



# Ecosystem Services and Typology of Urban Geodiversity: Qualitative Assessment in Natal Town, Brazilian Northeast

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## Abstract

Natal is a city located in northeastern Brazil that has a geodiversity composed of different landscapes, flanked by beaches, dunes, cliffs, rivers, mangroves, and lagoons. Throughout the city's history, which spans more than 400 years, geodiversity has always been present since the early days of local cartography, dating back to the Dutch occupation period, on the seventeenth century, in which the natural environment had been faithfully portrayed. The studies developed in this work approach the geodiversity of Natal City that occurs naturally, in situ. The identification of the main places in which the abiotic nature is highlighted was performed, allied to a geological-geomorphological description. The occurrences were classified according to their area extension and the ecosystem services of abiotic nature, in a system divided into five services (cultural, regulating, provisioning, supporting, and knowledge). In the study area, all services were identified, and of the subclassification in geodiversity goods and processes, 16 out of 25 were observed, which reaffirms the importance of the local abiotic nature. On the tipology of these occurrences, they were identified as sections, areas, point, and viewpoints. Due to its extension and variety, it can be used for science, culture, sports, and tourism, in order to promote, jointly, the dissemination of the natural and cultural beauties of the city and geosciences, helping the geoconservation process.

**Keywords** Ecosystem services · Northeast Brazil · Qualitative assessment · Urban geodiversity

## Introduction

Cities, over the centuries, were established in natural environments that initially favored their protection and agricultural maintenance. Environments near the coast were used in the installation of mercantilist urban centers from the late fourteenth century. The definitions of urbanism that emerged after the Industrial Revolution changed the needs, shapes, and constructions of cities, favored from the natural resources available for their development. In all these situations, geodiversity was linked to the beginning and expansion of *urbis* on the planet. Studies on urban geology, or geodiversity in cities, are also compatible with the understandings developed in the specialized literature.

The horizon unveiled by geodiversity studies in urban centers allows a direct relation between society and geosciences, being an important tool for dissemination of Earth Sciences. Since the cities were installed in places whose geodiversity favored their erection, mainly due to the availability of natural resources, it is not possible to dissociate the process of understanding the city without understanding its environment, which encompasses geodiversity. This is also applicable to the study area of this work, the city of Natal, in the Brazilian state of Rio Grande do Norte.

The city of Natal has a geodiversity very present in its landscapes, which comes from its installation in an environmentally rich region, still in the late sixteenth century. The abiotic diversity is made up of beaches, dunes, mangroves, rivers, and lagoons, among other important aspects for the local community, as well as for the environment. Discussions around this diversity are fundamental to support the necessary environmental conservation actions, mainly because they list priorities, such as through the values of geodiversity.

From the applicability of abiotic diversity concepts in the study of geology in Brazilian urban centers, as was done in

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Bahia (Pinto 2015), Paraíba (Pereira and Amaral 2014), Paraná (Liccardo et al. 2008; Calegari et al. 2011), and Santa Catarina (Covello 2011), this paper analyzes the local geodiversity in the city of Natal, focusing on in situ elements.

To complement the analysis, we also describe geodiversity ecosystem services associated with local abiotic elements, terminology applied in biodiversity studies for some years and which has been more widely used by geoscientists (Gray 2013; Silva and Nascimento 2016; Alahuhta et al. 2018; Gordon et al. 2018; Silva 2018; Silva et al. 2018; Garcia 2019). From this research, the importance of geodiversity for the city of Natal is proven, in environmental and socio-cultural terms.

## The Natal Town

Natal is the largest city and capital of the Rio Grande do Norte state, far northeast of Brazil (Fig. 1). It has a total area of 167.4 km<sup>2</sup> and an estimated population of 884,122 inhabitants, making it the 20th most populous city in the country (IBGE 2019). Its foundation dates to the late sixteenth century and was linked to the Portuguese need of mastering Brazilian lands. The geographical position of the city was fundamental for the expansion of Portuguese Kingdom conquering power to the interior of continent. This fact is related to the geology of this region, which was support for the city development.

## From Portuguese Occupation to Expansion in the Twentieth Century

It is hard to pinpoint a date when the lands of Rio Grande do Norte were first sighted (Lyra 1998). Even a date for its foundation is not a point of agreement in the literature. Nevertheless, Souza (2008) places December 25th, 1599, as the initial day of the city's history. At the beginning of the seventeenth century, the current neighborhood of Cidade Alta corresponded to the entire area of Natal, with its borders nailed with two crosses, one to the north, where today is the Praça

das Mães, and one to the south, in Praça da Santa Cruz da Bica (Souza 2008).

The Forte dos Reis Magos was, until then, the only building outside the perimeter demarcated by the crosses. It was built in the beach region, over the reefs, bodies of calcareous sandstones common in the coastal zone of the entire Northeast of Brazil, and was islanded at high tide. It still stands today and is located at the mouth of the Potengi River, in an area of great historical, cultural, and environmental importance for the city. Its construction began in the sixteenth century, but the remaining structure was not completed until 1628. Prior to that, the construction was of “mud and sticks harvested from the mangroves and surrounding areas. Over time, it deteriorated” (Souza 2008).

Although the city's largest urban and economic development took place only in the twentieth century, by the end of the nineteenth century, Natal already had a hospital, cemetery, tax office, and theater. There was then a radical change in the landscape and organization of *urbis* (Cascudo 1999).

The beginning of the twentieth century brought to Natal a new debate about urban organization. Nobre (2001) shows that the first structural interventions in the city were focused on improving hygienic conditions. From that moment, the city would be concerned with the protection of forests near the springs of rivers and public sources, as well as improvements in buildings used to supply the population. The city that until 1901 was formed only by the neighborhoods of Cidade Alta and Ribeira, gains new streets and limits, with the formalization of the Cidade Nova neighborhood, which currently corresponds to the neighborhoods of Petrópolis and Tirol (Nobre 2001).

At this point in history, a concern begins with the conditions of the urban landscape, seeking to respect the morphological characteristics of the terrain, its sandy soils and dune bodies, and promote the creation of green areas. The calls for organization of the city structure and public services also began. With the most intense traffic, the process of paving the streets and avenues started. Until 1924, the blocks taken from rocks found at the base of cliffs (ferruginous sandstones), easily recognized on the beaches of Natal, served as the “blocking” of the streets (Souza 2008). At that year, however, paving began with cobblestones made of granites (this one from the neighboring city, Macaíba). Nascimento et al. (2018) present the main rocks used, mainly in the Historic Center of Natal.

