinhos, praias): littoral zone (dunefields, marine terraces, beaches); pontos de coleta: places of sampling; sedes municipais: counties. Adapted from Brazilian Geological Survey Company – CPRM (2019, 2014).

Material and methods

A meticulous investigation of soil in the research area was essential for the development of this work and, for this, points of analysis of the ground were selected with the aid of photos in scale 1:25,000, 2001, which are available at the Ceará Meteorological Foundation (FUNCEME). Then, there was the demarcation of representative areas of each geomorphologic unit of the coastal tablelands, alluvial plains, marine alluvial plain and coastal zones. After the cabinet stage, the fieldwork served to open eight trenches, listed from 1 to 8. The description of the soil samples was according to the standards recommended by Lemos and Santos (1976).

The soil samples analysis occurred in the laboratory for physical (particle size), chemical and mineralogical analysis: The soil composition was

determined through the pipette method, according to Olarte and Codazzi (1979), using sodium hexametaphosphate as a dispersing agent. The sand fraction, after separated from the other materials by wet sieving, was separated in the sub-fractions by dry sieving using 4.76; 2; 1; 19; 0.59; 0.42; 0.297; 0.25; 0.149; 0.074 and 0.053 mm mesh sieves. The pipette method was also essential to determine the clay fraction by completing the dispersing medium with water, whereas the difference between the results determined the silt fraction (Vettori, 1969).

The samples used for the chemical analysis were first untangled and then put into a mill for reduction of the grain size (> 0.035 mm), with all the fine (dominant) and coarse fractions, including lumps and concretions. The following formulae defined the silica/aluminum (Ki) and silica/sesquioxide (Kr and Kr*) ratios:

$$Ki = \frac{SiO_2/PM \ SiO_2}{Al_2O_3/PM \ Al_2O_3} \quad (1)$$

$$Kr = \frac{SiO_2/PM \ SiO_2}{\frac{Al_2O_3}{PM \ Al_2O_3} + \frac{Fe_2O_3}{PM \ Fe_2O_3}} \quad (2)$$

$$Kr^* = \frac{SiO_2/PM \ SiO_2}{\frac{Al_2O_3}{PM \ Al_2O_3} + \frac{Fe_2O_3}{PM \ Fe_2O_3} + \frac{TiO_2}{PM \ TiO_2}} \quad (3)$$

The samples were then prepared on lamina and sent for mineralogical analysis in X-ray diffractometer at Júlio de Mesquita Filho São Paulo

State University, Unesp, Rio Claro Campus, which follows the Embrapa method (1999).

Discussion and results

Soil Profile Analysis -

It was analyzed four soil profiles on the coastal tableland, one on the alluvial plain, two on the marine alluvial plain and one on the coastal zone. Figure 2 presents the location of these profiles. The following paragraphs define the characteristics of the soils in each of these units.

Sertaneja Surface

Because of the small extent of the sertaneja surface in the research area, there are no physical, chemical, mineralogical and granulometric analyses of the soil samples of this relief unit. On the other hand, observations indicated the presence of soils representative of this spatial segment, namely the Litholic Neosol and Luvisol, which are characterized by a thin thickness of horizons and the presence of coarse sediments and rocky fragments. This fact matches the geological (impermeable crystalline rocks) and climatic conditions (semiarid climate), which do not favor the development of more evolved types of soil. Altitude is below 200 m and, the dominant vegetation is arboreal and shrubby caatinga.

Coastal Tableland

Profile 1. This point is in Vila Moura, in the municipality of Morrinhos. The relief is flat, the altitude is 66 m, and the vegetation is of the type tableland forest.

This profile can be divided into two horizons. The first horizon (Ap) presented a light reddish coloration, smoothly-rounded pebbles and rusty hematite, which indicates the occurrence of erosion process. There was also the presence of sediments with a sandy, friable, non-plastic and non-sticky texture. The second horizon (Bt) presented grayish coloration when dry and reddish when wet. Angular and subangular oriented quartz contents, sandy texture, non-sticky and non-plastic material were verified.

In the analysis with the magnifying glass, it was possible to observe a significant amount of quartz and a small amount of Kaolinite, Hematite, Goethite and Potassium Feldspar (Orthoclase) covering the quartz grains. The fine silt fraction highlighted kaolinite and goethite as a pseudomorph over the grains. This profile is kind of a thick sandy clay block.

