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MAPPING AND PHYSIOGRAPHIC CHARACTERIZATION OF THE MUNICIPALITIES OF GUARACIABA DO NORTE AND CARNAUBAL, CEARÁ, BRAZIL

Nayane BARROS SOUSA FERNANDES[1], José FALCÃO SOBRINHO[1*], Cleire LIMA DA COSTA FALCÃO[2]

[1] Universidade Estadual Vale do Acaraú/UVA. Programa de Pós-Graduação em Geografia. Av. da Universidade, 850 - Campus da Betânia - Sobral-CE, Brasil. CEP: 62.040-370

[2] Eniversidade Estadual do Ceará/UECE. Fortaleza, Ceará

Abstract

Human activities have been occupying and replacing natural landscapes with agricultural and urban areas and, if developed in a disorderly way, they interfere with the natural dynamics of landscapes. Such a relationship between external properties and internal characteristics of a landscape is notedly the physiography basic principle. Therefore, the researchers performed a mapping applied to the physiographic characterization of Guaraciaba do Norte and Carnaubal, Ibiapaba, Ceará. Furthermore, listing physiographic parameters helped to understand the local processes – biological, physical, and chemical. Geosystem applied at the scale of 1:300,000 was the guiding methodology, whose results demonstrated the need for effective measures for the recovery and preservation of the area, mainly about the riparian forest and some existing erosive processes.

Keywords: *Physiographic elements; Geosystem; Mapping; Landscape*

Introduction

Human activities have been occupying and replacing natural landscapes with agricultural and urban areas and, if developed in a disorderly way, they interfere with the natural dynamics of landscapes. Some environmental impacts are loss of vegetation cover, loss of soil, and erosion.

The physiography basic principle is the direct relationship between external properties and internal characteristics of a landscape, expressed in soil profiles [1]. It comprises then a relation of the processes involved in the genesis and evolution of landscapes that, in turn, allows knowing the internal characteristics of the existing soils, considering that they are records and testimonies of geological, geomorphological, and climatic events over time [1, 2].

The understanding of the elements of the physical environment and their interrelations are indispensable in environmental impact studies, geo-environmental zoning, municipal master

* Corresponding author: falcao.sobral@gmail.com

plans, conservation strategies, urban expansion, and other plans and policies strategies aimed at the rational and sustainable use of natural resources [3].

The lack of studies that focus on the integration of physical environment aspects and that consider the administrative area of the two municipalities in question generated motivation for the present research, which aims to perform a mapping applied to the physiographic characterization of the municipalities of Guaraciaba do Norte and Carnaubal, Ibiapaba, Ceará.

The knowledge of the different physiographic elements of the territory of the studied municipalities will be of great relevance since the results will serve as a basis for discussions about structural improvement policies, especially in the scope of the environmental-territorial planning of the municipalities.

Geo-technology, such as Geographic Information System (GIS) and remote sensing techniques, proved relevant to the research development by assisting the characterization, compartmentalization, and subsequent analysis of these spaces. The absence of spatial information about the municipalities is evident and led to the development of this research.

Thus, such actions are a must in wetlands from the Ceará semi-arid region because of their potential for exploitation and ecological support favoring sustainable actions. Ibiapaba Mountain, in Ceará, Brazil, is an example and, among its municipalities, the focus is Guaraciaba do Norte and Carnaubal for presenting a sharp natural substrate and ecological potential.

Therefore, one of the goals was to map the natural resources and provide information that contributes to sustainable planning in these municipalities.

Studied location

The area – known as Big Mountain, Ibiapaba Plateau, and Ibiapaba Mountain – is in northwestern Ceará on the border with the state of Piauí [4]. The cut of the area refers to two municipalities of Ibiapaba, Carnaubal (Lat: 4º 9' 4" S/ Long: 40º 56' 43" W) and Guaraciaba do Norte (Lat: 4º 10 '1" S/ Long: 40º 44' 60" W). According to the Brazilian Institute of Geography and Statistics [5], these municipalities correspond to a total area of approximately 987.826km² (Fig. 1).