From World War II, when a US base was established in the region, the largest outside the USA, the city experienced a period of rapid growth, road lighting became more efficient, more regular transportation, and more quickly delivered mail. It can be said that the twentieth century was also fundamental for the native population of Natal to enjoy, more daily, the natural resources, in terms of landscape, that the region has. At this time, occupation and enjoyment of beaches and coastlines

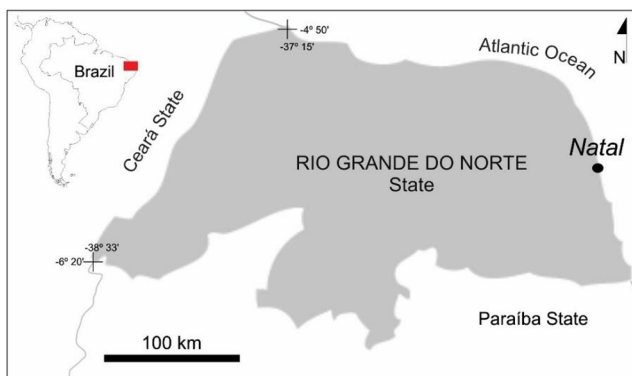


Fig. 1 Location map of the study area

became more common. Particularly noteworthy are the beaches of Meio, Areia Preta, Forte, Redinha, and Ponta Negra, the latter two being typically used as vacation spots.

## Historical and Regional Geology

Natal is located over a region in which geology studies have been developed for at least 145 years. As one of the results of Louis Agassiz's famous expedition to Brazil in the second half of the nineteenth century, Hartt developed a study of the geology and physical geography of the country, in which he pointed out that the province of Rio Grande do Norte is:

“composed of gneiss and other metamorphic rocks, which form in the interior a high and more or less mountainous country [...] Bordering this is a considerable band of tertiary rocks. The immediate vicinity of the sea is flat, sandy, and often, as in the vicinity of Natal, covered by dunes of blown sand” (Hartt 1870 p. 455).

Branner (1904) and Jenkins and Branner (1913) also described the geology of the state and especially of the coastal region of Rio Grande do Norte state, where the study area of this work is located. Almeida et al. (1977), in the classic work on the Brazilian structural provinces, define the region as one of the constituents of the Costeira Province. It is represented by Cretaceous sedimentary rocks, covered by the Barreiras Formation and sedimentary, alluvial to beach, deposits. The crystalline basement of the region correlates with the northern domain of the Borborema Province, also described by Almeida et al. (1977).

Although some authors place the region of Natal in the Potiguar Basin, Pessoa Neto et al. (2007) claim that this basin has its eastern limit at the Alto de Touros, located 84 km north of Natal. Therefore, Córdoba et al. (2007) identify this region as correlated to the Pernambuco-Paraíba Basin, as also did Almeida et al. (2015). The southern limit of this basin is the Alto de Maragogi, in the state of Pernambuco, while the northern limit is the Alto de Touros. It is a rift type basin, subdivided into two supersequences, one Rife and one Drifte. Its formation is associated with the South Atlantic Rifting event, which culminated in the final opening of the Atlantic Ocean and separation of the African and South American continents, still in the process of rupturing the supercontinent Gondwana, at the end of the Aptian.

## Local Geology

The local geology of the study area is essentially sedimentary, with outcrops from Cenozoic sediments and sedimentary rocks (Fig. 2). The base is formed by the Barreiras Formation, of age correlated to Paleogene/Neogene. It is a unit identified along the Brazilian coast, from north and northeast regions to Rio de Janeiro state, also comprising some parts of the Amazon region. It consists mainly of conglomerates and

conglomerate sandstones and also medium to fine sandstones and claystones, deposited in environments of intertwined or transitional river systems to alluvial fans (Angelim et al. 2006).

Distinguishing the rocks of this group is facilitated by their reddish coloration, with rust cementation and poor diagenesis. Some horizons may have oxy-reduction. In Natal, the Barreiras Formation is found on the Via Costeira cliffs, Ponta Negra and Areia Preta beaches, mainly, and on Redinha beach.

Sedimentary register is completed by alluvial, marine, continental, sandy, sandy-foam, fluvial-marine, coastal, beach, and wind deposits. In addition, there are prominent occurrences of sandstones (beachrocks), common throughout the state's coastal zone, arranged parallel to the shoreline.

Sandstones are mainly composed of inequigranular quartz, cemented by calcium carbonate, precipitated by the action of marine water, with some participation of freshwater (Cabral Neto et al. 2014). Granulometry is medium to coarse, and there is presence of bioclasts, especially algae. A general N-S orientation is noticed in the sandstone bodies found in the study area. These bodies, which sometimes appear as two parallel bands, were dated by Barreto et al. (2004) as having approximately 4000 and 9000 years for each of the rock tracks.

