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GEOENVIRONMENTAL UNITS DELIMITATION OF GEODIVERSITY OF THE SOUTHEAST COAST SECTOR OF MARANHÃO ISLAND, MA- BRAZIL

Thiara Oliveira Rabelo[1]; Zuleide Maria Carvalho Lima[2]; Marcos Antônio Leite do Nascimento[3]

[1]Mestre em Goegrafia, Programa de Pós-Graduação em Geografia, Universidade do Rio Grande do Norte (UFRN), Natal/RN, Brasil.
ORCID: https://orcid.org/0000-0002-6786-7376
Email: thiarageo@hotmail.com

[2]Doutora em Geodinâmica e Geofísica, Departamento de Geografia, Universidade Federal do Rio Grande do Norte (UFRN), Natal/RN, Brasil.
ORCID: https://orcid.org/0000-0002-6971-9801
Email: zcmlima@hotmail.com

[3]Doutor em Geodinâmica e Geofísica, Departamento de Geologia, Universidade Federal do Rio Grande do Norte (UFRN), Natal/RN, Brasil.
ORCID: https://orcid.org/0000-0002-8158-7186
Email: marcos@geologia.ufrn.br

Abstract

Geodiversity, which corresponds to the variety of elements such as rocks, minerals, geomorphological features and soils, constitutes an important part of the environmental system. The division of geoenvironmental units based on the geodiversity characteristics presents itself as an essential research tool to know the processes and interactions of the abiotic elements of an area, as is the case southeast sector of the Island of Maranhão, which presents few studies focused on the its geodiversity. The objective of the research was to delimit the main geomontial units of the area based on local geodiversity as a way to gather similar information about the abiotic resources and to increase the knowledge about it. Using the geosystemic approach and based on bibliographical and cartographic surveys, the use of GIS and field activities, it was possible to delimitate three geoenvironmental units of this sector: Coastal Plateaus, Fluvial-Marine Plain and Coastal Plain. It is estimated that this study is the basis for future research on this subject and for the planning and territorial ordering of the area.

Keywords: Geodiversity; Geoenvironmental Units; Seaside Resort.

DELIMITAÇÃO DAS UNIDADES GEOAMBIENTAIS DA GEODIVERSIDADE DO SETOR COSTEIRO SUDESTE DA ILHA DO MARANHÃO, MA- BRASIL

Resumo

A geodiversidade, que corresponde à variedade de elementos como rochas, minerais, feições geomorfológicas e solos, se constitui como parte importante do sistema ambiental. A divisão de unidades geoambientais com base nas características da geodiversidade apresenta-se como ferramenta de pesquisa essencial para conhecer os processos e interações dos elementos abióticos de uma área, como é o caso setor sudeste da Ilha do Maranhão, que apresenta poucos estudos voltados para a sua geodiversidade. O objetivo da pesquisa foi delimitar as principais unidades geomabientais da área com base na geodiversidade local como forma de congregar informações semelhantes sobre os recursos abióticos e de aumentar o conhecimento sobre o mesmo. Utilizando a abordagem geossistêmica e a partir do levantamentos bibliográficos e cartográficos, uso de SIG´s e atividades de campo, foi feita a delimitação de três unidades geoambientais deste setor: Tabuleiros costeiros, Planície flúvio-marinha e Planície Costeira. Estima-se que este estudo seja base para próximas pesquisas sobre a temática e para o planejamento e ordenamento territorial da área.

Palavras-chave: Geodiversidade; Unidades Geoambientais; Zona Costeira.

DELIMITACIÓN DE UNIDADES GEOAMBIENTALES DE LA GEODIVERSIDAD DEL SECTOR COSTERO SURESTE DE LA ISLA MARANHÃO, MA- BRASIL

Resumen

La geodiversidad, que corresponde a la variedad de elementos como rocas, minerales, características geomorfológicas y suelos, es una parte importante del sistema ambiental. La división de unidades geoambientales basadas en las características de la geodiversidad se presenta como una herramienta de investigación esencial para comprender los procesos e interacciones de los elementos abióticos de un área, como es el caso del sector sureste de la isla de Maranhão, que presenta pocos estudios centrados en el Su geodiversidad. El objetivo de la investigación fue delimitar las principales unidades geoambientales en el área en función de la geodiversidad local como una forma de recopilar información

similar sobre los recursos abióticos y aumentar el conocimiento al respecto. Utilizando el enfoque geosistémico y basándose en encuestas bibliográficas y cartográficas, el uso de SIG y actividades de campo, se delimitaron tres unidades geoambientales en este sector: tableros costeros, planicie fluvial-marina y planicie costera. Se estima que este estudio será la base para futuras investigaciones sobre el tema y para la planificación territorial y el ordenamiento del área.