It is important to note that Ibiapaba Mountain is an exceptional area amidst the semi-arid region. Specifically for the studied location, authors point to local specificities and exceptions, characterized by humid zones and remarkable throughout the extension of the Ceará semi-arid region, such as on coastal zones and mountains. The influencing factors on these mountains are the altitude mesoclimate, topographically high surfaces, milder temperature, and surplus water balance in the rainy season [6].

An example of reduced humid areas in Ceará is the Ibiapaba, located in the western limit of Ceará. From the economic point of view, the Ibiapaba region is notable for a significant diversity of crops (vegetables and flowers, above all) with industrial activities that are still underdeveloped, but with municipalities endowed with a consolidated commercial sector and a considerable tourist potential.

From an ecological point of view, Ibiapaba has unique characteristics, such as one of the last remnants of Atlantic Forest in Ceará, great potential for the occurrence of endemism and unknown species, besides being considered an area of extreme biological importance in the group of priority areas for the conservation of flora in the country [7].

The Ibiapaba is on the eastern edge of one of the most significant Brazilian sedimentary basins, the Parnaíba one [8], which, in turn, dates back to the Middle Paleozoic, more precisely, between the Silurian and Devonian periods [9].

According to [10], from the Cretaceous division of the Pangea, Ibiapaba started to evolve almost exclusively from external action modeled throughout the Cenozoic. The features of morpho-structural processes embedding the morpho-sculptural ones generated correlated deposits and, finally, elaborated the current geomorphological picture.

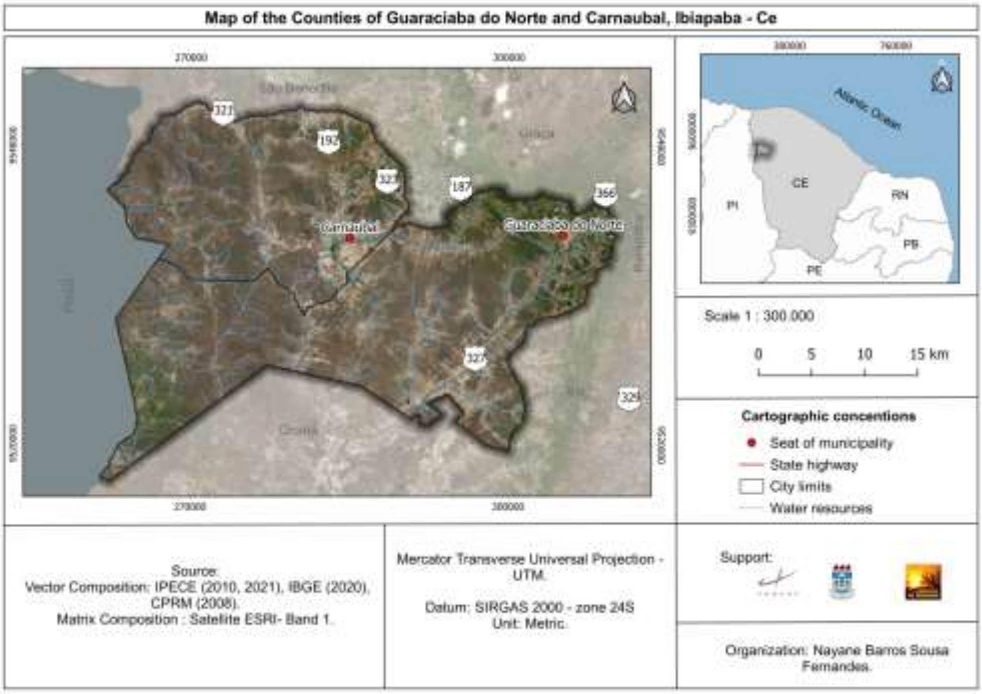

Fig. 1. Location map of the municipalities of Guaraciaba do Norte and Carnaubal

According to Ross [11], the plateaus in sedimentary basins are surrounded by peripheral or marginal depressions, as is the case of Ibiapaba Mountain. Conceptually, these sedimentary plateaus present regular and slightly undulated surfaces, horizontal or gently sub-horizontal rocks, that is, an extensive tabular form of relief [12].

Material and method

The research engaged cartographic and bibliographic surveys, physiographic mapping, fieldwork, results, and discussion. The first steps were location mapping, considering the cut for the research, and the production of maps that show the situation of the physiographic elements.