According to EMBRAPA (1999), the soil would be a Red-Yellow Acrisol. However, its characteristics correspond to a Pseudo Bt Eutrophic Regolith Neosol (figure 3).

Profile 2. The area is located in the municipality of Marco in flat relief at 77 m of

altitude. The soil is well-drained and the predominant vegetation is carnauba palm along with other caatinga species.

Concerning the morphological characterization, the profiles' horizons are the Ap, the A/B and the Bt. The Ap horizon is yellowish, gravelly with rusty concretion and medium to weak gravelly clay (pebbles with clay). The A/B horizon is reddish, sandy, non-plastic, non-sticky and presented pebble, laterite and concretion. The third horizon, the Bt, is reddish, gravelly, clayey, sandy, non-plastic and non-sticky. The Bt horizon is reddish and has yellow pebbles and weathered Plinthite (pebble and laterite). When wet, the Bt coloration turns to dark red.

This profile, which has a low level of kaolinite, suffered lateritization process in the Miocene and Pliocene Epochs. Latosol and non-laterite horizons have pebbles and concretion in different sizes, which causes rusty residual laterite. The clear stains possibly corresponded to a kaolinitic formation that is currently covered by alteration and accumulation of clayey colloids, covered by clayey-ferrous colloids.

The Brazilian Company of Farming Development (EMBRAPA, 1999) classified this soil as Red-Yellow Acrisol, however, its characteristics correspond mostly to a concretionary Neosol (figure 4).

Figure 3. Regolith Neosol.

Profile 3. This profile is located in the municipality of Bela Cruz, in a flat relief at 84 m

above sea level. The soil is well-drained and the predominant vegetation is carnauba palm with the presence of other species also from the caatinga.

As for the morphological characterization, two horizons constitute this profile: the Ap horizon, which is greyish-brown when it is dry and dark brown when it is wet. It is non-plastic and contains very thick sand. The A/B horizon is dark gray when it is dry and yellowish-brown when it is wet. It is sandy, but has 6% of clay and is muddy, slightly sticky, non-plastic. In the profile, there are indications of regolith with the presence of smoothly rounded and subangular quartz, little clay, which are characteristic of an environment with frequent waterlogging.

Even though EMBRAPA (1999) has classified this soil as Dark Red Latosol, its chemical composition allows to classify it as a Eutrophic Alluvial Neosol because it does not meet the Latosol prerequisite, which is 15% of clay (figure 5).

Figure 4. Concretionary Regolithic Neosol.

Profile 4. The area is located in the municipality of Morrinhos, in flat relief at 95 m above sea level. The soil is well-drained and, the predominant vegetation is carnauba palm with the presence of other caatinga species.

Regarding the morphological characterization, two horizons constitute this profile: the Ap horizon, with a greyish-brown color when dry and greyish when wet. This horizon

presents gravelly material, little altered, with rounded to smoothly rounded quartz grains.

The A/C and Ap horizons have a grayish-brown color when dry and grayish when wet. Its soil is clayey, gravelly, concrete. Besides, there are angular to subangular Quartz and rounded Laterite conglomerates because of the transportation by the river (alluvial colluvium).

Figure 5. Eutrophic Alluvial Neosol.

This profile corresponds to the sedimentary neo-basin that comprises the Laterite, thus, occurring a modern plinthic process.

Even though EMBRAPA (1999) has classified this soil as Dark Red Latosol, its morphometric characteristics indicate it as an Eutrophic/Salic Alluvial Neosol (figure 6).

Alluvial Plain

Profile 5. The area is in the municipality of Acaraú, in a low plain at 10 m above sea level. The predominant vegetation is the carnauba palm in well-drained soil.

Two horizons form this profile: the Ap horizon, which is light gray, sandy, non-plastic, non-sticky and has rounded regolith rocks. In addition to regolith rocks, there are angular and subangular quartz in the area. The B/C horizon is grayish-brown, lighter in the middle, has smoothly rounded to subangular quartz, rounded grains of coal and other rounded materials probably from the alluvial origin, occurring translocation or burial of organic matter of Ap horizon. When wet, it is grey, slightly sticky, non-plastic and friable. It is quite similar to profile 2. Even though EMBRAPA

(1999) has classified this soil as Acrisol, its characteristics classify it as a Eutrophic Regolithic Alluvial Neosol (figure 7).