Palabras-clave: Geodiversidad; Unidades geoambientales; Zona costera.

1. INTRODUCTION

Understanding the elements within an environmental system is essential to understand its dynamics and support for socioeconomic activities. The characterization of geoenvironmental processes and the forms of human appropriation of natural elements is important to think over management and conservation measures for these elements, with regard not only to biodiversity, but also to geodiversity.

Authors such as Gray (2004), Brilha (2005), Nascimento *et al* (2008), define geodiversity as the natural diversity of features, geological elements (rocks and minerals), geomorphological (relief forms) and soils, including their associations , relations, properties, interpretations and systems.

To better understand the processes, the interactions of these elements of geodiversity and their man-made uses, we consider in this work the division of geoenvironmental units based on the characteristics of geodiversity as an essential research tool to better understand the processes and interactions of abiotic elements of a given area, having as a basic principle the connectivity between the elements defended by the geosystemic approach, in geography.

The delimitation of units aimed at congregating the abiotic characteristics of an area, may be of essential importance for areas with few studies focused on its geodiversity, as is the case of the southeastern sector of island of Maranhão, located in the State of Maranhão. This sector corresponds to an area of 74 km², according to data from the GEOILHA Project (2015-2017) and covers part of the municipality of São Luís and São José de Ribamar. Currently, this region is pointed out by authors such as Reis (2005) and Lago (2012) as one of the sectors of urban expansion of the Island and do not have many studies related to its geodiversity that will subsidize future planning and management actions in this area.

The referred area (Figure 01) has a coastal environment of peculiar dynamics, presenting features such as fluvial-marine plains, trays, cliffs, sandy beaches, which have marked landscape potential and are of paramount importance for the populations located in these areas, whose economic activities are related to agriculture and mineral extraction, which make direct use of the potential of geodiversity.

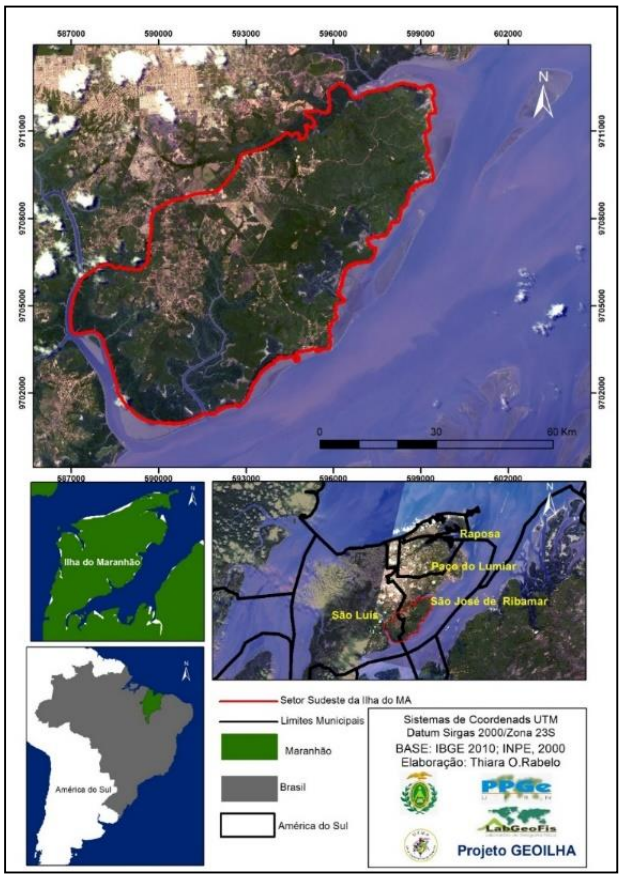

Figure 1 - Location of the southeastern coastal sector of island of Maranhão. Source: Rabelo (2018).

