



Characterization of the Physical-natural Units of the Hinterland Surface of the Pacoti Drainage Basin, Ceará, Brazil

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Authors' contributions

This work was carried out in collaboration among all authors. Author AAD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author JFS reviewed the methodological procedures and author FELB managed the bibliographic research. All authors read and approved the final manuscript.

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ABSTRACT

Because of the importance of preserving natural resources, especially drainage basins, it is essential to identify and manage the different types of natural landscapes found in these units, allowing the ecological balance of these regions. The application of geoprocessing techniques helps environmental agencies to make decisions, map and monitor the local conditions. The research proposes an examination of the Pacoti Drainage Basin, especially on its hinterland surface. The following cartographic databases were raised: Multimodal map of the state of Ceará scale 1:900,000, 2013, DENIT; Map of Geoenvironmental Subdivision Macroregion of Planning, scale 1:6,000,000, [5]; Simplified Geological Map of Ceará, scale 1:600,000 2015; Map of Phytocological Units of Ceará, scale 1:600,000, FUNCEME, 2007; Weather Map of Ceará, scale 1:600,000. The mapped physiographic characteristics are the climate, geology, geomorphology, soil, vegetation, land use and occupation, and conservation units. Therefore, geo-technology has become a decisive factor in the identification and analysis of the local physiographic characteristics.

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1. INTRODUCTION

Ceará, in Northeastern Brazil, is limited by the Atlantic Ocean to the North and Northeast, Rio Grande do Norte and Paraíba to the East, Pernambuco to the South, and Piauí to the West. Its total area is around 148,826 km², which corresponds to 9.37% of the Brazilian Northeast Region. The population is around 9,075,649 inhabitants according to the Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics, IBGE) [1] in 2018, the eighth-most populous state in the country.

In Ceará, 175 out of the 184 municipalities are part of the semiarid region polygon. It represents almost 95% of the state, according to data from the Superintendência do Desenvolvimento do Nordeste (Superintendence for the Development of the Northeast, SUDENE).

According to the Committee of Drainage Basins of Ceará [2], there are twelve drainage basins in Ceará. Their delimitations are an administrative-political arrangement found to manage the water resources in the state.

The Fortaleza Metropolitan Drainage Basin stands out for its importance and different geomorphological compartments. Created on January 2, 2003, by State Decree No. 26.902, it has an estimated population of 3,840,000 people distributed in 38 municipalities spread over 15,100 km² [2].

The Pacoti River, whose spring is on the Eastern slope of the Baturité Mountains, is the largest

watercourse crossing the Fortaleza metropolitan zone and runs about 150 km to the sea [3,4]. The studied area shares the same limits as the Pacoti River Drainage Basin, whose spring is in the Baturité Massif, running through the flattened surface until the coastal zone at its mouth in Aquiraz, Ceará. Because of its spatiality, the research goes over the hinterland surface, that is, the smoothly flat area of the basin. The objective is to characterize the hinterland surface of the Pacoti Drainage Basin using geoprocessing techniques. To this end, it was necessary to make maps with the help of spatial technology.

2. METHODS

The research has foundations on the General System Theory proposed by the German biologist Ludwig von Bertalanffy in 1930, based on the Pacoti Drainage Basin. In this perspective, when making a geographic study, it is necessary to use the concept of system to understand the complex issues as they are interdependent, that is, the variable natural units inserted in the study area [3,4,5].

Thus, in a systemic approach, drainage basins integrate a joint vision of the behavior of natural conditions and human activities developed in them, since significant changes in any of these units can generate changes, effects, and negative or positive impacts. As a rule, it establishes the relief as a possible unit to map more expressively without losing the sense that they are related [6,7].

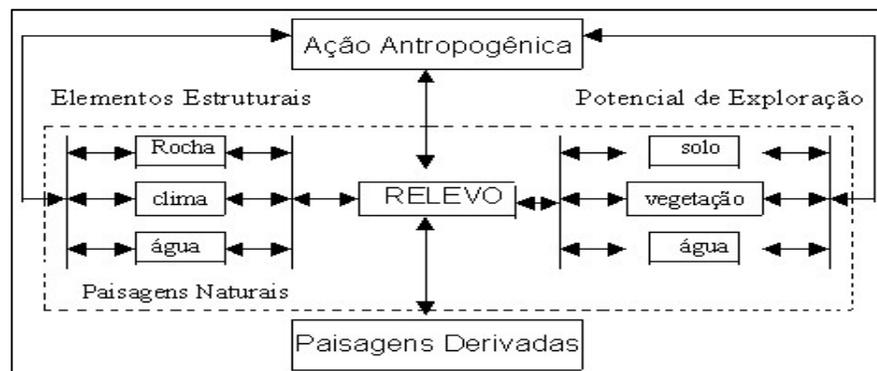


Fig. 1. Relief, the stage for joint landscape

Ação antrópica - anthropic action; Elementos Estruturais - Structural Elements; Exploration Potential; Rocha – Rock; Clima – Climate; Água – Water; Relevo – Relief; Solo – Ground; Vegetação – Vegetation; Paisagens Derivadas - Derived Landscapes.