Figure 6. Eutrophic/Salic Alluvial Neosol.

Figure 7. Eutrophic Regolithic Alluvial Neosol.

Profile 6. Profile is in the right bank of the middle course of the Acaraú River, in the municipality of Acaraú. The relief is slightly wavy, with an altitude of 61 m. It is a well-drained area, where the predominant vegetation is the caatinga.

The only horizon in the area, the A/C, is gray, gravelly, little altered, sandy, little cohesive, friable, non-plastic and non-sticky. Through observations made with a 60mm magnifying glass, it is possible to notice subangular to rounded quartz in a significant amount besides Microcline, Orthoclase and Gibbsite in a reasonable amount. Through the silt, it is possible to see Anatase, Orthoclase, and Magnetite in a significant amount and besides Kaolinite and Goethite in a small amount. In the clay fraction, there were kaolinitic clayey minerals, which shows a detrital origin when added to the silt.

Even though Embrapa (1999) had classified this soil as Red Yellow Acrisol, the characteristics observed at the region and subsequent laboratory analyses revealed that it was a Saline Alluvial Regolith Neosol (figure 8).

Profile 7. The area is located in the municipality of Acaraú, in the low plain of flat relief at 3 m above sea level. The soil is well-drained and, the predominant vegetation corresponds to the mangrove forest.

Two horizons make up this profile: the Ap horizon, whose color varies among grey, olive-grey and light grey, is plastic, clayey, sticky and friable. The representative part of the light gray coloration corresponds to 5% of the total sample, which is formed by fines sediments (silt + clay) transported from the alluvial plain, by fine Muscovite sand and by Siltstone added to a type of sand that is rich in quartz. Therefore, the accumulation of coarse material among the fines sediments in the area buries the organic material and generates oxidation of redder color.

The presence of this red material indicates that the area is well-drained, leading to oxidation of the ground and generating this light gray coloration. The dark grey color indicates the flow of organic matter on the horizon. When wet, the material is plastic and sticky, with a 2:1 expansive clay, presenting black grains due to the organic matter (5 to 7%) and smoothly-rounded, matte and thick grains of quartz. There is also 5% of Muscovite and Smectite with cation exchange in all reworked organic matter.

Figure 8. Saline Alluvial Regolith Neosol.

The horizon A/B presents a reddish-brown color and a light yellowish-gray color in a smaller proportion. The second color indicates the infiltration of water from the alluvial system and, the environment becomes rich in organic matter and hydrophilic roots when the tide is low. In this horizon, smoothly-rounded to subangular grains of quartz occur and, a small part of this material comes from the erosion of dunes. There are traces of Magnetite, Tourmaline or angular to subangular Mafic, Gneiss (Amphibole and Pyroxene) and pyramidal grains of quartz. The material is non-rusty, recent and presents smoothly-rounded Laterite.

Even though EMBRAPA (1999) has classified this soil as Vertisol, its morphometric characteristics indicate that it corresponds to a Ta Saline Sodic Melanic Eutrophic Gleysol/Carbon Ebony Vertisol (figure 9).

Figure 9. Ta Saline Sodic Melanic Eutrophic Gleysol/Carbon Ebony Vertisol.

Dunes Field

Profile 8. The area is in Arpoeira Beach, which has a flat relief and is at 5 m above sea level. The soil is well-drained, and the predominant vegetation is the Murici (*Byrsonima crassifolia*).

As for the morphological characterization, the analysis occurred on the Ap horizon. It has light grey, sandy, non-plastic and friable quartz grains. As for its classification, EMBRAPA (1999) named this soil as Quartz Neosol, which was proved by its morphometric characteristics (figure 10).

Figure 10. Saline Sodic Quartz Neosol.

Physical, chemical and mineralogical characteristics

Chemical Composition

The results of total chemical analyses are expressed as a percentage of elements and grouped by soil classes and surface and subsurface horizons, according to EMBRAPA (2006) (tables 1 and 2).