Thus, the objective of this work was to delimit the main geoenvironmental units in the southeastern sector of the island of Maranhão based on local geodiversity as a way to gather similar information about the area's abiotic resources, based on the understanding of their interactions and processes, serve as a basis for future research on this area and for the planning and management of these resources in this sector.

2. METHODOLOGY

This research is based on the conception of the geosystemic approach (Sotchava, 1977; Bertrand, 1997; Ross, 2006;) which is based on the General Systems Theory created by Bertalanffy in 1973. To reach the objective of the work, the research was developed following the main methodological steps below:

- ✓ Bibliographical and documentary information surveys that directly or indirectly address the geodiversity of the study area, such as the research by Silva (1973), Feitosa (2006), Klein and Souza (2012), Silva (2012); Flag (2013).
- ✓ Survey of cartographic materials in the area and compatibility of DSG charts, Google Earth images and LANDSAT 8 OLI satellite images from 2016 made available by INPE, and vector data referring to the geodiversity of the

State of Maranhão, made available by CPRM (2013), for greater detail and understanding of local geodiversity.

✓ Use of remote sensing and geoprocessing techniques that came to assist in the identification of geological typologies and differentiated geomorphological features, as well as for notes on the use of these resources from human actions, as well as for the association of this information with information acquired from research activities. field and later the spatial delimitation of geomabiential units.

✓ Field activities to validate the secondary data used in the research and analysis of the geodiversity characteristics of the area in loco, where the main objective was the observation of the landscape in order to understand the most visible implications in the study area resulting from the ways of using the elements abiotics in the area.

3. RESULTS AND DISCUSSION

3.1. The geodiversity of the southeastern coastal sector of Ilha do Maranhão

With regard to the geodiversity of the area, we can highlight that the geology of this sector is mostly understood by the sediments of the Barreiras Formation that is litogically formed for by "poorly selected sandstones, fine to coarse, variegated, generally clayey and with numerous shales intercalations" (AGUIAR, 1971). There is also the presence of swamp and mangrove deposits, which, according to Rodrigues *et al* (1994), consist on gray-colored, non-dense, massive and bio-wetted silt (clay and silt).

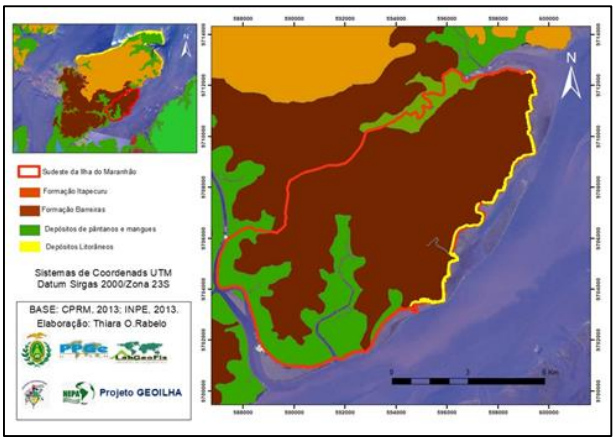

Figure 02 - Geological units present in the southeastern coastal sector of Ilha do Maranhão. Source: Rabelo (2018).

Although they are not present in the large mappings made for the State of Maranhão, Rabelo *et al (*2016) highlight that coastal deposits are also present in this area in the form of medium to very fine quartz sand.

In relation to Geomorphology, CPRM (2013) highlights for this sector the presence of: Dissected Boards, Fluvial-Marine Plains and Fluvial Plains. The dissected trays correspond to most of the area in question, and, according to CPRM (2013), they are sculpted in low dissected plateaus and tabular hills, carved by a network of channels of moderate drainage density (Figure 03).

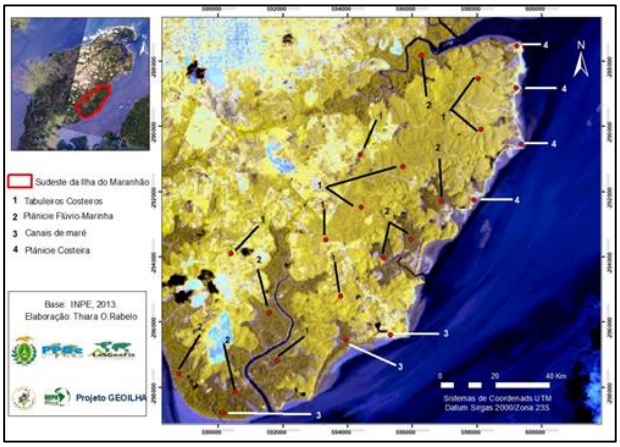

Figure 03 - Main geomorphological features of the southeastern coastal sector of Maranhão Island. Source: Rabelo et al, (2018).