Source: [6,7]

To the author, in Fig. 1, the structural elements (rock, climate, and water) composing the natural landscapes comprise in this study the exploitation potential constituted by the elements (soil, vegetation, and water) that make up the system. They unfold in the relief and results in the interaction of social actions originating the derived landscapes.

2.1 Literature

The data were collected for twenty years from stations at the Fundação Cearense de Meteorologia (Meteorology Foundation of Ceará, FUNCEME) [8] in Aquiraz and its surroundings. It is worth mentioning that the other areas are under the same rainfall regime. This stage seeks to understand the relief formation in the landscape at different times of the year according to the rainfall regime in Ceará.

Stations selected from the FUNCEME portal [8] provided data for the analysis of the rainfall indexes. The selected ones, three in different cities, represent distinct areas related to the geomorphological unit in that place.

The selected stations are in Horizonte (latitude 4°5'60.00"S and longitude 38°28'59.90"W). The monitoring stations collected yearly, monthly, and daily rainfall data between 1974 and 2019.

2.2 Cartographic Material and Georeferenced Bases

Not only cartographic data collected from reliable sources such as public agencies [8,9,10] contributed to this research, but also manuscripts found in various libraries. The maps were the Multimodal Map of the State of Ceará, scale 1:900,000, 2013, DENIT; Map of the Geoenvironmental Compartmentalization Macroregion of Planning, scale 1:6,000,000 [5]; Simplified Geological Map of Ceará, scale 1:600,000 2015; Map of the Phytoecological Units of Ceará, scale 1:600,000, FUNCEME,

2007; Map of Climatic Types of Ceará, scale 1:600,000 [5,11].

Cartographic material, georeferenced data, Geographic Information System (GIS), and geoprocessing software assisted the creation of maps that show the Pacoti River dynamics in its mouth. Geostatistical methods – interpolation of data by kriging or Inverse Distance Weighted (IDW) – also aided the production.

Geoprocessing software [12] also contributed to the production of slope maps, classifying the landscape relief based on the results found in percentages after digital processing of the data, as seen in Table 1.

The orbital images from the TM LANDSAT 8 satellite supported the extraction of information regarding the topic. The composition used was band 543 in the RGB (RED, GREEN, BLUE) spectrum in digital format. The image processing happened through MAPGEO 1.0, Spring 5.5.2, and QGIS 3.0.3. Functions related to the classification and treatment of images aimed at extracting spatial information relating to vegetation, land use, hydrography, road network, and urban areas [3,4,5].

The maps had a 1:100,000 scale using Arc GIS 10.2. The developed research models assisted the detection, identification, qualification, and cartographic quantification with geoprocessing techniques. The use and occupation of the land underwent monitoring along with the analysis of the environmental impacts. The data and information from the surface and the phenomena and processes involved followed according to methodology [13].

The methodology proposed by Lima aided the interpretation of the orbital images [14] [15]. The connection of visualized elements and environmental characteristics happened with the interpretation criteria in orbital images through the texture, color, shape, size, volume, and location.

Table 1. Relationship between the slope types and relief [12]

Slope type (%)	Relief
0-3	Floodplain
3-6	Plain to gently undulating
6-12	Gently undulating to undulating
12-20	Undulating to heavily undulating
20-40	Heavily undulating to mountainous
>40	Mountainous

Fonte: Elaborado pelo autor, 2020

The interpretation was through the image segmentation function in SPRING 5.5.5, a Brazilian software for a geographic information system that had its origin in the Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research, INPE). The segmentation consists of the identification and delimitation of the areas identified in the image.

3. RESULTS AND DISCUSSION

3.1 Climate

The Pacoti River Drainage Basin area – identified as hinterland surface and represented by Itaitinga, Horizonte, Pacajus, Acarape, Guaiúba – presents two main types of climate (Fig. 2). One is the tropical dry climate covering 50% of the area in the middle course of the Pacoti River, on the hinterland surface. The second is the tropical wet climate, around 40% of the region in the upper and middle course of the Pacoti River.

Not only the tropical dry climate is present in the hinterland surface but also the tropical wet. The second one is present in the Aratanha Mountain, which has 750 m of altitude. Therefore, the two

kinds are common and can occur on the hinterland surface.

From the data collected in the stations, Horizonte represents the hinterland surface because of the absence of rainfall data in the collection stations of nearby municipalities.

The limits of Horizonte are Aquiraz and Itaitinga to the North, Pacajus to the South, Cascavel and Pindoretama to the East, and Itaitinga and Guaiúba to the West. The data shows a yearly rainfall average of 780 mm, temperature ranging between 26°C and 28°C, and the wet season from January to May [10].

The data made it possible to tabulate and analyze the rainfall rates between 2000 and 2019 in the hinterland surface (Fig. 3). It is worth mentioning that 2009, 2011, and 2019 present the highest averages in the period. On the other hand, they went up and down from 2009 to 2012.

In Fig. 4, it is possible to make a monthly analysis regarding the rainfall averages throughout the year. The wet season in Ceará is in the first half of the year, specifically in the first four months.