According to Ki and Kr levels, the profiles 1 and 8 presented low weathering. Profiles 2, 3 and 5 are similar in their mineralogical constitution and in the proportion of chemical elements, which determines values of bad weathering change of 0.74 (almost 30%) for profiles 3 and 5. Thus, the Red Yellow Latosol proposed by EMBRAPA (1999) cannot be maintained. On the other hand, profile 2 is less weathered, similar to the original material of profiles 3 and 5.

However, when normalized, the Ki in profiles 3 and 5 indicates that the upper horizons (Ap) are more weathered (between 40 and 50%), whereas the B latosolic and B horizons, according to EMRAPA (1999), present a change of approximately 20%. Thus, they are actually B exchangeable.

Profile 4 shows two depositional sequences (Ap and A/B – 1st sequence and, Bt and Btf – 2nd sequence), whose materials are quite weathered (the sequence on the top presents 85% modification and the buried sequence, 60%). These are usually polycyclic sediments from nearby areas since they do not present significant modifications. The presence of Feldspars makes the Ki level very high in the tops of the sequences (2 and 5, respectively). Profile 6 and 4 show 20% modification and transformation of Feldspars and, therefore, they are Alluvial Neosol in both cases.

Profile 7 shows little weathering since its Ki level is higher than the profile 1, besides existing titanium close to the unit. Therefore, it is not an oxide, but a hydroxide, which makes the soil very soluble.

Mineralogical Composition

The diffractograms of the soil sample helped in the observation of the results of the mineralogy.

Profile 1, whose horizon is the A/C, is stratified and has Muscovite/Mica, Vermiculites and Montmorillonite, which needs a high pH level in its formation process. The soil, although sandy, is much more arcossian, which is confirmed by the presence of Feldspar and Quartz. Very small transformations of Feldspar and Mica give rise to stratified minerals represented by values from 14 to 21Å. The peaks of 12, 10, 3.7 and 3.4Å indicate the presence of Atapulgite and Sepiolite, which represent arid environments, present debris in the area characterized as marine alluvial terraces that are, currently, being dissected by the Acaraú River. Even though this soil is classified by Embrapa (1999) as a Red Yellow Acrisol, the local characteristics reveal it as a Saline Sodic Psammite Regolith Neosol.

The Bt horizon presents stratification dominated by Montmorillonite. The Feldspars is changing to Marble in association with Chlorite, Kaolinite, a small amount of Atapulgite (peaks of 10,14; 3,34 and 4,24Å) and Hematite. When burning at 500°C, the stratification peaks were maintained, especially those of Montmorillonite and Chlorite. There was a decrease in Feldspar levels in the modifying process due to the burning.

Table 1. Result of Chemical Analysis by X-Ray Fluorescence Spectrometry in Oxides (Ki, Kr) (LABOGEO/IGCE – UNESP/Rio Claro).

Pedon	Amostra	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Ki	Kr	Kr*
1	A/C	86,3	0,06	6,88	1,26	21,32	19,09	18,91
2	Ap	93,17	0,33	2,77	1,46	57,18	42,80	38,43
	Bt	93,36	0,34	2,86	1,44	55,49	42,01	37,69
3	Ap	90,92	0,47	4,56	1,17	33,90	29,13	26,17
	A/B	93,62	0,3	3,43	1,01	46,40	39,07	35,71
4	Ap	82,01	0,43	8,86	3,33	15,74	12,69	12,09
	A/B	70,12	0,79	15,59	4,65	7,65	6,42	6,09
	Bt	93,62	0,3	3,43	1,01	46,40	39,07	35,71
	Btf	72,24	0,62	15,16	4,62	8,10	6,78	6,50
5	Ap	90,71	0,43	4,77	1,56	32,33	26,75	24,43
	A/B	92,97	0,32	3,63	1,25	43,54	35,70	32,69
6	Ap	95,95	0,39	1,68	1,44	97,09	62,78	52,70
	A/C	96,29	0,37	1,38	1,34	118,62	73,27	60,49
7	Ap	62,22	0,95	16,61	5,41	6,37	5,27	4,97
	A/B	59,01	0,94	16,37	6,05	6,13	4,96	4,68
8	Ap	72,35	0,1	5,4	1,1	6,30	20,16	19,75

Profile 3 presented the same characteristics as profile 2, thus the same source of material. Arcosian sand prevails due to the presence of Feldspar in a significant proportion. The proportion of fine sediments is only 6%, and its pH is close to 7 in both samples. It is altimetrically higher than the Latosol, as classified by Embrapa (1999), and must be a Eutrophic Alluvial Regolith Neosol.