The delimitation polygon for the area was established through an automatic technique, making it necessary to cut a mosaic with Shuttle Radar Topography Mission (SRTM) images, acquired from the Earth Explore (USGS) website of the LANDSAT 8 satellite. Later, the images underwent a classification with color composition of bands 7, 6, and 4. The vectorial layers of [5, 13, 14] helped to set the municipal and state delimitations, as well as sectoring of the municipalities.

The generation of the synthesis maps occurred through geoprocessing techniques assisted by Geographic Information Systems (GIS). After the treatment of the information, the generated data provides objective information about the studied location, enabling the production of maps and consequently a clearer perception of theoretical discussions.

The QGIS 3.10 assisted the processing of vector and matrix data at scale 1: 300,000 along with the datum SIRGAS 2000 – UTM Zone 24S. The local delimitation polygon occurred through an automatic technique, assembling images from the Shuttle Radar Topography

Mission (SRTM) acquired from the Embrapa website. Later, the images underwent a classification using vector layers from [5, 15] and others.

Successive fieldwork pointed to the elements liable to recognition in the field.

Result and discussion

Geology

The studied location is, according to Geological Map of the State of Ceará [16, 17], in the geological unit of Big Mountain Group, presenting the Tianguá and Jaicós Formations. The terrain and its description prove the resistance of the Big Mountain against erosive processes during the Cenozoic era. The erosion produced a hillside carved in the sedimentary formation, characterized by a cornice at the top of Ibiapaba. At the base and foot, the dissected and flattened rocks represent the crystalline basement [18].

Sedimentary rocks supporting crystalline ones at the mountain top, as it is in Ibiapaba, define a klint known as cuesta, which demonstrates the intensity and duration of the local erosive process. The klint represents a relief formed by a high and steep escarpment whose slope (or part of it) and foothill contain crystalline rocks because the crystalline suffered erosion beyond the level of the sedimentary material [19].

The outstanding lithology in Ibiapaba belongs to the Big Mountain Group, the basal formation of the Parnaíba Drainage Basin in the Paleozoic Era. However, the municipality surroundings present a lowered topography with a diverse and complex lithological composition. It results from the intercalation and superposition of several geological groups of different ages [20].

The Big Mountain Group, which dates back to the Paleozoic Era of the Silurian age (~410-435Ma), represents the first supersequence of sediment deposition in the Parnaíba Drainage Basin, overlying the basement. The Big Mountain Group comprises, from its base, the Ipu, Tianguá, and Jaicós Formations. The oldest unit is Ipu Formation [20]. Two types of formations belonging to the Big Mountain Group are present in the studied location (Fig. 2).

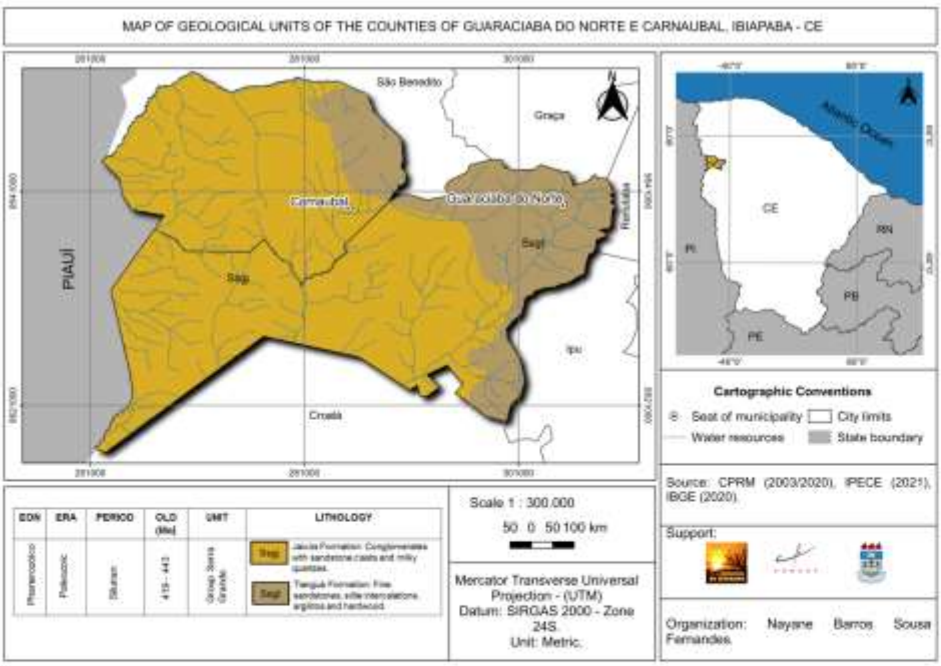

Fig. 2. Map of the geological units of the municipalities of Guaraciaba do Norte and Carnaubal. Source: Adapted from [17] CPRM (2020).