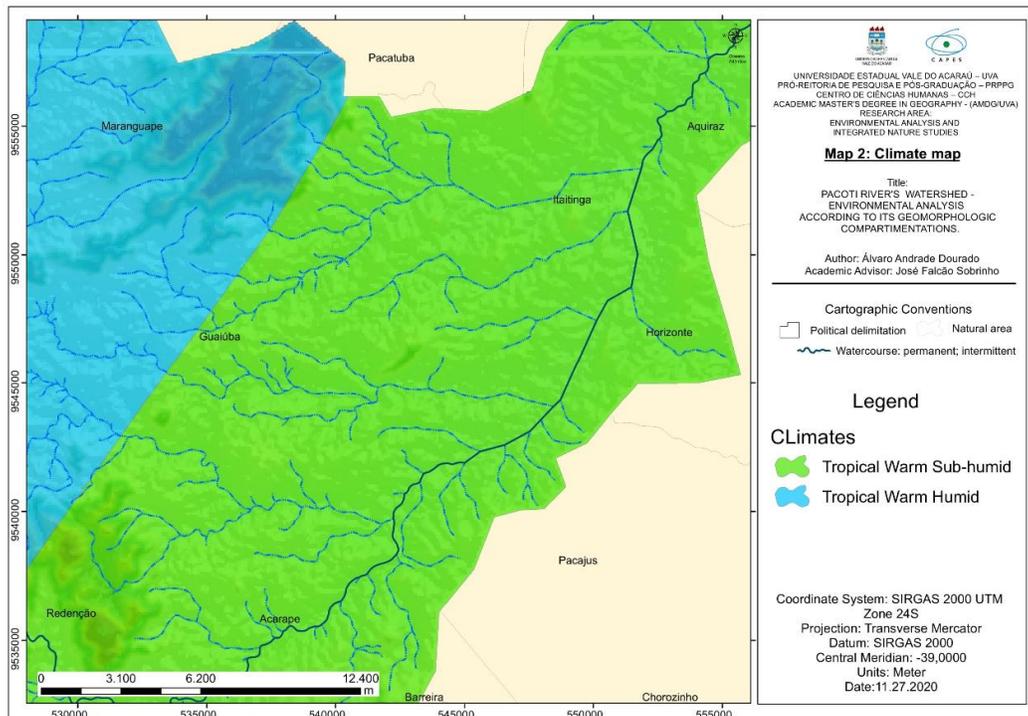


Fig. 1. Climatic map of the hinterland surface

Source: made by the author, 2020

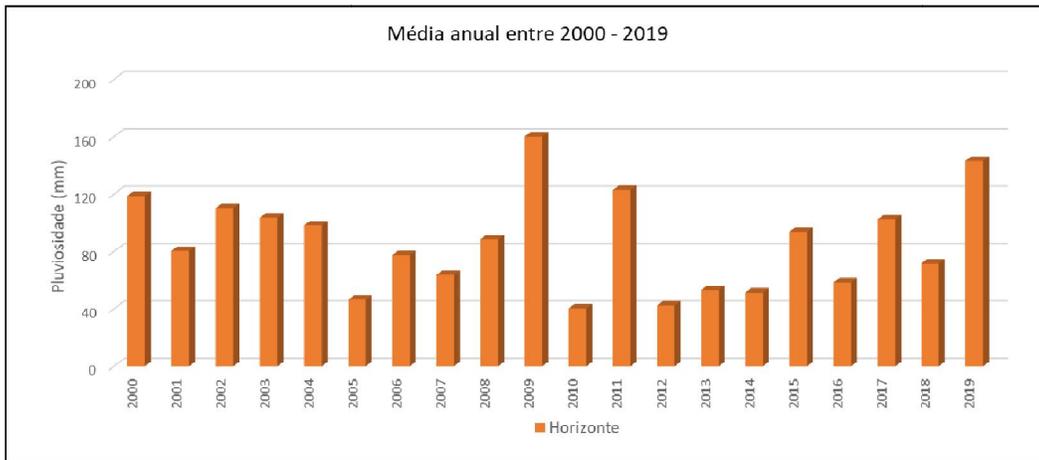


Fig. 3. Yearly rainfall average in Horizonte
 Source: adapted from FUNCEME data [5]

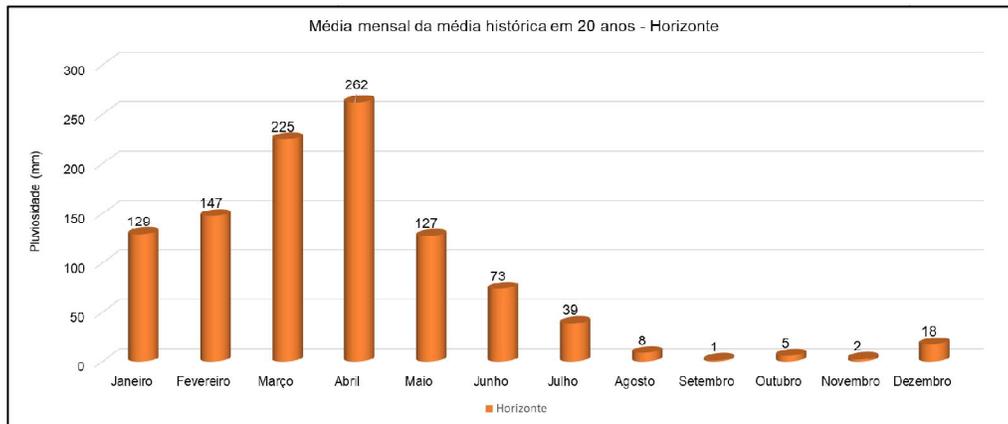


Fig. 4. Monthly average in Horizonte
 Source: Adaptation from FUNCEME data [8]

It is notorious in the figure below that the highest averages during the year are in March, April, and May, with high values compared to the other months.