Rabelo *et al* (2016) highlight that these boards end in the form of cliffs present in the study area, as is the case of the beaches of Guarapiranguinha and Catatiua Beach. The Fluvio-Marine Plain is formed by estuarine areas of drainage networks, being most representative in the vicinity of the Tibiri and Tijupá River, and is characterized by the predominance of mangroves, flat surfaces and contact zone between the continental and marine depositional systems, associated with the tidal channels.

The coastal plain of this area is less extensive compared to the coastal plains of the western coast of Ilha do Maranhão, but they have immense landscape potential and are of paramount importance for the environmental dynamics of the study area.

As for pedology, according to the data from the mapping carried out by CPRM (2013) in this sector, the yellow red argisols, yellow latosols and indiscriminate mangrove soils are present. The red-yellow argisols (Figure 4), according to Silva (2012), are not hydromorphic and are shallow, well drained and, in general, have strong limitations to agricultural management and mechanization due to the amount of laterite on the surface and inside their profiles. Yellow oxisols, on the other hand, have good physical conditions for moisture retention and good permeability and we note their presence in the flat relief parts, with gentle undulations, as is the case of the tabular areas of the southeastern sector of the Island.

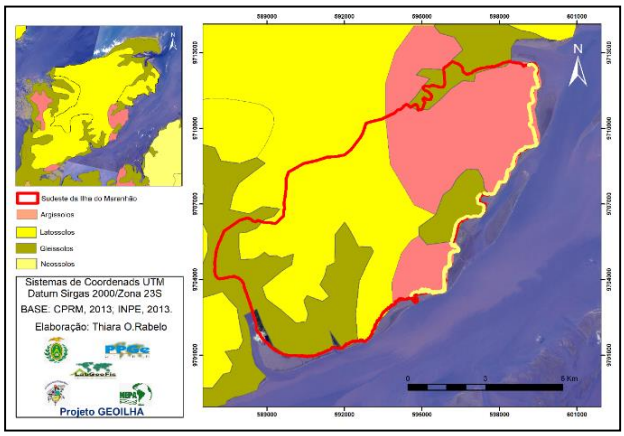

Figure 4 - Pedological units present in the southeastern sector of Ilha do Maranhão. Source: Rabelo (2018).

Gleisols are present in all the flatter areas related to fluviomarine plains, and, according to Silva (2012), they contain high levels of sulfur compounds, due to the changes in water level by the tides, and with the oxidation process, become more acids. Silva (2012) also highlights the presence of quartzenic or somatic aluminum neosols in this area, which occur in small patches in the area across the coastal plain.

With regard to the main types of use of geodiversity in the area, we highlight agriculture, which presents itself as the most prominent economic activity on the location; mineral extraction, which occurs mainly in the form of extraction of sand and mineral resources for civil construction.In addition, the tourist activity, which even though it is still incipient in this sector of the Island of Maranhão, the landscape potential of the beaches in this area are already attracting the attention of visitors. The Pontes de Guarapiranga and Juçatuba, the first consisting of the beaches of Guarapiranga and Guarapiranguinha and the second having the main attraction of Praia de Juçatuba, are the most visited points by tourists in this sector.

3.2. Processes and interactions

The elements inserted in a system, whether of a natural order or from human actions, interact with each other, and participate in processes that are essential in the dynamics of an environment. When this dynamics refers to coastal systems, we know that these are much more fragile processes and interactions, since these areas are in transition environments between the sea and the continent.

Christofolletti (1982) infers that coastal processes result from the interaction of geological factors (shape and resistance to erosion), climatic factors (action of physical, chemical and biological processes), biotic factors (organisms can present erosive consequences, excavating and promoting disaggregation rock minerals, or protective and constructive, facilitating the retention of sediments and the accumulation of debris), winds (generation of waves and currents) and oceanography (nature of seawater, with variations in salinity).