The Ap horizon of profile 4, presents little stratification, with the occurrence of Marble, Chlorite, Sepiolite and Atapulgite in the total sample. In the glycol sample, there are Nacrite and Dickite. In the horizon A/B, the stratification is less evident, but it has

Sepiolite and Atapulgite, besides the Feldspar and Chlorites in low proportion. It receives contributions from the highest massifs of the region, which present modified Laterite or Plinthite substrates. Therefore, this horizon has great contributions from continental areas, such as the covering of the fluvial-marine sediments. It corresponds to a relatively new type of soil classified as a Gravelly Alluvial Laterite-Regolith Neosol with alluvial clayey Plinthite. The mineralogy of the Bt and Btf horizons of this soil was not analyzed

Table 2. Total chemical analysis of elements by X-Ray Fluorescence Spectrometry, using samples fused in Borate. LOI is the water loss at the burning process (LABOGEO/IGCE - UNESP/Rio Claro).

Perfil	Horizonte	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI
1	A/C	96,3	0,06	6,88	1,26	0,02	0,01	0,38	1,23	3,37	0,03	0,45
2	Ap	93,17	0,33	2,77	1,46	0,01	0,01	0,06	0,1	0,13	0,02	1,95
	Bt	93,36	0,34	2,86	1,44	0,02	0,01	0,06	0,12	0,12	0,02	1,66
3	Ap	90,92	0,47	4,56	1,17	0,01	0,01	0,05	0,08	0,06	0,01	2,67
	A/B	93,62	0,3	3,43	1,01	0,01	0,01	0,05	0,08	0,04	0,01	1,47
4	Ap	82,01	0,43	8,86	3,33	0,01	0,02	0,05	0,08	0,12	0,02	5,07
	A/B	70,12	0,79	15,59	4,65	0,01	0,05	0,05	0,07	0,2	0,03	8,43
	Bt	72,85	0,68	14,74	4,32	0,02	0,04	0,05	0,07	0,18	0,03	7,06
	Btf	72,24	0,62	15,16	4,62	0,01	0,04	0,05	0,07	0,17	0,03	7,01
5	Ap	90,71	0,43	4,77	1,56	0,01	0,01	0,05	0,08	0,05	0,01	2,32
	A/B	92,97	0,32	3,63	1,25	0,01	0,02	0,04	0,12	0,04	0,01	1,59
6	Ap	95,95	0,39	1,68	1,44	0,02	0	0,05	0,09	0,17	0,01	0,21
	A/C	96,29	0,37	1,38	1,34	0,01	0,02	0,04	0,08	0,15	0,01	0,32
7	Ap	62,22	0,95	16,61	5,41	0,06	1,36	1,04	2,22	3,34	0,1	6,68
	A/B	59,01	0,94	16,37	6,05	0,23	1,54	2,12	2,18	3,2	0,11	8,24
8	Ap	72,35	0,1	5,4	1,1	0,02	0,97	8,37	1,5	1,9	0,03	8,27

Table 3. Result of the granulometric Analyses of the soils in each of the profiles performed.