3.2 Geology

The hinterland surface is in the crystalline basement, based on a complex geological structure resulting from the consolidation of blocks since the Precambrian and with faults in the Northeast. The structural factors are related to the crystalline basement and sedimentary basins. As mentioned in the 1995 Atlas of Ceará published by the Fundação Instituto de Planejamento do Ceará (Planning Institute of Ceará Foundation, IPLANCE), the crystalline rocks cover 85% of the state and have a direct influence on the drainage patterns of the region [16].

Local drainage receives the influence of climatic and geological factors. Concerning the hinterland surface region, geology is a fundamental aspect of the drainage pattern. For example, in a dry climate with a short season of heavy rains, typical of flattened surfaces, anastomosing rivers are common because of the drainage network [17].

The three local geological units are the Santa Quitéria-Tamboril Suite, Canindé Unit, and Independência Unit (Fig. 5). Santa Quitéria-Tamboril Suite covers most of the surface, including the Aratanha Mountain. The Independência Unit is present along the main course of the Pacoti River, extending to the coastal area. Finally, the Canindé Unit is near the Pacoti-Riachão Dam.

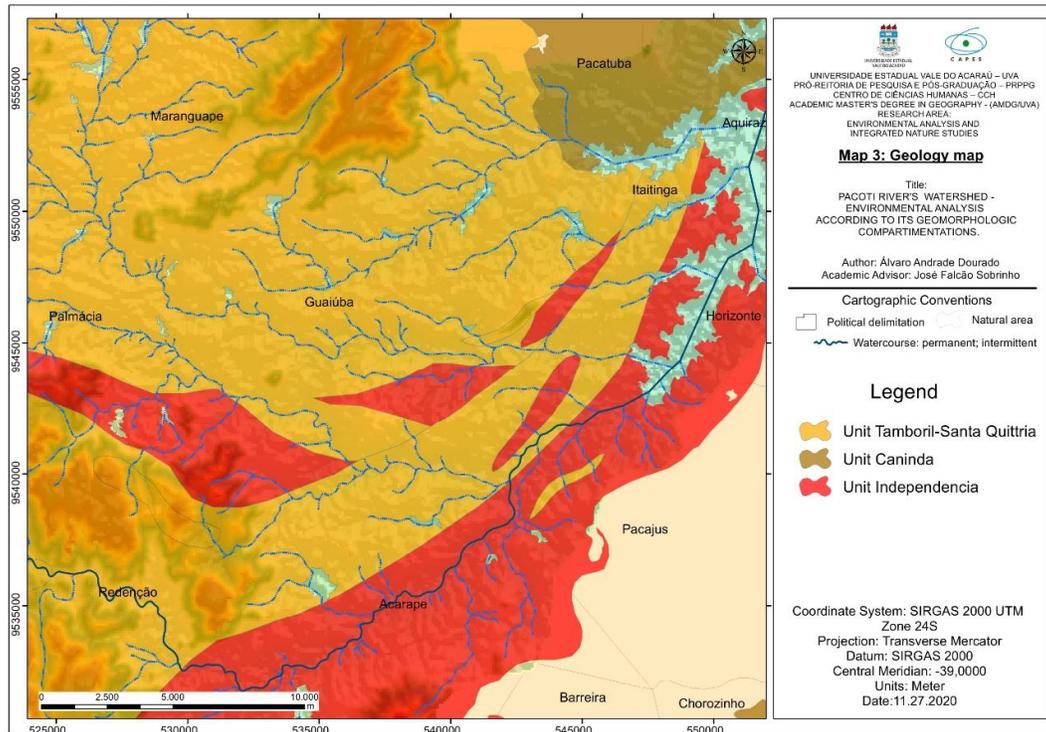


Fig. 5. Geological map of the hinterland surface

Source: made by the author (2020)

3.3 Geomorphology

According to the denomination proposed by the IBGE [18], the flattened surfaces from Ceará are the Hinterland Depression and Plateau. Concerning the topography, these units are lower than the surrounding crystalline massifs and plateaus, which characterizes the entire hinterland surface as a vast interplanetary depression.

The first segmentation – called hinterland depression I – is characterized by a set of pediplain covered by caatinga. It has vast pediplains dissected by a low-density drainage network and by extensive pediments positioned at the foot of mountainous massifs or the edge of cuestas and escarpments of chapadas.

The second segmentation – the hinterland depression II – is characterized by a higher dissected level in its innermost portion. However, it falls into the semiarid interplanaltic depressions of Northeastern Brazil at levels ranging from 250 m to 550 m. The pediplains in this segmentation are different relief forms, such as hills and

mountains, whose dissection meets extensive structural lineaments [19].