The Tianguá Formation [21] has gray shale, siltstone, and micaceous sandstone deposited in a shallow marine environment from the Silurian Period. Caputo and Lima (1984) divide the Tianguá Formation – which reaches up to 270m in its surface – into three lithostratigraphic components, which are (i) black and dark gray shales, (ii) sandstone intercalated with shale, and (iii) siltstone intercalated with shale. The sedimentation environment is the shallow marine, which happened during the maximum extension phase of the global glacial-eustatic transgression that followed the ice melt in the North of Africa.

The Jaicós Formation consists of medium to coarse sandstone and occasional pelite, with a maximum thickness estimated at more than 400m at the northeastern edge of the drainage basin. *M.V. Caputo, E.C. Lima* [22] interpreted that the regressive sedimentation in the formation occurred in alluvial and deltaic fan systems, in the outcrop areas, subsurface, and in front of the deltaic fan.

*A.M. Góes and F.J. Fei*jó [21] consider that the sediment in Jaicós Formation were deposited by interlaced fluvial systems in the Neossilurian (Ludlovian).

The Jaicós Formation correlates with the Manacapuru (Trombetas Group, Amazonas Drainage Basin), Fumas (Paraná Drainage Basin), and Ataiataba Formations in the Algerian Sahara Drainage Basin [22]. Table 1 provides succinct descriptions as to the geological characteristics.

Table 1. Geological aspects of the municipalities of Guaraciaba do Norte and Carnaubal. Source: adapted from [16]

STRATIGRAPHIC UNIT	Geological Formation	LITHOLOGY
Ssgj	Jaicós Formation	Conglomerates with sandstones and milky quartz clasts. Sandstones in part arcoseanos, beige color and medium to leafy granulometry. Conglomeritic sandstones that graduate to fine sandstones and silicates. Presence of plane- parallel and cross stratification, medium to large part, tabular and parallel.
Ssgt	Tianguá Formation	Fine sandstones, beige and yellow, with spherical grains and well selected. There are intercalations of silites, argilitos and ruffles. Presence of wave marks and fish-spine stratifications.

Geomorphology

According to [17], the area presents four types of geomorphological units – Plateaus, Structural Steps and Erosive Ridges, Mountainous Escarpment, and Tablelands (Fig. 3).

Plateaus (R2c) are reliefs of degradation in sedimentary rocks, elevated tabular surfaces, or uplifted relief, which is flat or flattened, and little or not dissected. The edges of these surfaces, positioned at high elevations, are generally delimited by steep and craggy slopes [23].

Structural steps and erosive ridges (R4e) are rugged reliefs consisting of predominantly rectilinear and concave hillsides, slightly rounded top and slope, which represent a transitional relief [23].

Mountain escarpment (R4d) is a rugged mountainous relief that represents a transition between two surfaces elevated of different altitudes [23].

Tablelands (R2b3) is higher than the surrounding terrains, dissected into tabular forms or broad hills. Thick and well-drained soil formation process is predominant, in general with low or moderate susceptibility to erosion [23].