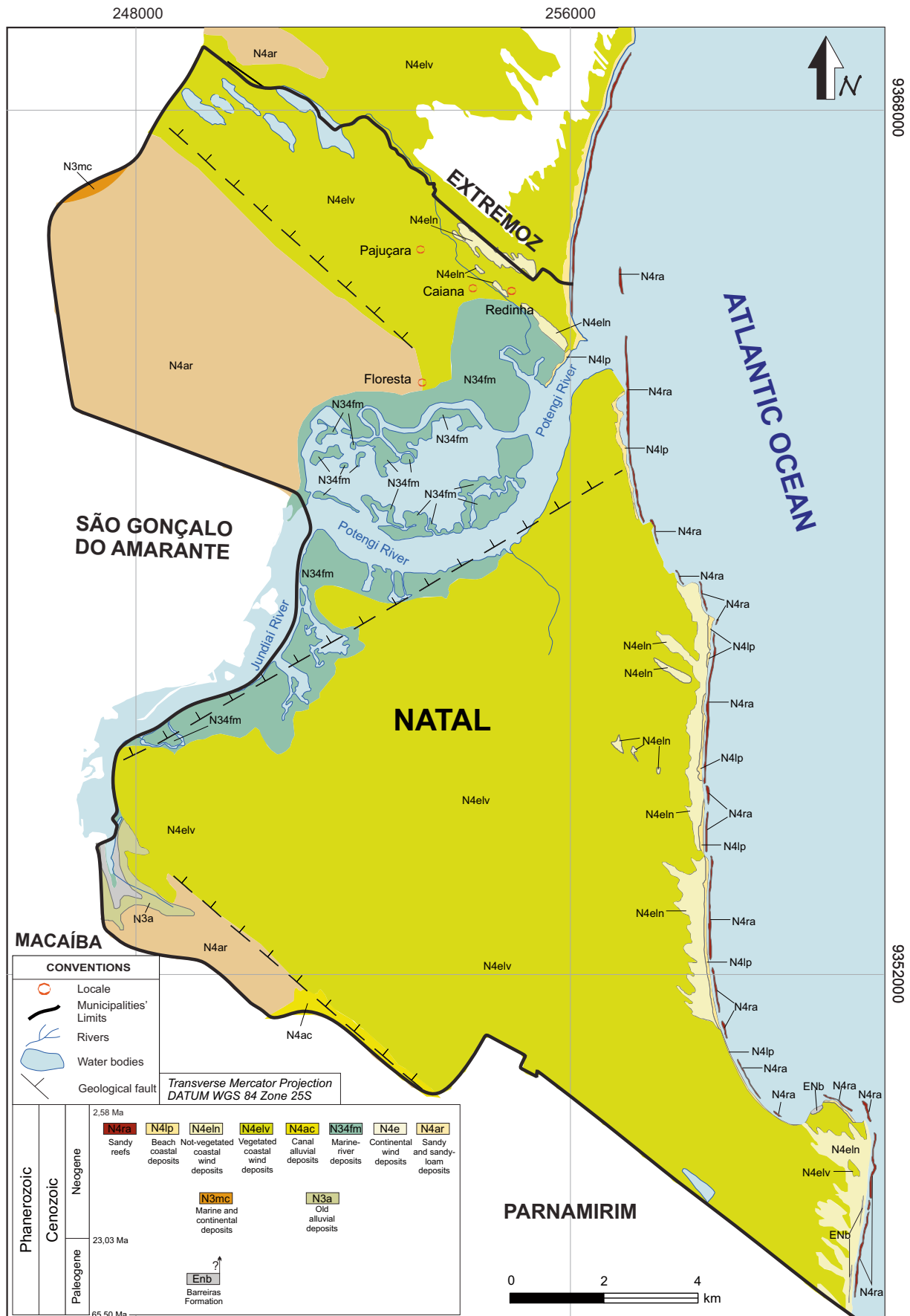
## Methods

### Selection of Sites

The development of the work was started with the selection of sites to be evaluated. It was made through the methodology indicated by Wimbledon et al. (1999), a method of systematic and comparative survey of the places to be worked. The selection was based on literature review activity from material published in books, articles, journals, as well as undergraduate studies, dissertations and thesis, as well as electronic websites. The database obtained provided geological and geomorphological informations, which made it possible to differentiate units, with the aid of remote sensing tools. Geological descriptions were made in all the chosen places, adding, when available, historical informations that show the evolution of geodiversity use in Natal City. These descriptions included mineralogy, petrography, geomorphology, sedimentology, and stratigraphy.

### Area Classification

The selected sites were classified according to their extension, following the methodology of Fuertes-Gutiérrez and Fernández-Martínez (2010), developed from the analysis of 125 places in the Leon region, Spain, where the authors



◀ Fig. 2 Geological map of the study area

observed that similarities could be determined in the topologies of in situ occurrences of geodiversity in that area. These similarities made it possible to create five categories: points, sections, areas, viewpoints, and complex areas. Associated with this definition, the authors determined degrees of assessment of site degradation. Thus, the degrees of fragility and vulnerability were evaluated. The degree of fragility measures the risk of degradation that the site has under the acting natural conditions. A place is fragile when a process of damage or total destruction occurs. Vulnerability measures the risk of destruction of a site’s characteristics due to anthropic action. Although this methodology was developed for an extensive area, for a classification of geosites, we believe that the area typology of occurrences can be an interesting way of observing how the geodiversity of an urban area behaves, through its different elements, which is why this classification was used in this work.

Adapting the methodology to the study area of this work, a new classification was elaborated with modifications to the work of Fuertes-Gutiérrez and Fernández-Martínez (2010). These modifications were necessary to adapt the authors’ classification to the urban reality since their work was carried out in an area larger than 15,000 km<sup>2</sup>. From this, the classification has been simplified for four classes: point, section, area, and viewpoint (Table 1).

The definition of the smallest geodiversity location (point) was made by measuring the area extension of the Manoel Felipe Lagoon, the smallest interdunar lagoon in the city, with 8000 m<sup>2</sup>. Thus, this threshold between points and areas was determined to be the measure immediately above the lagoon’s extent. The class of complex area was removed from the classification because, in the understanding of this work, this class would encompass, on its original definition, the whole area of study: the city of Natal.

### Ecosystem Services

For each identified site, the geodiversity valuation procedure was also performed, following the values of Gray (2013), which refers to abiotic ecosystem services. The author defines 5 services (cultural, regulating, provisioning, supporting, and knowledge) as well as 25 associated goods and processes (Fig. 3).

Cultural services relate the abiotic elements of nature to the surrounding communities through their presence in the landscape, often incorporated into the imaginary and local identity of peoples. They are also associated with the practice of leisure activities that are developed on the geodiversity environment, among others. Associated with these services are five goods and processes of abiotic nature (Gray 2013).

The regulating service is concerned with the responsibility and participation of geodiversity and its elements in maintaining the balance of natural processes and conditions throughout the earth. Four goods and processes are associated by Gray (2013) with this service are listed.

The provisioning service indicates the importance of geodiversity as a source of raw material for humans. It is possible to correlate this service with monetary values of abiotic elements. In all, Gray (2013) lists seven goods and processes associated with this type of ecosystem service.

The supporting service includes anthropic activities in which some abiotic element is used by humans as the basis for their development. In essence, the human being is very dependent on geodiversity as a foundation for various activities, but this service highlights, in particular, the relationship between agriculture and construction with nature. This service comprises four goods and processes (Gray 2013).

The knowledge service reflects the scientific importance of geodiversity, especially as an object of study for geosciences. Therefore, it reflects a scientific value of the abiotic elements

**Table 1** Classification of geodiversity typologies, based on Fuertes-Gutiérrez and Fernández-Martínez (2010)

Typology	Symbol	Definition	Fragility	Vulnerability
Point	●	where geodiversity resources are present in a polygonal under 8,000 m <sup>2</sup>	Low to High	High
Section	∥	where geodiversity structures and resources develop along parallel lines	Medium	Medium
Area	◊	where geodiversity resources are present in a polygonal with over 8,000 m <sup>2</sup>	Low	Low
Viewpoint	◡ ◊	observatory sites for an area where geodiversity is prominent in the landscape	Low	High (the panoramic view)

of nature. Five goods and processes are associated with this service (Gray 2013).

### Results

Geodiversity is represented by all components of abiotic nature, such as minerals, rocks, soils, rivers, relief, and the natural relations and processes involved by these resources. It is present, therefore, in all environments of the planet, occurring in various forms and extensions. In this work, seven main groups of geodiversity occurrence were identified in situ in the study area: beaches, dunes fields, natural parks, mangroves, rivers, interdunar lagoons, and Pedra do Rosário. Through the methodology of Fuertes-Gutiérrez and

Fernández-Martínez (2010), four geodiversity viewpoints were characterized.

### Geodiversity Occurrences

The geodiversity of Natal is essentially sedimentary, which directly reflects the local geology, dominated by sandy sediments, with an important eolian and fluvial influence. This first results section describes the groups of occurrence of abiotic diversity in the study area.

#### Beaches

Natal has a vast coastline, over 17 km long, comprising 7 beaches, from north to south: Redinha, Forte, Meio, Artistas,