The type of relief evident on the hinterland surface of the Apodi Drainage Basin is flat with horizontal topography. The unevenness is tiny or smoothly undulated with gentle slopes (Fig. 6).

Some residual massifs are in the hinterland surface, such as the Aratanha Mountain, which is a humid enclave with tropical montane cloud and temperate deciduous forests in the caatinga. It is in the Fortaleza metropolitan zone, Guaiúba, Maracanaú, Pacatuba, and Maranguape.

3.4 Soil

According to EMBRAPA [19], the two types of soil in the hinterland surface are the Red-Yellow Acrisol and Haplic Planosol. The Red-Yellow Acrisol predominates in the middle course of the drainage basin, around the Pacoti-Riachão Dam and Aratanha Mountain (Fig. 7). The Haplic Panosol is in the North-South direction of the analyzed area and around the Baturité Massif and Aratanha Mountain.

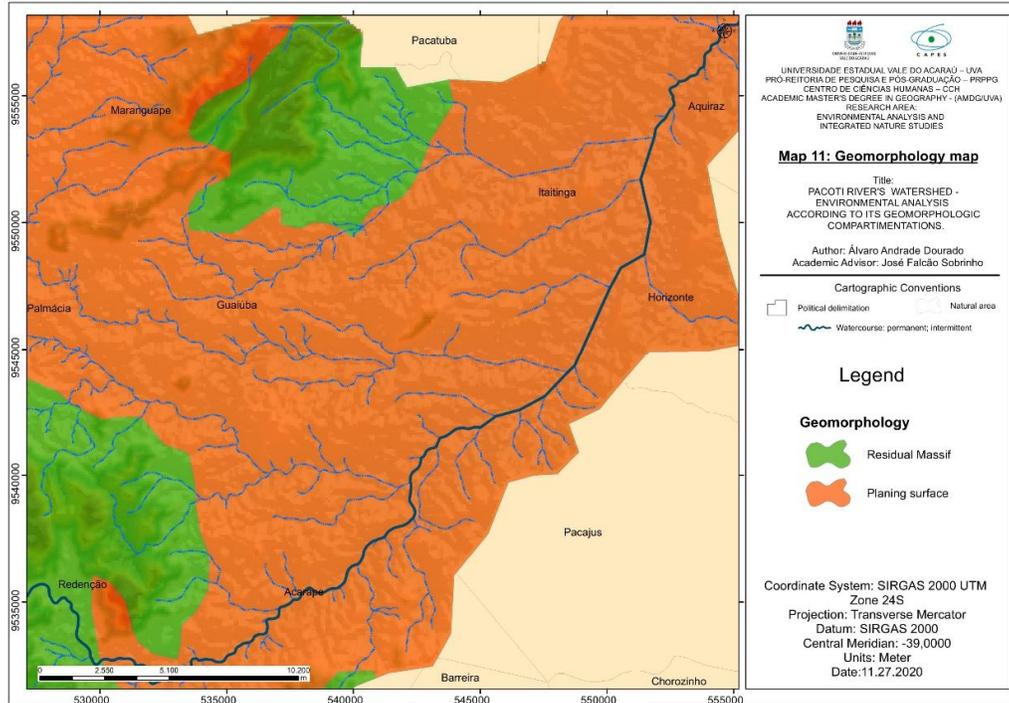


Fig. 6. Geomorphology map of the hinterland surface
Source: made by the author (2020)

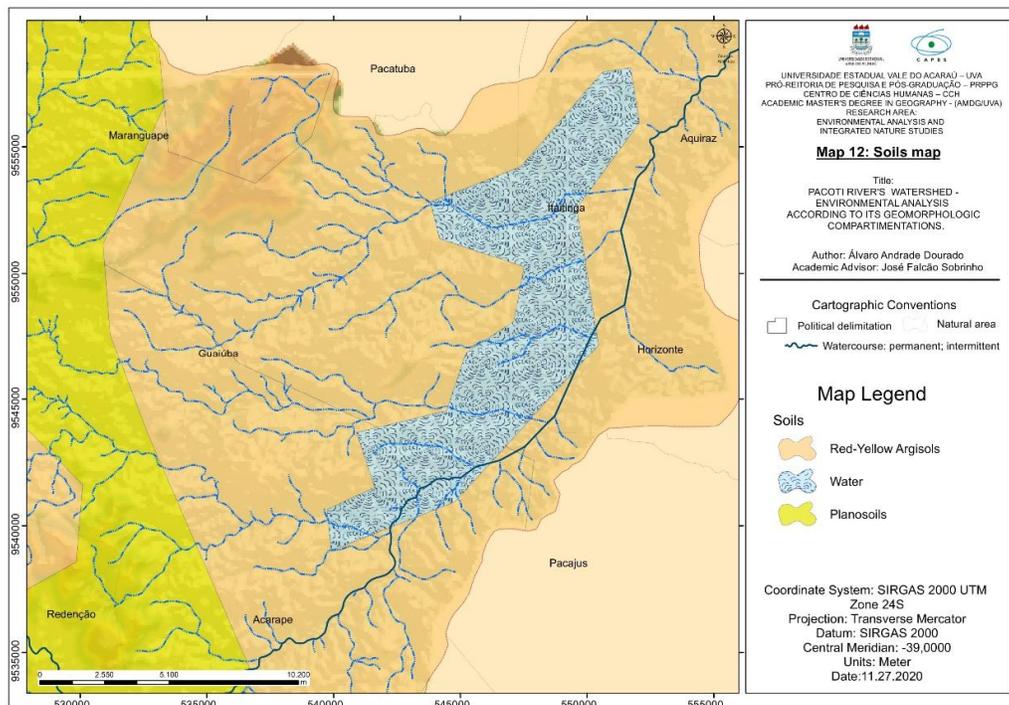


Fig. 7. Soil map of the hinterland surface
Source: made by the author (2020)