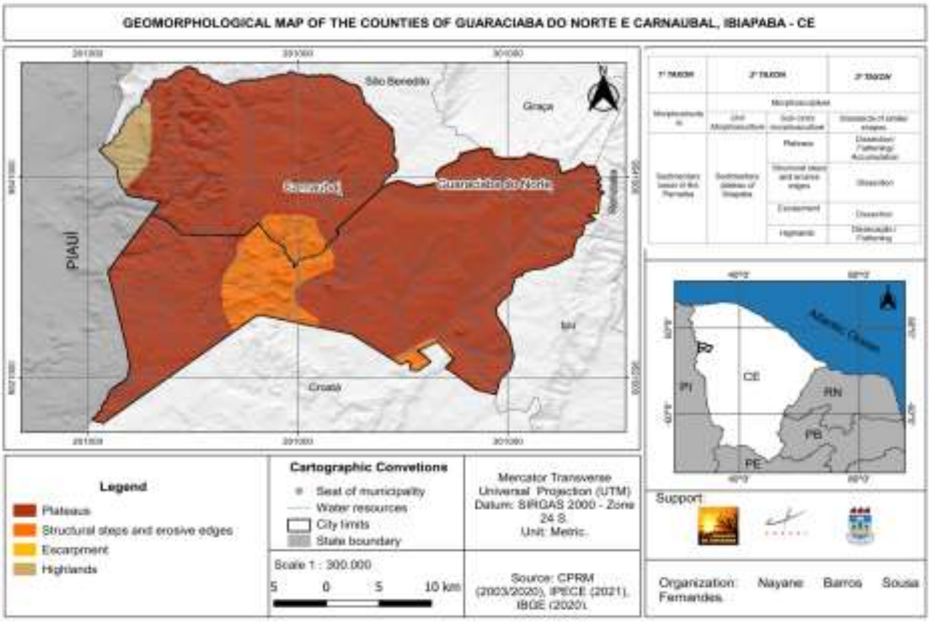

Fig. 3. Geomorphological map of the municipalities of Guaraciaba do Norte and Carnaubal.
Source: Adapted from [16]

Climate and water resources

As for the Ceará climate, the state is in the semi-arid climate domain, which has an irregular rainy period and a prolonged dry period [24].

The rainfall distribution around Ceará suffers variation because of the action of atmospheric systems and the relief influence. It is notable in areas with higher altitudes, such as Ibiapaba, where the rainfall rates are higher because of the humid winds coming from the coast, which rises when meets orographic barriers. It originates from clouds that cause orographic or relief rains, enabling favorable rainfall conditions than in the surrounding areas [24].

A.G. Ferreira and *N.G. da Silva Mello* [25] highlight that the principal large-scale atmospheric systems influence the climatic conditions in northeastern Brazil, inhibiting or provoking rainfall (Table 2).

According to *Cirilo, J.A. et al.* [27], the ITCZ is a cloud band that surrounds the equatorial strip of the globe, formed by the confluence of the trade winds of the Northern (Northeast trade winds) and Southern (southeast trade winds) Hemispheres. It is one of the most relevant precipitation generating systems in the Northeast.

The ITCZ moves over the year, whose daily and seasonal disposition is conditioned by several factors, such as the continentality, the relief, and vegetation [28].

Other components form the Ceará climate besides the ITCZ, such as the cold fronts, which are orderly atmospheric systems that cause rainfall, the upper tropospheric cyclonic vortex from January to February [29], the squall lines, the Eastward waves, and the mesoscale convective complexes [24, 30].

Table 2. Atmospheric systems in the Northeast region

Atmospheric Systems	Characteristics
Intertropical Convergence Zone (ITCZ)	It originates from the meeting of trade winds from the northern and southern hemispheres at low levels. Such a system is determinant for the occurrence of rainfall in northeastern Brazil.
Cold Front	It happens in the region of contact between cold and warm air masses. Cold fronts act between November and January.
Upper Tropospheric Cyclonic Vortex	In the vortex, clouds penetrate northeastern Brazil from November to March, forming rain clouds in the periphery but inhibiting them in the center.
Squall Line (QLCS)	The cloud bands originate in convective processes that intensify from February to March with the ITCZ influence.
Mesoscale Convective Complex (MCC)	These are cloud clusters formed by favorable local conditions (relief, temperature, pressure), causing heavy rainfall and short-lived gusts of wind.
Eastward Waves	The origin is in the contact area of the trade winds moving from West to East, causing rain in the northeastern forest zone between the Recôncavo of Bahia and Rio Grande do Norte. When ocean conditions are favorable, these waves cause rain in Ceará.

Source: Adapted from [26]

In Ibiapaba Plateau, the climatic conditions encompass diversified characteristics concerning the general picture of the state. According to *FUNCEME* [31], the average yearly pluviometry is higher than 1200 mm/a, with regular rainfall distribution. The average annual temperatures vary around 22º and 24 ºC. The lower temperatures significantly reduce evapotranspiration, preserving the local humidity.