In this context, although the most punctual climatic and oceanographic data on this coastal sector on the island of Maranhão is still scarce, it is possible to observe that the geographical location of this area implies changes in the dynamics of this environment, since the lower intensity of waves and winds influence in the presence of more extensive abrasion terraces in the area, for example. However, Silva (2012) points out in his study the role of waves and coastal currents in coastal plains in the southeastern sector are indicating points of erosion on this region.

As for the tidal regime, this sector is located in the mouth of the Bay of São José, which according to Coutinho and Morais (1976) has marine action as the predominant process in the area. Silva (2012), points out that the Maranhão Island, being an area of macro-tides, that is, with amplitudes greater than 4 meters, presents extensive areas covered by tidal plains, with the Southeast of the Island being one of these places.

Several factors related mainly, its geographic location close to Baia de São José, make this area more protected from the action of the waves and become conducive to the formation of mangroves that are located close to the estuaries of rivers in the Southeast sector.

However, in some points more distant from the mouth of the Bay of São José (Figure 5) and where it is already possible to feel the strongest effect of the winds in the East-West direction that operate in the Golfão Maranhense region, according to MUEHE (2006), it is possible to perceive its influence in accentuating the dynamics of the waves.

Figure 5 - Location of São José Bay showing the proximity to the southeastern sector of the Maranhão Island. Source: Rabelo (2018).

At Ponta de Guarapiranga, we can see this situation, also mentioned by Silva (2012), who says that this is one of the points on the island where cliffs are receding due to the action of the waves in the area, where in several points of the Southeast sector it is It is possible to observe the presence of sediments eroded and

reworked by the action of the winds on the abrasion terraces of the area, coming from the cliffs of that environment.

It is also important to consider the statement by Popp (2010), that the speed of erosion of the rock is variable, depending mainly on its size and strength. This interaction can be seen in the coastal plain of the Southeast sector, since there is the presence of lithological layers parallel to the coastline, which contribute to the formation of abrasion platforms and modify the wave energy, thus reducing the processes of coastal erosion at these points.

It is also important to emphasize the interaction between social and coastal processes, since human beings have always given preference to the establishment of settlements close to the environments of rivers and beaches. This aspect is of paramount importance for understanding the processes of the dynamics of these environments.

In the Southeast sector of Island of Maranhão, a large part of their communities are located near rivers and beaches. We found that anthropic interference in the area, in a general context, is not accentuated and still does not cause irreversible negative impacts in the area, man is still not considered a major threat to the environment of this sector.

Although the main economic activities that occur in this region, directly linked to geodiversity (agriculture, mineral extraction and geotourism), do not have as many negative impacts yet for the area, however its development is already taking place without proper planning. And, in the future, they may lead to situations of degradation of these environments, mainly due to the large population increase (Table 01) that is occurring in this sector, fact that can be proved by the IBGE census data, which in the year 2000 was 107,384 inhabitants and in the last IBGE census in 2010 had a population of 163,045 inhabitants.

Table 01 - Population growth of the citizens of Ilha do Maranhão. Source: Rabelo (2018).

County	Population	
	2000	2010
São Luís	870.028	1.014.837
São José de Ribamar	107.384	163.045
Paço do Lumiar	76.188	105.121
Raposa	17.088	26.327

As an example of this, we cite some points located in the board areas, where some recent communities are located, such as the Conceição Settlement, where we can observe some nearby points destined for the disposal of garbage. These sites do not yet have public policies related to the collection of solid waste, which can lead to problems related to soil or aquifer pollution, further compromising the health of the local population.

Understanding the correlations between the elements of a system is essential to understand, according to Magalhães and Silva (2010), how the spatial and landscape (re) formation process that constitutes the territory takes place; and the understanding of these elements within an environmental system, is fundamental to understand its dynamics and the support to socioeconomic activities.

3.3. Geoenvironmental units of geodiversity

Taking into account the characteristics of geodiversity, the main types of uses of these resources, their processes and interactions, it was possible to gather this information and delimit the main geoenvironmental units of geodiversity in the southeastern coastal sector of Ilha do Maranhão.