The Red-Yellow Acrisol is a production of the Barreiras Group of crystalline rocks or under its influence. It has a clay accumulation horizon, B textural (Bt), with yellowish-red colors because of the mixture of iron oxides, hematite, and goethite. It is deep, well structured, drained, strongly acidic, and with low activity clay and natural fertility [20].

Haplic Platosol contains a considerable amount of basis, which gives it a high nutritional status. However, it has physical limitations concerning soil preparation and root penetration because of densification. Under densified conditions and because of the textural contrast, it is susceptible to erosion [20].

According to Brandão [18], the soil in the caatinga is recent and shallow because of its material of origin, lithological diversity, and climatic aridity (Litholic Neosol (<50cm); Luvisol and Acrisol (<100cm)). The author states that climatic conditions influence the formation of soils affected by salts (Sodium Planosol).

The soil in the caatinga has a low water storage capacity because of the small weathering coverage. Therefore, it can not retain enough water during the rainy season to maintain a continuous flow. So, the caatinga rivers are intermittent [17].

3.5 Vegetation

According to the IPECE database [10], the three vegetation types in the hinterland surface are the Crystalline Caatinga, Coastal Vegetational Complex, and Crystalline Seasonal Tropical Forest (Fig. 8).

The Crystalline Caatinga covers most of the hinterland surface, a type of vegetation adapted to the conditions imposed by the type of soil and climate, such as shallow and low-nutritive soils. Thus, it causes native species to be small to medium height with shallow roots and small leaves.

The Crystalline Seasonal Tropical Forest presents residual massifs, such as the Baturité and Aratanha Mountains. The environmental conditions favor the development of species of this type of vegetation, with medium-sized shrub trees.

Finally, the Coastal Vegetational Complex covers part of the hinterland surface. Because of the

proximity to the coastal zone, the species found in this complex are characteristic of the region. Although not as developed as those found on the coast, they depend on greater availability of water, greater vulnerability because of human exploitation, and other factors.

3.6 Land use and occupation

The herds of goats and sheep arrived from Europe to Brazil in 1534 as domestic animals to supply the farms with meat and milk. Cattle only came in the 17th century to support the sugar cane mills [21] as pack animals.

The subsistence farming activity [22] arrived in the countryside during its formation and occupation. Agriculture and livestock are the income sources in the semiarid municipalities, given the adaptation of animals to the place and the natural food diet. The caatinga meets part of the nutritional needs associated with the conditions of the northeastern hinterland, especially in the Pacoti Drainage Basin.

The changes in the landscapes have to do with land use and occupation. About the spatial-environmental transformation, the substitution of the planted pasture for the native caatinga, the vegetational suppression, and trampling are significant as well. In the depressions with flat-rounded surfaces, there is more usage and occupation of the land because of large areas that favor agricultural activity. However, the natural restrictions of climate, relief, soil, and vegetation cause insecurity in this economic sector [23].

The main activity on the hinterland surface concerning land use and occupation is agriculture (Fig. 9). It has two different forms - one is annual, temporary and permanent plantations.

The yearly crop covers most of the hinterland surface because of its cultivation style. It adapts better to the natural conditions that, despite adverse, are constant throughout the year. On the other hand, horticulture demands much water, which is scarce in the hinterland.

3.7 Conservation Units

The Área de Proteção Ambiental (Environmental Protection Area, APA) of Aratanha Mountain is in the Fortaleza metropolitan zone, which comprises Maranguape, Pacatuba, and Guaiúba.

Its physical limit is the altimetric quota of 200 meters. It is a sustainable use conservation unit, occupying 6,448.29 hectares and created by State Decree 24.959/99 with the polygon illustrated in Fig. 8 [23].

According to SEMACE [23], in the Aratanha Mountain APA, it is not allowed:

- i. The implementation or expansion of potentially polluting or degrading activities capable of affecting water sources, relief forms, soil, and air;
- ii. The execution of earthworks and opening of canals or roads, as well as their maintenance, when these initiatives imply sensible alterations in the local ecological conditions;
- iii. The deforestation and the performance of activities that imply the killing, capture, extermination, or molestation of wild animal species of any kind;
- iv. The urbanistic projects, land subdivisions, and land plots without the authorization of the Superintendência Estadual do Meio Ambiente (State Superintendence of the Environment, SEMACE), preceded by environmental impact studies, in the terms of the legal and regulatory prescriptions according to articles 11 and 14 of the Law 11.411 of December 28, 1987;
- v. The use of pesticide in disagreement with the official technical standards and recommendations;
- vi. Any form of use that can pollute or degrade the water resources covered by the APA, as well as the dumping of effluents, waste, or debris, capable of causing damage to the environment;
- vii. Other harmful activities in the environmental legislation.