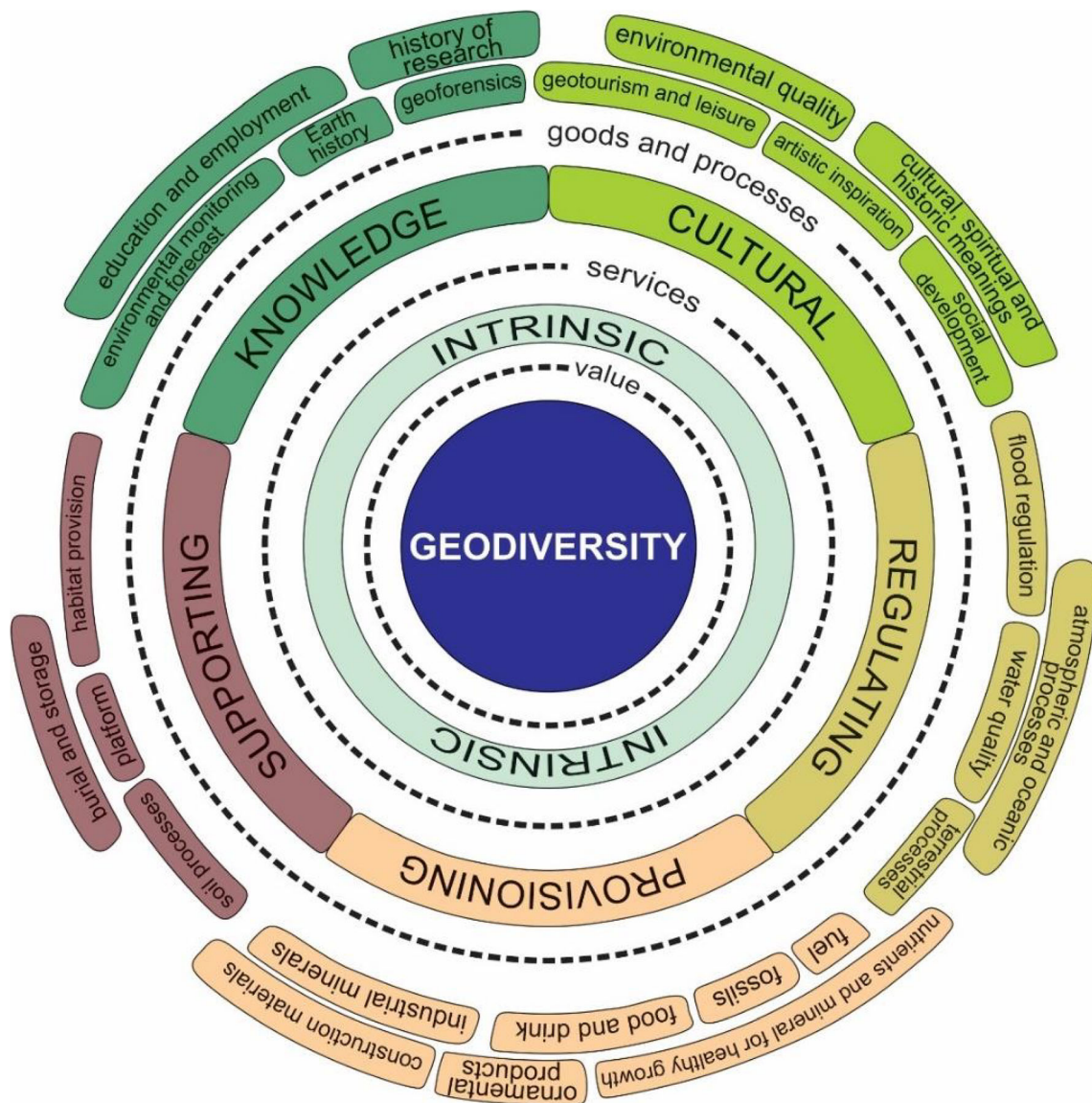


Fig. 3 Simplified diagram of geodiversity ecosystem services as elucidated by Gray (2013). Source: Silva (2016)

Areia Preta, Via Costeira, and Ponta Negra. The Via Costeira is still subdivided into some small beach lanes, which will be understood on this work as a single compartment, along with the Ponta Negra beach. Due to similarities in essentially morphological and geological elements, Natal beaches were grouped into 4 different units that will be described here: North Coast, which comprises Redinha beach, unique north of the mouth of the Potengi River; Central Coast, represented by the beaches of Forte, Meio and Artistas; Areia Preta; and South Coast, which goes from Via Costeira to Ponta Negra (Fig. 4).

The North Coast is geologically formed by vegetated and non-vegetated coastal wind deposits, beach coastal deposits, and sandstone that are found submerged in the shore face region, far from the beach face. During the sixteenth and seventeenth centuries, the region was occupied by an indigenous village of the Potiguara Tribe led by Filipe Camarão, hero in the expulsion of the Dutch from the then Portuguese land (Costa Jr 2005). Nowadays, the beach is very popular on weekends and holidays, when hundreds of people use the sand strip to play football and volleyball and take a bath in the sea.

The Central Coast is bordered to the north by the mouth of the Potengi River and to the south by Morcego’s cusp, where rocks related to the Barreiras Formation (ferruginous sandstones) occur and are remnants of cliffs in the region. Until the 1920s, the region was not used for leisure in Natal. With the increase in the flow of people, the area, especially Meio’s Beach, had avenues and had the first luxury hotel in the city, the Reis Magos’ Hotel, opened on September 7th, 1965 (Souza 2008).

Geomorphologically, this region is well characterized by sandy beaches, with some remnants of vegetated dunes, and it is also possible to identify frontal dunes in the region of Forte’s Beach. The main difference from this region of the Natal coast to the others, however, is the presence of beach sandstone bodies parallel and near to the coastline. At the beginning of the city’s history, the importance of the presence of sandstone reefs as a component of the landscape was already perceived. Maps depicting the time of the Dutch occupation, when Natal was renamed New Amsterdam, show and identify the prominent reefs in the Central Coast region. However, only at the beginning of the twentieth century the main scientific studies begin. Branner (1904) was the first to map the region, showing the existence of two parallel lines of sandstone reefs, called the “inner and outer reef”. This classification was reaffirmed 74 years later by Oliveira (1978).

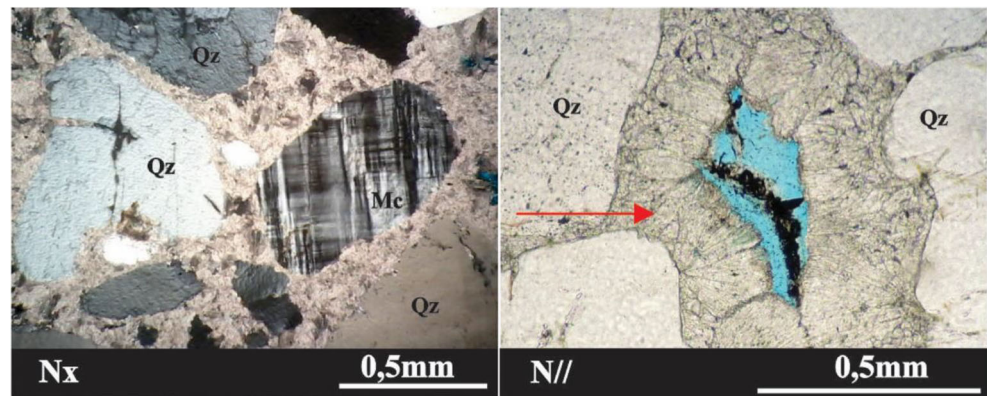
The two reef lines have similar genesis, and their origin is related to the percolation of calcium carbonate-saturated waters from the continent that, upon contact with the marine waters, precipitates CaCO<sub>3</sub> in the form of cement giving rise to rocks (sandstones and conglomerates). From the analysis, it can be stated that the rocks are composed essentially of monocrystalline quartz, plagioclase, and microcline. Accessory minerals are: bioclasts, apatite, tourmaline, epidote, muscovite, titanite, and biotite. Carbonate mosaic cementation and fiber-radial fringe can be observed (Fig. 5), while the predominant porosity type is primary intergranular.