Although it is understood that geoenvironmental units are part of a holistic geographic view that involves both the characteristics of the biotic and abiotic environment, it is important to note that this division of geoenvironmental units of geodiversity in this work was done based on the methodology of mapping and division of units geological-environmental or geo-environmental, proposed by CPRM (2010) and already applied in several compartmentalized volumes for Brazilian states (BANDEIRA, 2013; BRANDÃO AND FREITAS (2014); ADAMY (2015); where the greatest focus is given to the geodiversity characteristics of the delimited units associating their potentialities and limitations of use.

The geoenvironmental units of geodiversity that were delimited with geomorphology as the main starting point, the most prominent element of geodiversity in the area. Thus, three geoenvironmental units were delimited: coastal plateaus, fluvial-marine plains and coastal plain (Figure 6).

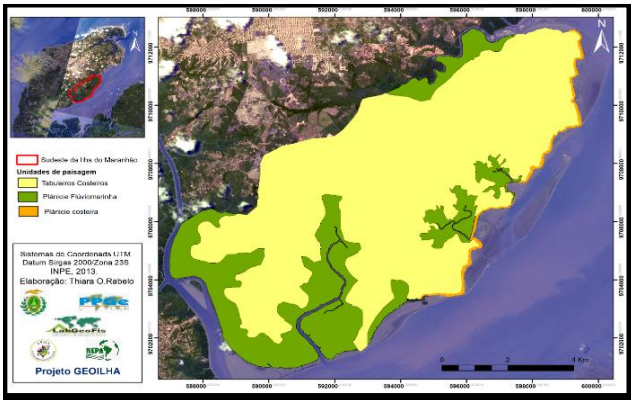

Figure 06 - Delimitation of geoenvironmental units in the southeast coastal sector of Ilha do Maranhão. Source: Rabelo (2018).

A)Coastal Boards

This unit is mainly associated with the Barreiras Formation, and according to the CPRM geodiversity report (2013), this area mainly comprises sand-deposits, which are very weathered and, in some points, very ferriginized and laterated.

The relief of this region is associated with tabular areas that correspond to dissected boards , according to the classification of CPRM (2013), covered mainly by oxisols soils that present, according to the information available on the EMBRAPA website, good physical conditions for moisture retention and good

permeability, being intensively used for crops, such as cassava in that region.

Likewise, the argisols are present in this unit, and are also soils developed from the Barreiras Formation and which have good capacity to retain nutrients and store water. In the places where these soils occur, some areas of weir excavations were observed (Figure 33) which, associated with the tabular relief, becomes easily excavable, as it does not need deep cuts to minimize its slopes, according to Bandeira (2013).

These Coastal Boards are configured in gently dissected forms of relief that sometimes end abruptly in the form of cliffs and paleophalies that can be found in various points of the Southeast sector, already in contact with the coastal plain as in Ponta de Guarapiranga, Satuba, Praia da Moça.

✓ From the observations made in the field and the information extracted from the geodiversity report of the State of Maranhão (BANDEIRA, 2013), this unit has the potential to:

✓ Construction of engineering works, since it is easy to excavate, without the need for deep cuts to minimize slopes;

✓ Medium to high support capacity;

✓ Potential for exploring sand, clay and lateritic concretes for civil construction;

✓ Water storage capacity with good physical-chemical quality;

✓ Presence of deep, permeable, acidic soils with low natural fertility capacity, subject to mechanization and corrections from fertilizers;

In addition, it still has the potential to:

✓ The trays that are closed by cliffs have a marked landscape potential, which enhances the development of geotourism in the area.

✓ Exploration of sand, clay and lateritic concrete for civil construction;

B)Fluvio-Marine Plains

This unit is mainly associated with the swamps and Mangrove Domains with clayey sand deposits, which according to CPRM (2012) are made up of sands and sludge with organic vegetable remains, presenting areas with medium and fine gravel and sands, due to river sedimentation. According to Rodrigues *et al* (1994), these deposits are constituted, predominantly, by muddy sediments (clay and silt), gray in color, not dense, massive and bioturbated.

It is located on the most level surfaces near the rivers of this sector. This area comprises estuarine areas of the drainage networks of the hydrographic basins, an area of contention between the continental and marine depositional systems, influenced by the tide and with a predominance of mangroves.