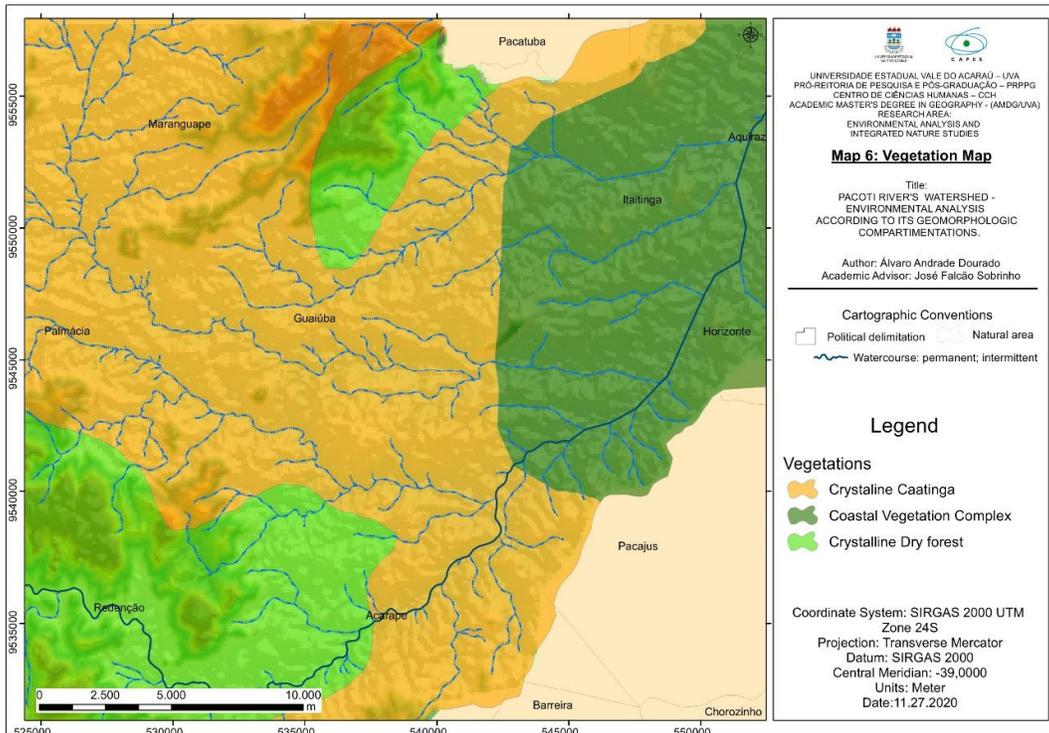


Fig. 8. Vegetation map of the hinterland surface
Source: made by the author (2020)

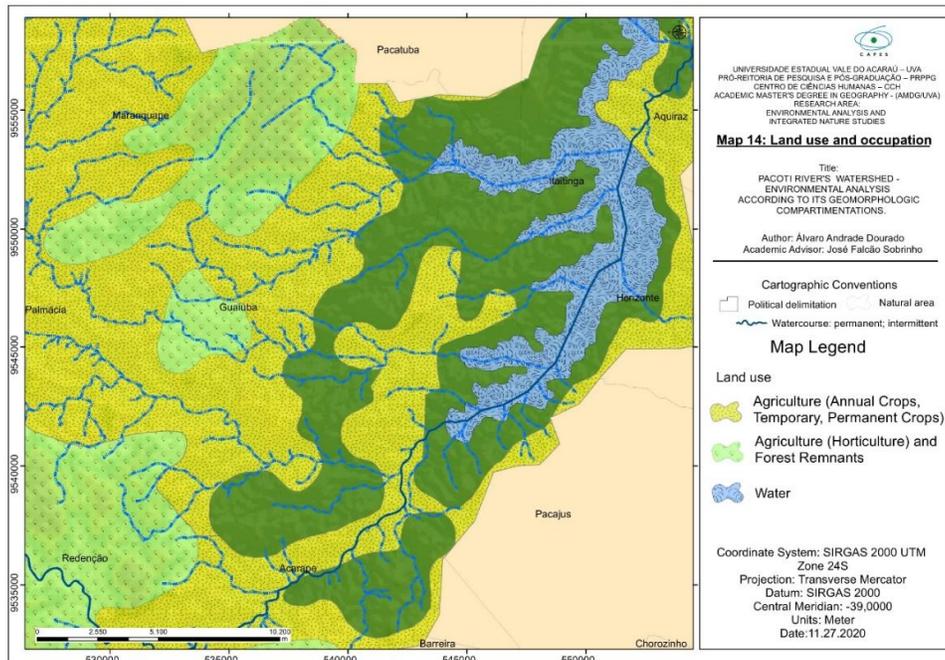


Fig. 9. Land use and occupation map in the hinterland surface

Source: made by the author (2020)

The Aratanha Mountain APA stands out for its environmental peculiarities. It presents a humid enclave of tropical montane cloud forest in the semiarid caatinga ecosystem, a species of ecological refuge [23].