The differences concerning the hinterland are notable in the topographic compartmentalization, which conditions the behavior of temperature and rainfall, indexes that, if compared with the studied location and the semi-arid region, contrast significantly.

According to *FUNCEME* [31], the studied location presents four climatic types belonging to the semi-arid climate (Fig. 4).

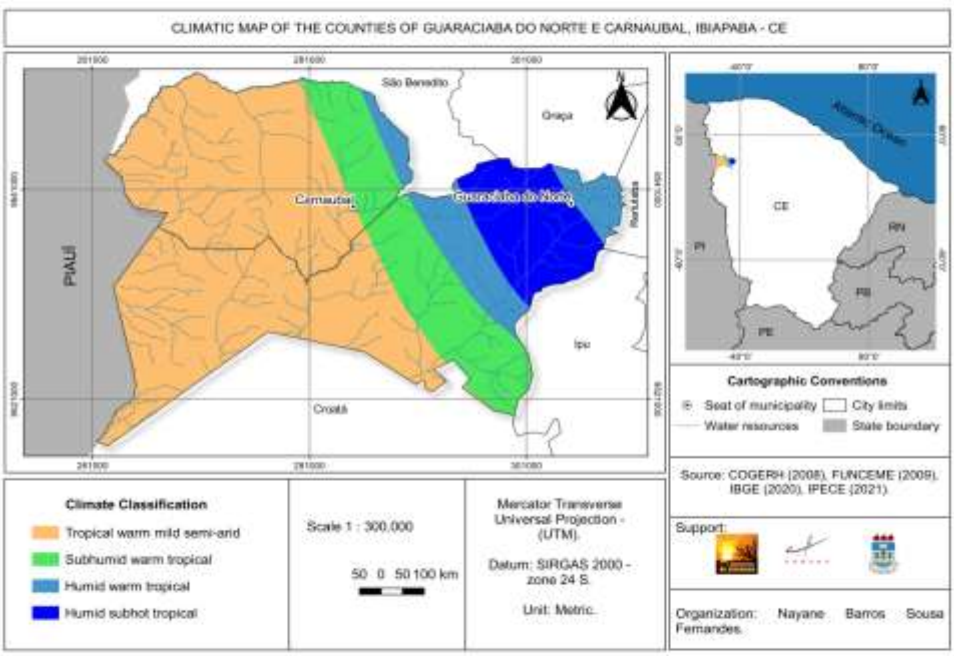

Fig. 4. Climate map of the municipalities of Guaraciaba do Norte and Carnaubal.
Source: Adapted from [31]

Tropical Warm Semi-Arid Climate: It occurs in the Ibiapaba central strip, precisely in areas that characterize the dry reverse towards the West. The yearly rainfall rates range from 800 to 1000mm, with an average temperature above 24ºC.

Tropical Hot Sub-Humid Climate: It is predominant in the Ibiapaba reverse, from North to South. Pluviometric indexes range between 850 to 1350mm, with an average temperature above 24°C.

Tropical Hot and Humid Climate: It is in Ibiapaba high sectors, above 800m height, having rainfall indexes above 1000mm, and occupying a considerable portion of the municipality of Guaraciaba do Norte, with an average temperature above 22ºC.

Tropical Sub-hot and Humid Climate: the rainfall index is higher than 1350mm per year and an average temperature below 22°C in the Ibiapaba northern strip, precisely between the municipalities of São Benedito and Guaraciaba do Norte.

Soils

The soil classes that correspond to the studied location underwent desk work, which had the support of the Brazilian Soil Classification System [32] and some definitions of the Embrapa Agency for Technological Information [33].