Sandstone bodies in the Central Coast region are also responsible for shoreline morphology, as small reef openings



Fig. 4 Satellite images showing the beaches of the city of Natal: a North Coast; b Central Coast; c Areia Preta; d South Coast. Source: Google Earth

**Fig. 5** Photomicrographs on crossed and parallel nicols (NX and N//) of beach sandstone samples found on the Central Coast. Qz quartz, Mc microcline; red arrow indicates carbonate cementation in fiber-radial fringe



generate wave diffraction that, upon reaching the beach, shapes it into a concave shape.

Areia Preta beach is between Morcego's cusp and Mãe Luíza's cusp. Among the urban beaches of the city, this is the one with the smallest extent, but was the first to be used by the population for leisure in the early twentieth century. Over the years, the entire backshore region has been occupied by a dense urban network. The name of the beach already shows a strong relationship with geodiversity, as "Areia Preta" comes, according to Souza (2008), from the black rocks that exist there, referring, therefore, to the remains of ancient Barreiras Formation cliffs, whose rocks are sandstones cemented by iron oxide.

The South Coast corresponds to the beaches of Ponta Negra and Via Costeira, has a bay-like morphology, whose headlands are, to the north, Mãe Luíza's cusp, and to the south, Morro do Careca. The region consists of sandy beaches, with remnants of frontal dunes and vegetated dunes. Geologically, beach coastal deposits are found, composed of fine to very coarse quartz sands, with presence of bioclasts and heavy minerals. It is possible to observe low angle stratifications, typical of shorelines, and blocks of ferruginous sandstones related to the Barreiras Formation (Fig. 6).

Currently, this region of the coast of Natal is very popular throughout the year, also concentrating most of the tourist equipment of the city. Water sports such as surfing and stand up paddle are practiced, and there is, especially on the

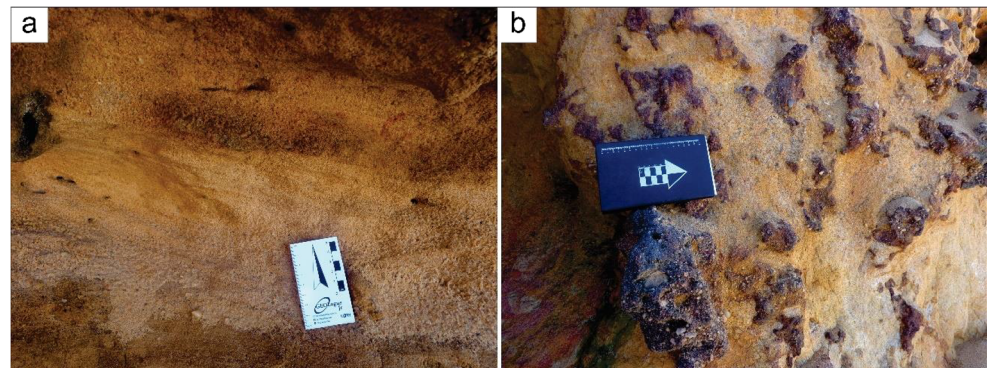
boardwalks of the beach, intense cultural, sports, and leisure programs. Since the development of beaches, their processes and elements occur through linear zones, they are classified as sections, according to the definition of Fuertes-Gutiérrez and Fernández-Martínez (2010).

### Dune Fields

The dunes are, along with the beaches, the main geomorphological features on Natal landscape. They are geologically classified by Fonseca et al. (2012), as vegetated and non-vegetated wind deposits. There is a predominance of parabolic dunes, in plant. Dune bodies of considerable length are present in the four administrative zones of the city, and the main remaining bodies are protected by Environmental Protection Zones (ZPA, in portuguese), as described in Lei Complementar 082/2007, municipal law governing zoning throughout the city, also known as the city's Master Plan.

The main variation in bodies occurs in the colors of sediments, ranging from reddish, in the case of the body of west dunes, to whitish in other places. This is due to the presence or absence of iron oxide, capping the quartz grains, and organic matter. In all regions, the dune sands are well selected quartz. Due to the extent of the dune fields, all are classified as areas, as defined by Fuertes-Gutiérrez and Fernández-Martínez (2010).

**Fig. 6** Low angle stratification (a) and blocks of ferruginous sandstone (b) correlated to the Barreiras Formation. Photos: Matheus Lisboa





## Natural Parks

The city of Natal has two natural parks regulated by state and municipal laws: Dunas' Park and Cidade's Park, respectively. Both have vast diversity of fauna and flora, for which they have great prominence. However, geodiversity in both conservation units is of fundamental importance, with different abiotic elements.

Formed by an extensive NW-SE direction dune field, Dunas' Park is geologically composed of well-selected quartz sands formed by vegetated and non-vegetated coastal wind deposits (Fig. 7a). The two types of wind deposits in the Dunas' Park region also define two generations, one older, fixed by vegetation, of yellowish to reddish quartz material, and one younger, formed by mobile dunes, in which there is the presence blowouts areas (Fig. 7b). Under the dune bodies are found bodies of ferruginous sandstones, in the form of inactive cliffs (Fig. 7c), correlated to the Barreiras Formation.

Dom Nivaldo Monte Cidade's Park was created to function as a space for the promotion and protection of the environment and local culture. It comprises the dune field of the Candelária,

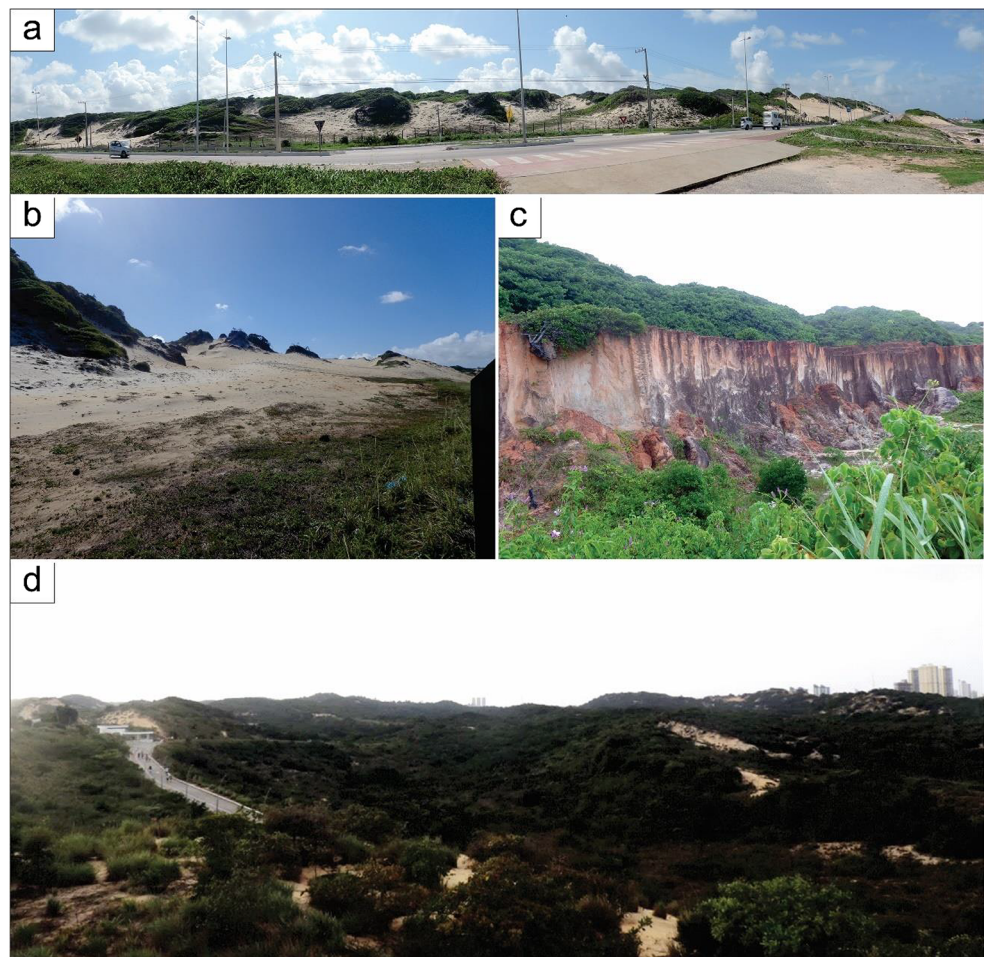
Cidade Nova and Pitumbu neighborhoods, within the limits of ZPA-01, regulated in 1995.