Perfil	Horizontes	Profundidade (cm)	Argila (%)	Grossa (%)	Areia (%)		Silte (%)	Areia/argila (%)	Textural
P1-1	A/Cg	0 - 60	40,00	33,00	8,00	41,00	19,00	1,03	Argilo arenoso
P1-2	2Bg	60 - 2	43,00	37,00	13,00	50,00	7,00	1,16	argilo arenoso
P1-3	Crf	2 - 3m	11,00	34,00	10,00	44,00	45,00	4,00	franca
P1-4	Crg	5 - 10m	40,00	26,00	12,00	38,00	22,00	0,95	argila
P2.1	A/Crg	0-40	8,00	68,00	11,00	79,00	13,00	9,88	areia franca
P3.1	A/Bw	0 - 1m	61,00	14,00	4,00	18,00	21,00	0,30	muito argiloso
P3.2	2Crf/Fm	1 - 2m	57,00	18,00	5,00	23,00	20,00	0,40	argila
P3.3	Rrfv	3 - 5m	12,00	62,00	9,00	71,00	17,00	5,92	franco arenoso
P4.1	Ab/Cg	15/20-50/80	21,00	34,00	16,00	50,00	29,00	2,38	franca
P4.2	C	50 - 80	24,00	42,00	12,00	54,00	22,00	2,25	franco argilo arenoso
P4.3	2Crfc	0,50 - 2m	55,00	30,00	4,00	34,00	11,00	0,62	argila
P4.4	Fm	2 - 3m	58,00	23,00	4,00	27,00	15,00	0,47	argila
P5.1	Ap/Cg	0 - 20	17,00	57,00	13,00	70,00	13,00	4,12	franco arenoso
P5.2	A/Cg	20 - 30	22,00	54,00	12,00	66,00	12,00	3,00	franco argilo arenoso
P5.3	2Brt/Crt	0,70 - 1,50m	26,00	58,00	8,00	66,00	8,00	2,54	franco argilo arenoso
P6.1	Ap/Cg	30 - 40	23,00	48,00	12,00	60,00	17,00	2,61	franco argilo arenoso
P7.1	Ap	0 - 20	4,00	73,00	23,00	96,00	0,00	24,00	areia
P7.2	2Bi	25 - 40	29,00	51,00	10,00	61,00	10,00	2,10	franco argilo arenoso
P7.3	3C	40 - 50	5,00	85,00	10,00	95,00	0,00	19,00	areia
P7.4	4Crf	2m	6,00	42,00	39,00	81,00	13,00	13,50	areia franca
P8.1	Ap	0 - 10	10,00	82,00	8,00	90,00	0,00	9,00	areia

Profile 5 presents the same material as soils 2 and 3. Even though Embrapa (1999) has classified it as Dark Red Latosol, its characteristics correspond to a Eutrophic Alluvial Psammite Neosol/Eutrophic Cambisol. Soils 2, 3 and 5 show that the same surface area has been raised and recently scaled. They possibly date back to the Holocene epoch.

Grain Composition

The granulometric analyses (table 3) show that the contents of the clay fraction are relatively insignificant and do not satisfy the determinations and proportions required by the Brazilian Soil Classification System (EMBRAPA, 2006). Such requirements serve to maintain the definition of Acrisol and Latosol for the area, as suggested by EMBRAPA (1999). Alluvial, Regolith and Quartz Soils compose almost all the profiles, which are Eutrophic or Saline in some cases. These profiles are usually thick, except the 7, which manifests a Ta Saline Sodic Melanic Eutrophic Gleysol/Carbon Ebony Vertisol.

The set of analyses performed on the soils representative of the various landscape units in the study area demonstrates the occurrence of very sharp erosive processes, which results in loss of clay minerals. The erosion process is a consequence of the indiscriminate use of the soil that removes the riparian vegetation from the riverbanks, which contributes to the degradation process characterized by the loss of ground, the formation of rusty crusts, the development of saline crusts on the ground surface and the accelerated transport of sediments.

On the other hand, irrigation activities that focus on agriculture in the alluvial plain and the crustacean farms in the fluvial-marine plain have generated several changes in the landscape of the low course of the river, such as the loss of material and the occurrence of denudation processes. Besides, leaching is present in all the analyzed profiles. The presence of titanium was also verified in some samples, probably derived from probably derived from chemical industries in the region, such as small cosmetic industries, but also from the shrimp farms. These activities silt up the river valley and consequently produces an input of sediments in the coastal zone, which impacts both the river and the mangrove fauna. It is not a new situation and has already been happening in the area for more than ten years (Diniz et al., 2008), but it seems to be accelerating.

The direct economic consequences of this set of impacts are the shortage of fish in the Acaraú River, the extinction of reproduction areas in the

mangrove forest and the reduction in the number of commercial species, which is a consequence of the increasing turbidity and eutrophication of the water. The impoverishment and lowering of the water level close to the river cause losses of pasture and cultivation areas besides the reduction of productivity. Therefore, these areas are liable to undergo a desertification process.

Conclusions

The morphological, chemical, physical and mineralogical characterizations performed in the soils considered in this article allow classifying the pedodiversity of the low course of the Acaraú River as being predominantly characterized by the occurrence of Neosol, followed by Gleysol and Vertisol. Such characterization updates the data related to the diversity of existing soils in the area, as indicated in previous works.