In the municipalities of Guaraciaba do Norte and Carnaubal, the most representative soils (Fig. 5) are the Red-Yellow Latosol, Litholic Neosol, Quartzarenic Neosol, and Chromic Luvisol. Table 3 shows the specific characteristics of each soil

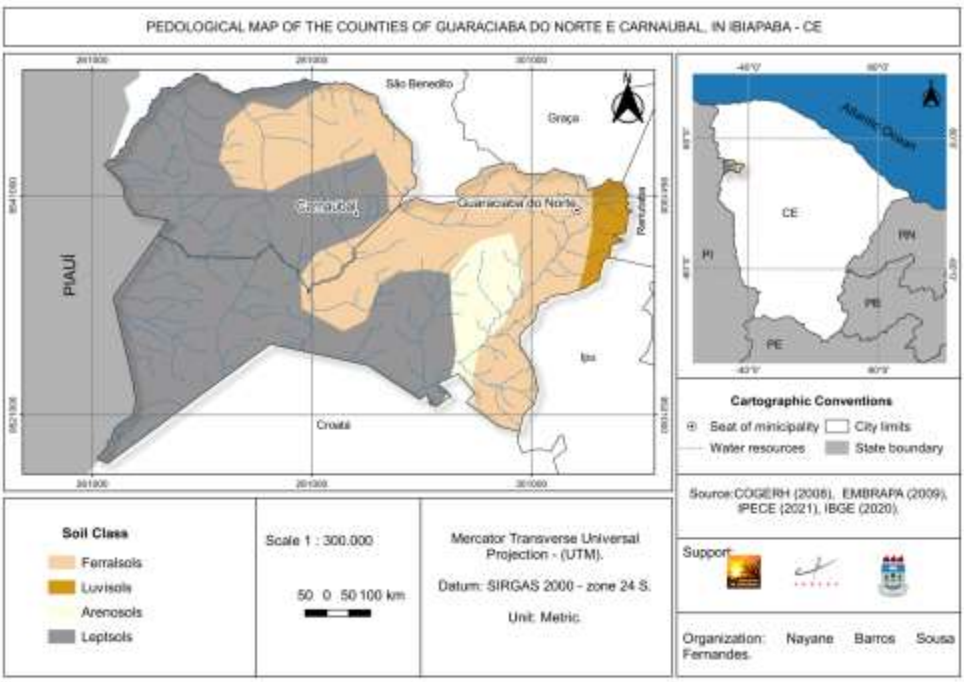

Fig. 5. Soil map of the municipalities of Guaraciaba do Norte and Carnaubal.
Source: Adapted from Embrapa (2009)

Vegetation

As stated by *B.V. Carvalho et al.* [4], the primary vegetation that composes the Ibiapaba Plateau is the carrasco and cloud forests. The two outstanding local phytogeographic features are the carrasco and tropical sub-evergreen cloud forest (rainforest).

The Ibiapaba reverse is a structural model that presents smooth topographic fall from the top to the West. The pedological recognition rises mainly from the dystrophic Quartzarenic Neosol, which does not present expressive changes concerning the original material.

Its origin in the dry reverse is predominantly from the physical degradation of the Big Mountain Group sandstones, probably under more arid climatic conditions, less humid than the current ones, which denotes its characterization as a Paleosol [26].

Carrasco is a dense shrubby xerophytic vegetation, little known, and that occurs specifically in Ibiapaba and Araripe Plateau at the same altitude – between 700 and 900m. It predominantly contains shrubby micro-fanerophits with thin stems and significant spatial variability in floristic composition and abundance of populations [26].

Table 3. Soil classification in the municipalities of Guaraciaba do Norte and Carnaubal

Soil	Morphologic Unit	Outstanding Characteristics	Usage Limitation	Farming
	(Red-Yellow Latosol) Plateaus	Deep soil in sedimentary locations	Low natural fertility	Banana, beans, and corn
	(Chromic Luvisol) Plateaus	Shallow soil in dry-climate areas (water shortage) with high and low temperatures	High natural fertility, potent to agricultural matters, prone to erosion in steep areas, good permeability	Pasture e subsistence plantation (beans and corn)
	(Litholic Neosol) Tablelands and Plateaus	Shallow soil associated with rocky outcrops	Limited to agricultural purposes, prone to erosion, low permeability	Short-cycle farming; beans and corn plantations
	(Quartzarenic Neosol) Plateaus	Deep soil with a sandy texture	Limited to agricultural purposes, prone to erosion	Evergreen plantations and pasture

Carrasco designates some types of vegetation in northeastern Brazil and out of it, including shrubby caatinga with stony soil, secondary vegetation, and areas of open vegetation with small shrubs in Minas Gerais Plateaus.