This is the main aquifer recharge area of Natal City, being essential for the supply of potable water in the city. The dunes of this region have main direction NW-SE, following the main orientation of the winds in the city. The dunes of this region are understood by Fonseca et al. (2012) as vegetated coastal wind deposits (Fig. 7d). They are essentially formed by well-selected quartz sands of whitish to yellowish color. Due to the extensions of the two Natal parks, both are classified by area, as defined by Fuertes-Gutiérrez and Fernández-Martínez (2010).

## Mangroves

Mangroves in the city of Natal are found on the Potengi River estuary, on its two shores. They constitute the Environmental Protection Zone 8, according to the current Master Plan (Lei Complementar 082/ 2007). They are geologically understood as fluvial-marine deposits, consisting of fine sands, silt, and clays, whose lamination is fine. Its composition is rich in carbonate and organic matter. Mangroves are sources of food,

**Fig. 7** Photographs of the natural parks of the city of Natal. **a** Frontal dunes in the Dunas' Park; **b** blowouts in the Dunas' Park; **c** paleo-cliff in the Dunas' Park; **d** vegetated dunes in the Cidade's Park. Photos: Matheus Lisboa



refuge, and reproduction of various species of crustaceans and fish. Over the years, many areas of mangrove swamps in Natal have been devastated to make way for shrimp farms and old salt flats. This type of geodiversity occurrence is classified as area by the definitions of Fuertes-Gutiérrez and Fernández-Martínez (2010).

### Rivers

Three main rivers run through the city of Natal (Doce, Pitimbu and Potengi) and are responsible for supplying surface water to the supply system as a complement to groundwater. They are classified as perennial, which is justified by a good and constant discharge throughout the year. They are components of the Barreiras Aquifer, principal of the coastal region of Rio Grande do Norte. Bezerra et al. (2001) show that there is an evident structural control over the courses of these three rivers, whose origins are related to sets of faults that formed structural valleys.

Alluvial terrains are common along rivers where medium to coarse quartz sands are present and pebbles and fine-grained portions may occur near the mouth. Due to the length of the rivers, they are classified as areas, as defined by Fuertes-Gutiérrez and Fernández-Martínez (2010).

### Interdunar Lagoons

In Natal, 10 sets of natural lagoons are known, 5 in the region north of the Potengi River and 5 in the south, many of which have been waterproofed by anthropogenic action over the years. Medeiros (2001) and Amaral et al. (2005) show that of the natural clusters, only 1 remained intact and 3 were completely destroyed. All were part of the city's natural drainage system that, with its partial or total suppression, began to require engineering works for rainwater runoff in Natal.

Currently, two sets of lagoons are included in Environmental Protection Zones 05 and 09 (Lei Complementar 082/ 2007), which protect the association of dunes and lagoons in the Ponta Negra neighborhood and along the Doce River valley, respectively. However, the city's best-known lagoon is Manoel Felipe, located in the Tirol neighborhood, where it was founded in 1962, Cidade da Criança, a green area around the lagoon, with various facilities and equipment for public use, such as paddle boats that can be used for pond rides. The classification by extent of occurrence, defined by Fuertes-Gutiérrez and Fernández-Martínez (2010), defines that partially or totally preserved Natal lagoons can be classified as areas.

### Pedra Do Rosário

The Pedra do Rosário has been a place of Catholic devotion since November 21st, 1753, when the image of Nossa

Senhora da Apresentação, patron saint of the city, was found on a wooden crate that read: "Where this image comes, no misfortune will happen".

The Pedra do Rosário is a block of ferruginous sandstone related to the Barreiras Formation, covered by bioclasts. This block is related to an old line of cliffs that goes around the Historic Center and proceeds to the Central Coastal zone. On the block of sandstone, a pillar was built on which was placed a replica of the patron saint. Still on the rock was erected a gazebo, from which it is possible to observe the landscape framed by the Potengi River and the mangroves (Fig. 8).

The classification of Fuertes-Gutiérrez and Fernández-Martínez (2010) defines two classifications for this location: as a point, due to the extent of its occurrence being restricted, and as a viewpoint, since from the observatory over the Pedra do Rosário, it is possible to look on the Potengi River and its estuary on the opposite bank.

### Geodiversity Viewpoint

Following the classification of Fuertes-Gutiérrez and Fernández-Martínez (2010), used in this work, it is possible to identify places in the city of Natal where geodiversity has wide prominence in local landscapes. These observatories, or geodiversity panoramas, are identified as viewpoints and there are four in the city, from which can be observed, separately or together harmoniously, the different resources that make up Natal's in situ geodiversity: Dunas' Park Observatory, Cidade's Park Observatory, Historic Center Observatory, and Onofre Lopes Observatory.

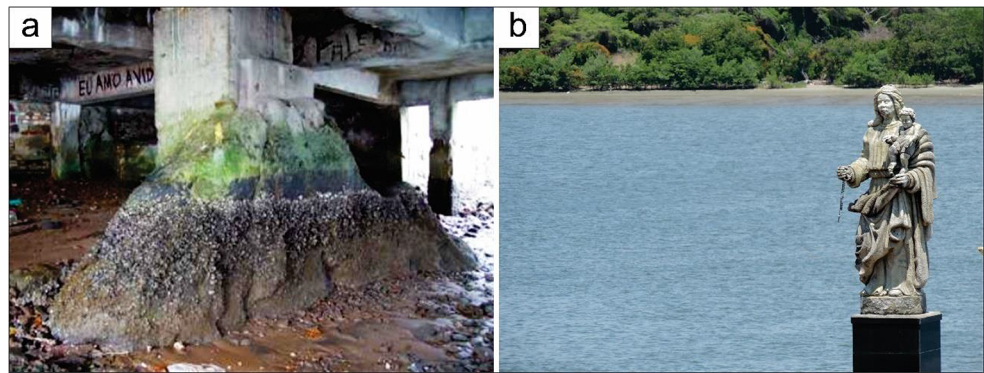
The Dunas' Park Observatory is located at the end of the trails made through the vegetation that covers the wind sediments in the Dunas' Park. This observatory allows to look on the southern beach zone, as well as the dune bodies of the park itself. The Cidade's Park Observatory is located at the top of the Natal's Memorial tower in the Cidade's Park, where it can viewed the entire dune body of the park, as well as part of the west dune body and the Dunas' Park.