The inadequate use of these soils is accelerating erosion processes to varying degrees. These processes are most common in areas where occur remotion of the caatinga for pasture and agriculture. At the same time, the river floodplain has been receiving an accentuated sediment load, which is resulting in the silting up of the river plain, the reduction in the water level and its salinization. This situation has several negative economic and socio-environmental implications, which should undergo a perspective of better management and exploitation of these natural resources.

The data presented here, which also detail the most common characteristics of these types of soil in that region, may be used for the benefit of the communities and regional users, as they can contribute to the proper management of natural resources and thus allow rational exploitation of the environment. They can also be useful in ensuring a better production and crop adequacy in the region. With this, it would be possible for users to avoid the desertification of these areas and have adequate productivity to the prevailing environmental conditions in this territorial segment.

Acknowledgment

The authors thank Professor Jairo Roberto Jiménez-Rueda (UNESP); the Development Foundation of Unesp (FUNDUNESP), the Foundation to the Support of Research of São Paulo State (FAPESP); National Post-Doctorate Program (PNPD- CAPES), Master on Geography of the Acaraú Valley State University (UVA), Environmental Studies Laboratory (LEA – UVA) and FUNCAP (Foundation of Ceará State for the Support of Scientific and Technological Development).

References

- Ab'Sáber, A.N., 1969. Participação das superfícies aplainadas nas paisagens do Nordeste brasileiro. *Geomorfologia USP*, vol. 19, p.1-38.
- ANA. Agência Nacional de Águas, 2020. Monitor de Secas. Disponível: <http://monitordesecas.ana.gov.br/mapa?mes=4&ano=2020>. Acesso: 12 mar. 2020.
- Brandão, R.L., Freitas, L.C.B. (Eds.), 2014. Geodiversidade do Estado do Ceará. Fortaleza: CPRM.
- Castro, S.S., Cooper, M., 2019. Fundamentos de Micromorfologia de Solo. Viçosa: Sociedade Brasileira de Ciência do Solo - SBCS.
- Claudino-Sales, V., 2016. Megageomorfologia do Estado do Ceará. São Paulo: NEA.
- Claudino-Sales, V., 1993. Lagoa do Papicu: natureza e ambiente na cidade de Fortaleza, Ceará. Dissertação de Mestrado, Universidade de São Paulo.
- COGERH. Companhia de Gestão dos Recursos Hídricos do Estado do Ceará, 2019. Atlas de Recursos Hídricos do Estado do Ceará. Disponível: <http://atlas.cogerh.com.br/>. Acesso: 20 out. 2019.
- Colares, M.C.S., Pinheiro, L.S., Meneses, M.O.B., Morais, J.O., 2016. Sedimentary characterization of the channel of Coreaú River's estuary, Ceará State, Brazil. *Arquivos de Ciências do Mar*, v. 49, p. 5-12.
- CPRM. Companhia de Pesquisa de Recursos Minerais, 2019. Atlas Digital de Geologia e Recursos Minerais do Ceará. SIG Escala: 1:500.000. Fortaleza: CPRM.
- CPRM. Serviço Geológico do Brasil, 2014. Mapa de Geodiversidade do Estado do Ceará. Escala 1.500.000. Fortaleza: CPRM.
- Diniz, S.F., Moreira, C.A., Corradini, F.A., 2008. Susceptibilidade erosiva do baixo curso do Rio Acaraú-CE. *Geociências*, vol. 27, p.355-367.
- EMBRAPA. Centro Nacional de Pesquisa de Solos, 1999. Sistema brasileiro de classificação de solos. Brasília: Embrapa Solos.
- EMBRAPA. Centro Nacional de Pesquisa de Solos, 2006. Sistema brasileiro de classificação de solos. Brasília: Embrapa Solos, 2ª ed.