It has a deciduous character, similar to the caatinga, which extends over the Ibiapaba Plateau, that is, in the sedimentary areas of inner Ceará. According to [32], the vegetation is a result of the degradation of the Cerradão caused by agricultural activities and cattle raising, giving origin to Carrasco.

Cerradão is characteristic in sedimentary areas, composed of a sparse herbaceous stratum and aspect dominated by tall perennial trees [26]. Its preservation is the objective of the Ibiapa Plateau APA, a significant conservation unit in the region [20].

SIBCS, [32] and *AGEITEC*, [33] stated that the carrasco comes from the destruction or partial devastation of cerradão, assuming the aspect of dense vegetation. It is notable on the high and tabular levels of Ibiapaba Plateau reverse, Araripe Plateau, and Diamantina Plateau vicinities.

At the top of Ibiapaba and in the highest quartzite massifs (São Joaquim and Umari Mountains), which are in contact with each other, the modelings have covers consisting of dense and tree-like vegetation, the rainforest or tropical sub-evergreen cloud forest.

Fig. 6. Adulteration in the riparian forest

The Tropical Sub-Evergreen Cloud Forest (Rainforest) occupies the highest areas of the tops and slopes of the humid mountains and sedimentary plateaus, as is the case of the studied location. Reliefs are orographic barriers to the trade winds with moisture coming from the Atlantic Ocean. They favor the occurrence of orographic precipitation, causing rainfall and enabling the evergreen forest [28].

Ibiapaba peak is a summit surface whose altitude, topography, and edaphology supported the evolution of the red-yellow latosol, establishing and developing a large vegetation cover [20].

The forest typology of the rainforest results from the climatic conditions caused by the high relief, which favors precipitation and recycling of moisture by the constant formation of fog and dew, known as hidden precipitation [28].

According to *L.P. Soares* [30], it is one of the greatest biodiversities in Ceará, present in some areas of the Ibiapaba Plateau. Adulterations in some areas from the studied location rise mainly from human action – agriculture – as shown in figure 6. The place is the municipality of Guaraciaba do Norte, representing the uncharacterized riparian forest of Picadinho Creek.

The area is an accumulation model without native vegetation with adulteration of the riparian forest because of sugar cane and banana plantations in the surroundings of Picadinho Creek.

Conclusions

With physiographic characterizations, it is notable the diversity in Ibiapaba and why it is an exceptional environment. The local geology consists of sedimentary coverings, which relate to large and deep sedimentary drainage basins from the Syneclisis – depositional, continental, marine, and desert environments. Stratified sandstone and conglomerate are outstanding, which means that the sedimentary rocks are in layers or overlapping beds.

The place is, according to geomorphology, a cuesta with dissymmetric relief by erosion in layers, resulting in the four local geomorphological units defined according to their altimetry and slope. The altitude ranges from 600 to above 900m and slopes between 6% to 12%, presenting a mild wavy terrain typical of plateaus. Although inclinations ensure slow or medium surface runoff in part of the dry reserve, the inverse happens in the West.

The elevations in Ibiapaba favor climatic conditions that encompass diversified characteristics concerning the general picture of the state. Rainfall occurs regularly with an average yearly pluviometry of over 1200mm/year and temperature between 22 to 24°C. The low temperatures sensitively reduce evapotranspiration and preserve the local humidity, which presents four variants of the semi-arid climate.

Pedologically, Ibiapaba has a great lithological and altimetric homogeneity with high and uniform rainfall levels. Consequently, the soil is not so diversified, has deeper profiles, and more developed land that rises from chemical weathering and bioclimate if compared to the surroundings such as the hinterland surface.

The prevailing semi-arid conditions cause the plants to lose leaves in the dry season, as in carrasco, given its deciduous character and other morphological and physiognomic adaptations. On the other hand, more humid sectors present differentiated vegetation – larger and denser – such as in rainforests. These distinct vegetation alternates as the relief, climate, and soil conditions change.

The physical geography parameters revealed local instability caused by the adulteration of the riparian forest, natural erosion, and human action. Thus, it is urgent the development of measures to recover and preserve the area.

It is necessary to think of a human development model based on sustainability that does not come at the expense of the environment. For instance, investments in environmental education are relevant to achieving this goal.

Acknowledgments

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