Located in front of the Rosário dos Pretos Church in Natal's Historic Center, the Historic Center Observatory offers views of the Potengi River and the mangrove swamp in its estuary.

Located in front of the hospital of the same name, the Onofre Lopes Observatory (Fig. 9) allows the view of the entire Central Coast and part of the North Coast, as well as the mouth of the Potengi River. It is also possible to observe the north dunes field and also the Genipabu dunes, in the municipality of Extremoz.

From the descriptions and classification of the typology of occurrences of in situ geodiversity in Natal City, an informative map of the location of these sites was constructed (Fig. 10).

**Fig. 8** “Pedra do Rosário” is a block of ferruginous sandstone (a), on which was erected a monument in honor of Nossa Senhora da Apresentação (b), patronesse of Natal. Photos: Carvalho (2010) and Matheus Lisboa



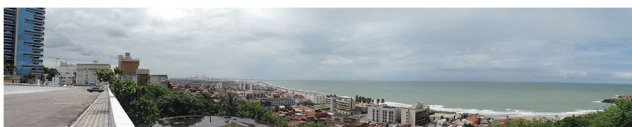
## Ecosystem Services

Ecosystem services have been presented as a way to analyze and identify the importance of elements of nature for ecosystems and for humans. It is a way of understanding the environment and demonstrating scientifically and socially the need to protect natural diversity, whether for maintaining environmental balance or for anthropic well-being. From this understanding, the services provided by the abiotic nature of the study area were identified, according to Gray’s methodology (2013), and the main results are presented below.

### Cultural Service

This type of service is identified in all elements of the study area, which demonstrates the relationship of the community with the natural environment. Beaches, rivers, lagoons, and natural parks are ideal environments for *leisure activities* (such as soccer, volleyball, rowing, hiking, swimming), which denotes a fundamental importance for the quality of the population life. These environments, together with the dune fields also allow the contemplation of the landscape, adding an *environmental quality* to the elements of geodiversity, which also serves as *artistic inspiration* for the production of works of various expressions of the arts, such as music, poetry, and painting, among others.

Two places where the *cultural meaning* of geodiversity is well expressed are the Pedra do Rosário and the mangroves. In the first, it is related to the fact that the image of the patron saint of the city was found there on November 21st, 1753. The devotion to Nossa Senhora da Apresentação, related to the sandstone block that is in the place, takes thousands of people every year to celebrate the Christian festival. On the other



**Fig. 9** Panoramic view on the Onofre Lopes Observatory, from which it is possible to observe the entire Central Coast of the city. Photo: Matheus Lisboa

hand, in the mangroves, in a cultural and sustainable way, the “Os Cão” Block, since 1964, has promoted a carnival parade in which everyone uses the mangrove mud on their body as fantasy. The mud, an abiotic resource of nature, has a cultural expression in carnival times (Fig. 11a).

Geodiversity also generates *social development* with community participation in sustainability and environmental protection actions, such as the “Amigo da Praia” project, on the North Coast, and by garbage collection in the city’s rivers.

### Regulating Service

The dunes present in the dune fields and in Natal’s natural parks are fundamental for the city’s water supply as they act as filters that feed the local aquifer; thus, they are important for the *water quality* that everyone uses. The dunes, along with the rivers, also participate in the hydrological cycle and are therefore an integral part of *atmospheric and oceanic processes* within the regulation service classification (Fig. 11b).

The reefs found on the city’s coastline are also fundamental for *flood regulation* of the margins, mitigating the invasion of marine waters; similarly, the interdunar lagoons serve as the final site of natural or artificial runoff, which will be infiltrated through the soil, avoiding flooding in some regions of Natal.

*Terrestrial processes* are another type of regulation service that can be identified in the geodiversity of the city, mainly because they are responsible for modeling beach features through sea currents.

### Provisioning Service

This service is identified by the availability of potable water, mainly by the participation of dunes (natural parks and dune fields), lagoons, and rivers in the process of supply and storage of this *drink*, which characterizes a geodiversity good. The reefs found on the city’s coastline are currently no longer explored, but were, until the early twentieth century, sources of *construction material* for various city buildings and streets (Fig. 11c), which used blocks of calcareous and ferruginous sandstones (Nascimento et al. 2018).

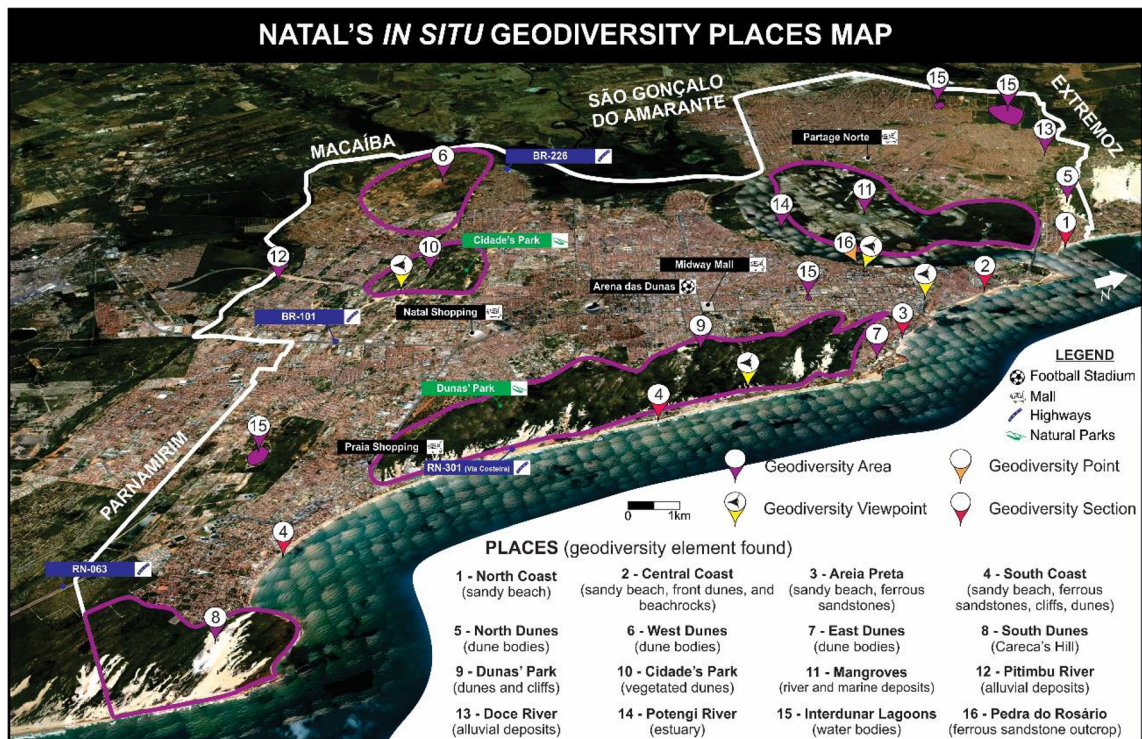


Fig. 10 Natal's in situ geodiversity map

### Supporting Service

In the Central Coastal region, the reefs served as a solid *platform* for the construction of Forte dos Reis Magos, the city's main historical building (Fig. 11d). Likewise, Rosário's

and Cidade's Park have also added this type of support service as they were the foundation to erect the monument and a memorial, respectively.