- Falcão Sobrinho, J., Mendes, M.V.R., Silva, E.V., Costa Falcão, C. L., 2017. Os recursos hídricos em ambientes geomorfológicos distintos do nordeste brasileiro. *Fórum Ambiental da Alta Paulista*, v. 13, p. 39-54.
- Fernandes, A., 1990. Temas fitogeográficos. Fortaleza: Stylus Comunicações.
- Fernandes, A., Bezerra, P., 1990. Estudo fitogeográfico do Brasil. Fortaleza: Stylus Comunicações.
- Figueiredo, M.A., 1997. A cobertura vegetal do Ceará (Unidades Fitoecológicas). In: Atlas do Ceará. Governo do Estado do Ceará: Fortaleza: IPLANCE.
- FUNCEME. Fundação Cearense de Meteorologia, (2019). Indicadores de monitoramento para cheias no Vale do Rio Acaraú. Disponível: <http://www.hidro.ce.gov.br/hidro-ce-zend/app/pagina/show/179>. Acesso: 20 set. 2019.
- IPECE. Instituto de Pesquisa e Estratégia Econômica do Ceará, 2002. Atlas escolar do Estado do Ceará. Fortaleza: IPECE.
- Janssen, P., Piegay, H., Evette, A., 2020. [Fine-grained sediment deposition alters the response of plant CSR strategies on the gravel bars of a highly regulated river](#). *Applied Vegetation Science*. doi: 10.1111/AVSC.12494.
- Lemos, R.C., Santos, R.D., 1976. Manual de método de trabalho de Campo. Rio de Janeiro: SBCS.
- Maia, G.G.O., Gastão, F.G.C., Pinheiro, L.S., 2018. Evolution of the coast line and associated impacts in coastal Ceará State, Northeast, Brazil. *Revista Brasileira de Geografia Física*, v. 11, p. 1215-1225.
- Melo, M.S., Claudino-Sales, V., Peulvast, J.P., Saadi, A., Mello, C.L., 2005. Processos e produtos morfogenéticos continentais. In: Souza, C.R.G., Suguio, K., Oliveira, A.M.S., Oliveira, P.E. (Eds.). *Quaternário do Brasil*. São Paulo: Editora Holos, p. 332-345.
- Mesquita, F.N.S., Caracristi, I., Diniz, S.F., Sousa, M.C., 2016. Análise Socioambiental do Médio Curso do rio Acaraú, Ce. *Revista de Geociências do Nordeste*, v. 2, p. 442.
- Morais, J.O., Ximenes Neto, A.R., Pessoa, P.R.S., Pinheiro, L.S., 2019. Morphological and sedimentary patterns of a semi-arid shelf, Northeast Brazil. *Geo-Marine Letters*, v. 1, p. 1-10.
- Moro, M.F., Macedo, M., Moura-Fe, M.M., Costa, R.C., 2015. Vegetação, unidades fitoecológicas, e diversidade paisagística do Estado do Ceará. *Rodriguesia*, vol. 66 (33), p. 717-743.
- Olarte, L; Codazzi, L., 1979. Métodos analíticos de laboratorio del suelo. Bogotá: Instituto Geografico de Bogotá, 320p.
- Peulvast, J.P., Claudino-Sales, V., 2005. Surfaces d'aplanissement et géodinamique. *Géomorphologie: Relief, Processus, Environment*, vol. 11(4), p. 249-274.
- Stanford, J.P., Ribeiro, A.G., Barros, M.J.G., Fonseca, R.A., 1981. Geologia - Potencial dos Recursos Hídricos. Projeto RADAMBRASIL. Folha AS. 24. Fortaleza. Rio de Janeiro: Ministério da Minas e Energia.

- Silva, F.E.R., Falcão Sobrinho, J., Costa Falcão, C.L., Branco, M.L.X.C., 2019. A água e sua importância para o sertanejo no ambiente semiárido cearense. *Revista Equador*, v. 8, p. 186-208.
- Vettori, L., 1969. *Métodos de análise de solo*. Rio de Janeiro: EMBRAPA.
- Ximenes Neto, A.R., Morais, O.J., Ciarlini, C., 2018. Modern and relict sedimentary systems of the semi-arid continental shelf in NE Brazil. *Journal of South American Earth Sciences*, v. 83, p. 45.
- Zanella, M.E., 2005. As características climáticas e os recursos hídricos do Estado do Ceará. In: Silva, J.B., Dantas, E.W.C., Meireles, A.J.A. (Orgs.). *Ceará: um novo olhar geográfico*. Fortaleza: Edições Demócrito Rocha, p.169-188.