These areas of more flattened surfaces are covered by gleisols, which when flooded, have some restrictions on agriculture. But in times of drought, they are apt to produce irrigated products. Some plantations of farmers' cooperatives in the southeastern sector are located within this unit, such as the community and Coquilho II.

It is worth mentioning that in this unit are located the main rivers of this part of the Island, which support the survival of many local riverside communities, not only through animal extraction, but also many use those waters for their daily needs and use the rivers for moments leisure (Figure 36).

According to Bandeira (2013), and with the observations made during the field activities, the geodiversity of this unit presents mainly the following potentialities:

✓ In some places it presents sandy layers with aquifer potential in subsurface. However, they are discontinuous with a few meters thick, which reduces the aquifer's potential;

✓ Flooded soils with limitations for agriculture and have aptitudes for irrigated plantations.

And it still presents potentialities such as:

✓ Favorable geological environment for the occurrence of clays for the manufacture of ceramics;

✓ Areas of rivers and mangroves with prominent landscape potential for the development of geotourism.

C)Coastal Plain

This unit is directly associated with the coastal deposits that occur on Island of Maranhão. Muehe (2006), states that the coastal plains of Maranhão are characterized by a significant dynamic, above all, because it is a transgressive coast dominated by macromaré.

The unit is located near the mouth of the Bay of São José and according to Muehe (2006), in this area there are "ends of spurs or asymmetrical sand banks with ENW-WSW direction, oblique to the coast, separated by narrow channels. Some sandbanks, located a little further east, run parallel to the coastline ".

The coastal plain is associated with the flatter areas close to the sea, and occur where we can observe environments of beaches and abrasion terraces, which have direct contact with the cliffs, and which are associated with the dominant mangrove trays and areas in the fluviomarine plain.

From the observations made in the field, we can highlight that beaches on the coastal plain of the southeastern sector of island of Maranhão are predominantly made up of quartz sand, associated with some fragments of shells and plant remains and ferruginous sandstones. It is worth mentioning the observations made by Muehe (2006) on the barrier beaches of the Maranhão coast that border mangrove areas and are dominated by the semi-daytime macro-tide processes, being "the barrier beaches constituted essentially by linear sandy strands constituted, mainly by fine unimodal quartz sand, of gray to light whitish color, well selected, with fragments of shells, plants and other organisms".

We emphasize that in this unit many buildings are already concentrated referring to second homes, being a region that is gradually becoming more and more attractive for the construction of more houses and establishments in this area. However, it is necessary to emphasize the observations made by Bandeira (2013), that the sediments of this environment are poorly consolidated, with low support capacity, becoming limited to urban occupations.

Based on the observations made in the field in the area corresponding to this unit in this sector, and according to the data extracted from the geodiversity report of Bandeira (2013), this unit has especially the following potentialities:

✓ Comprises surface aquifers with high potential for groundwater, able to meet significant demands by means of large diameter tubular wells;

✓ They have the potential for low-cost exploitation, by means of excavated wells and cacimbas to meet family demands;

Or even features:

✓ High landscaping potential found on its beaches, with some different characteristics found on the western coast of Maranhão Island. Which greatly enhances the development of geotourism in this unit.

4. CONCLUSIONS

The surveys carried out on the geodiversity of the southeastern sector of island of Maranhão are incipient compared to other areas of island of Maranhão. The research effort aimed at understanding the characteristics of the geodiversity of this sector is of paramount importance for the management of these resources in the region, since it is considered one of the urban expansion zones of the Island, therefore, the conservation of the environmental systems present there must be considered.

The division of the geoenvironmental units in this sector based on the characteristics of geodiversity was important to understand the relationships that involve the abiotic elements of the area and to identify the potential of each unit for the development of human activities and identification of its importance for the communities of the region. This contributes directly to the planning, management and conservation of local geodiversity.

Research aimed at dividing geoenvironmental units is still little used in studies on geodiversity. Understanding these characteristics from the delimitation of geoenvironmental units is important for studies on this theme, due to the possibility of gathering similar information from the abiotic resources of a given area in large groups. In addition, to understand the main processes and interactions between these elements and their influence with human activities and biotic elements, as it was possible to verify in the southeastern coastal sector of Maranhão Island.

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