The Aratanha Mountain, which contrasts with the semiarid countryside landscape, has elevated surfaces of mountainous relief and provides good environmental conditions under the influence of high altitude mesoclimate, exuberant greenery, and the Atlantic Forest remnant. Its natural units are what we know as dry and humid mountains. In the humid ones, there are better natural conditions in the semiarid context, which is an exceptional area or landscape enclave [22].

According to the environmental zoning of Aratanha Mountain, the vegetation cover is one of its kind. The three vegetational units are the deciduous (caatinga), semi-deciduous (tropical and subtropical dry broadleaf forest), and perennial (rainforest).

The rainforest occupies most of the mountain, covering the plateau and the highest points of the slopes, above 600 m. The tropical and subtropical dry broadleaf forest occupies an area

between 300 m and 600 m. It is an intermediate vegetation cover between the rainforest and the caatinga.

The Aratanha Mountain APA (Fig. 10) comprises part of Maranguape, Pacatuba, and Guaiúba. The natural attractions are as follows [23].

Maranguape: Rajada Peak, diversity of orchids and bromeliads, waterfalls, Cascatinha, Lajedo Mountain, and forest garden.

Pacatuba: Aratanha Mountain, Andréia Waterfall, Recanto do Bispo, ecological trails; Pirapau Lagoon, and Boaçú Lake, which is the source of the Cocó River.

Guaiúba: Aratanha Mountain and Urubus Waterfall.

SEMACE is currently working in the Aratanha Mountain APA in inspection, monitoring, and environmental education. The actions developed by SEMACE always rely on partnerships with the city hall, Empresa de Assistência Técnica e Extensão Rural (Company for Technical Assistance and Rural Extension, EMATER), Civil Defense, and the community.

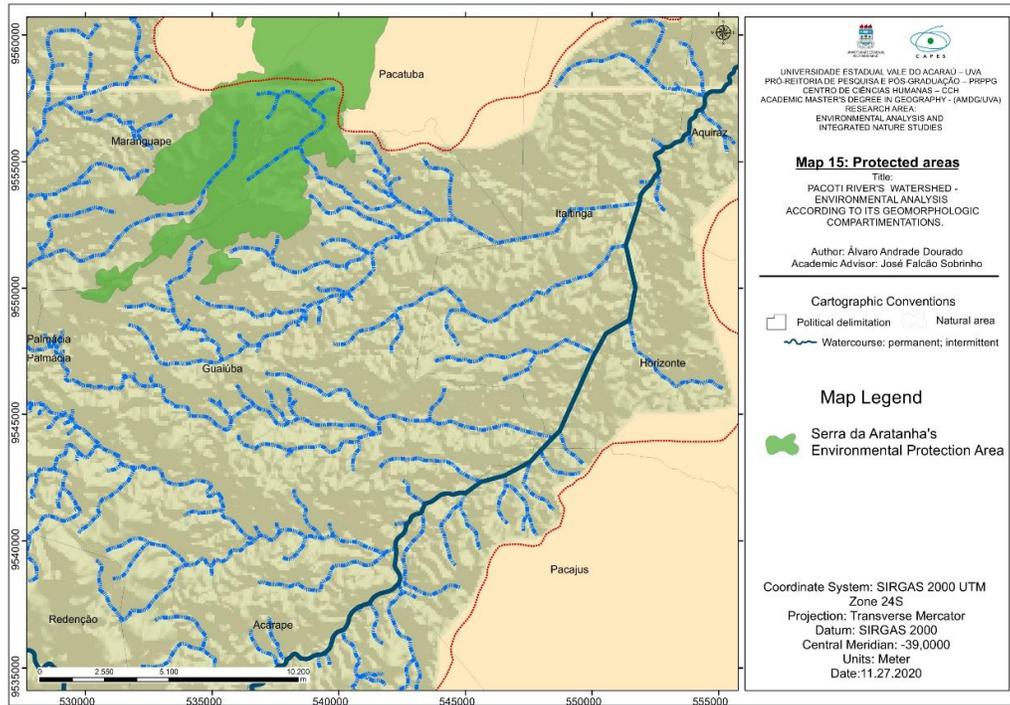


Fig. 10. Conservation unit map of the hinterland surface
 Source: made by the author (2020)

4. CONCLUSION

The digital image geoprocessing techniques used in the physical characterization of natural landscape units in the Pacoti Drainage Basin have been efficient, fast, and precise when identifying local characteristics.

The Geographic Information System (GIS) assisted the characterization process of the Baturité Massif, outback surface, and coastal zone in the Pacoti Watershed. Characterizing the climate, geology, geomorphology, soil, vegetation, land use and occupation, and conservation units constitute a significant step to evaluate environmental impacts potentially harmful to the local natural conditions.

The cartographic bases of public agencies and geoprocessing techniques assisted the production of maps that characterize the local natural units. According to the maps, the Pacoti Drainage Basin has differentiated geomorphologic compartments that require an integrated analysis to understand the natural phenomena that occur in the region and receive influence from humans. Since this is a hinterland

zone, it remains the comprehension of landscape units, geological elements, soil diversities, and visible responses in the vegetation landscape.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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