This type of geodiversity service can still be identified by its function as *habitat* for several species, such as bivalves and

Fig. 11 a Carnival reveler using the mangrove silt/clay sediments to cover herself in the "Os Cão" block, a type of cultural service; b Doce River, part of the city's water system, an example of a regulating service; c blocks of ferruginous sandstones were used in the construction of the Redinha Church, a provisioning service; d Forte dos Reis Magos was built on the reefs in the Central Coastal region of the city, which exemplifies the supporting service. Photos: a Aléx Regis; b, c, d Matheus Lisboa



crustaceans, among other invertebrates, in the beach reefs, and fish and crustaceans in the city's rivers and mangroves.

### Knowledge Service

It is linked to the scientific and educational content of geodiversity and is identified in the beaches, dune fields, natural parks, and rivers of the study area. This service is justified by works such as those by Barreto et al. (2004) and Cunha (2004), in addition to activities that develop research, teaching, and extension work on the beaches of Natal, aimed at promoting *education and employment* regarding the use of available abiotic resources on the beaches, and beaches *environmental monitoring* as the “Água Azul” Program does through beaching studies on the urban beaches of Natal and other municipalities in the state. In the case of the Central Coast,  $^{14}\text{C}$  dating made by Oliveira et al. (1990) and Barreto et al. (2004) in shells in the region's sandstones collaborated with the Holocene mapping in Rio Grande do Norte, which characterizes a writing process of the *Earth history*.

There are several studies with geological-geomorphological focus on the natural parks of the city, such as Jesus (2002), Fracasso (2005), and Freitas and Saraiva Jr (2013), who worked in Dunas' Park, and Silva Jr (2015), which shows the geomorphological features of Cidade's Park as an important highlight. There is also a substantial amount of scientific work that deals with the Doce, Pitimbu, and Potengi rivers, which collaborate in the formation of professionals who may come to work in the area. All rivers are fundamental in several studies of local hydrogeological dynamics, such as Kobayashi et al. (2010), Rocha (2012), Buruaem et al. (2013), Lucena et al. (2013), and Moreira et al. (2016).

Table 2 shows a summary of geodiversity services and classifications in the study area of this paper.

### Discussion

The results obtained in this work demonstrate the abiotic diversity of the city of Natal, and most places were classified according to the area typology, which may represent a strong presence of natural elements in the urban landscape of the study area, mainly through their bodies dunes, admittedly one of the main abiotic elements of the region, along with the beaches. Despite not being the focus of this work, a good state of conservation of the evaluated places is observed, which is corroborated by specific laws, of municipal scope, that govern the zoning of the city and define environmental protection areas.

In relation to the ecosystem services identified in the evaluated sites, it was observed that coastal areas and rivers are the only ones that present all five services of abiotic nature according to the applied methodology. Beaches are fundamental

to the ecosystem, besides representing the coast line, where the relationship between continent and ocean is more intense, and are also necessary places for the life of some species of invertebrates, as well as being the main places of leisure for the human being. Especially in countries such as Brazil, which have a large coastal area. Rivers also occupy an important place in local ecosystems, being fundamental in the water supply system of the region, in addition to representing features that stand out in the Natal landscape, mainly by the Potengi River, which at the time of Portuguese colonization was responsible for naming the then captaincy of Rio Grande (Big River), today the state of Rio Grande do Norte.

The Central Coast region has the highest amount of goods and benefits, 11 in total, which denotes a higher qualitative value of this place compared with the others evaluated. Next, in disbelieving order of the number of identified services are North Coast, Areia Preta, South Coast, Potengi River, Cidade's Park, Dunas' Park, Dunes Fields, Pitimbu River, Doce River, Interdunar Lagoons, Mangroves, and Pedra do Rosário.

The city of Natal presents, as demonstrated in this work, a vast geodiversity, with sedimentary characteristic, present in striking coastal landscapes along the geomorphological lines of the study area. The importance of these abiotic elements for the local ecosystem as well as for the local population is explained by the ecosystem services identified, which justify the need for environmental awareness of communities in the area and environmental preservation, in order to postpone their permanence in the environment for future generations.

### Conclusions

Natal is one of the oldest cities in Brazil, and its inaugural landmark was the construction of Reis Magos' Fort in 1599. Throughout more than four centuries of history, the city initially experienced a slow development, which was boosted from the twentieth century.

The foundation of the city was linked to its geographical position and natural conditions of the region, which allowed a greater defense of Brazilian lands by the Portuguese Kingdom. These conditions are associated with the local abiotic nature, which was typified in this work in geodiversity areas, sections, points, and viewpoints.

Of the 25 goods and processes associated with geodiversity ecosystem services, in Gray (2013) methodology, 16 were identified in the elements of abiotic nature in the city of Natal. Most types of unobserved services are related to provisioning service, which has an associated monetary value. This is due to the lack of regular and legal mineral exploitation within the municipal limits of the city, occurring, however, in the Metropolitan Region where there is extraction of

**Table 2** Summary table of ecosystem services and typology classification of Natal’s in situ geodiversity

Typology (1)	Section	Section	Section	Section	Section	Section	Area	Area	Area	Area	Area	Area	Area	Point and viewpoint
	North Coast	Central Coast	Area Preta	South Coast	Dunes Fields	Dunas’ Park	Cidade’s Park	Mangroves	Pitumbu River	Doce River	Potengi River	Interdunar Lagoons	Pedra do Rosário	
<b>Place</b>														
<b>Services (2)</b>														
Cultural	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leisure activities	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Environmental quality	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Artistic inspiration	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cultural meaning								x						x
Social development	x													
Regulating	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Water quality					x	x	x							
Atmospheric and Oceanic Processes					x	x	x							
Flood regulation	x													x
Terrestrial processes	x	x	x	x										
Provisioning	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Drink					x	x	x							
Construction materials	x	x	x	x	x	x	x							
Supporting	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Platform					x	x	x							
Habitat	x	x	x	x				x						x
Knowledge	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Education and Employment	x	x	x	x	x	x	x							
Environmental monitoring	x	x	x	x	x	x	x							
Earth history														x

1—Fuentes-Gutiérrez and Fernández-Martínez (2010); 2—Gray (2013)

mineral water, sands, clays, and granite, the latter occurring only in the municipality of Macaíba.

Thus, it is observed that the geodiversity of Natal is diverse and can be found in all regions of the city. Due to its extension and variety, it can be used for science, culture, sports, and tourism, in order to promote, jointly, the dissemination of the natural and cultural beauties of the city and geosciences, helping the geoconservation process.

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