sociedade & natureza

DOI: 10.14393/SN-v32-2020-48038
Received: 11 April 2019 | Accepted: 23 July 2020

Analysis of the landscape and land use changes in the Brazilian northeast, semiarid coast

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Keywords:
Geotechnology
Geoenvironmental Systems
Mapping

Abstract
The Brazilian northeast coast has tourism potential, and in the last decades its landscapes have been impacted by the expansion of tourism activity. The present research aimed to survey the change s that occurred in the evolution of soil cover in the municipality of Cajueiro da Praia, Piauí, in 2000 and 2015, using Remote Sensing and Geoprocessing techniques. The supervised classification of images LANDSAT 8 and LANDSAT 5, OLI/TIRS and TM imager instruments, respectively, in 2015 and 2000, using the *Maxver* method, processed in the *Arcgis* 10.2 software, made possible the production of the maps of use and coverage and the dynamics of land cover. The analysis identified nine classes of land use and land cover, which showed changes observed from the dynamics between the two dates. The analysis of these data, together with socioeconomic data from the census and surveys carried out by the Brazilian Institute of Geography and Statistics, showed a context of land use and land cover changes, with growth of urban areas, the increase of water bodies of the municipality. The change in the quantitative population of the municipality occurs perceptibly in its coastal area, the increase of water bodies is especially due to the growth of shrimp tanks. The issues of environmental legislation are factors that may explain the recovery of some vegetation areas, as their non-compliance explains the loss of others, such as mangrove vegetation, which was observed throughout the work.

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INTRODUCTION

The coastal area is very dynamic and important for the economic, ecological and social sectors. It is frequently the target of several public policies and academic studies that seek the best management practices.

The occupation of coastal regions has been occurring constantly, since the beginning of humanity because they are attractive environments, considering their geodiversity and biodiversity. The diversity of the natural landscape, represented by the beaches, dunes, restingas and mangroves, explains the growing population demand in these areas.

In this context, the study aimed to analyze the changes in land use and land cover over time, with the help of the GIS tool, to provide subsidies for environmental planning and management in the municipality of Cajueiro da Praia, Piauí - Brazil.

The municipality of Cajueiro da Praia is located on the coast of the State of Piauí. It has attracted the attention of tourists interested in its peaceful beaches, in addition to the receptivity of the local community in a bucolic environment. It is also the first Brazilian municipality to receive the title of natural heritage of the marine manatee.

The human activities promoting destabilization of natural landscapes must be monitored periodically (VENTURIERI *et al.*, 2005). The Federal law Nº 12.651/2012 – Brazilian Forest Code in force (BRASIL, 2012a) regulates the protection of vegetation areas, such as mangroves, restingas and interconnected areas, such as salgados and apicuns, can permit loopholes for an inappropriate or disordered use, which may cause damage to the environment. Because it considers mangroves and restingas as permanent preservation areas, the others as "ecologically sustainable use" (BRAZIL, 2012b; ALBUQUERQUE *et al*, 2015).

When making and analyzing the land use and land cover map, it is possible to evaluate temporally and spatially the changes occurring in a given location and period. The interpretation of satellite images allows for the identification of elements by color, depth, size, shape, texture, location, association and arrangement patterns. (ROSA, 2003; JENSEN, 2009).

STUDY AREA

The study area is the municipality of Cajueiro da Praia, Piauí - Brazil (Figure 1), and has approximately 7,163 inhabitants, according to the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese) (2010), the federal agency responsible for the official collection of statistical, geographic, cartographic, geodetic and environmental information in Brazil. This municipality was founded by the dismemberment of 281.75 km^2 of the city of Luís Correia, in 1995, located on the coast of Piaui, in an Environmental Preservation Area. It is located in the extreme north of the state, 402 km from its capital, Teresina, with Barra Grande beach as one of its main tourist points. It is limited to the north with the Atlantic Ocean, to the south and west with the city of Luís Correia and to the east with the State of Ceará (IBGE, 2010).

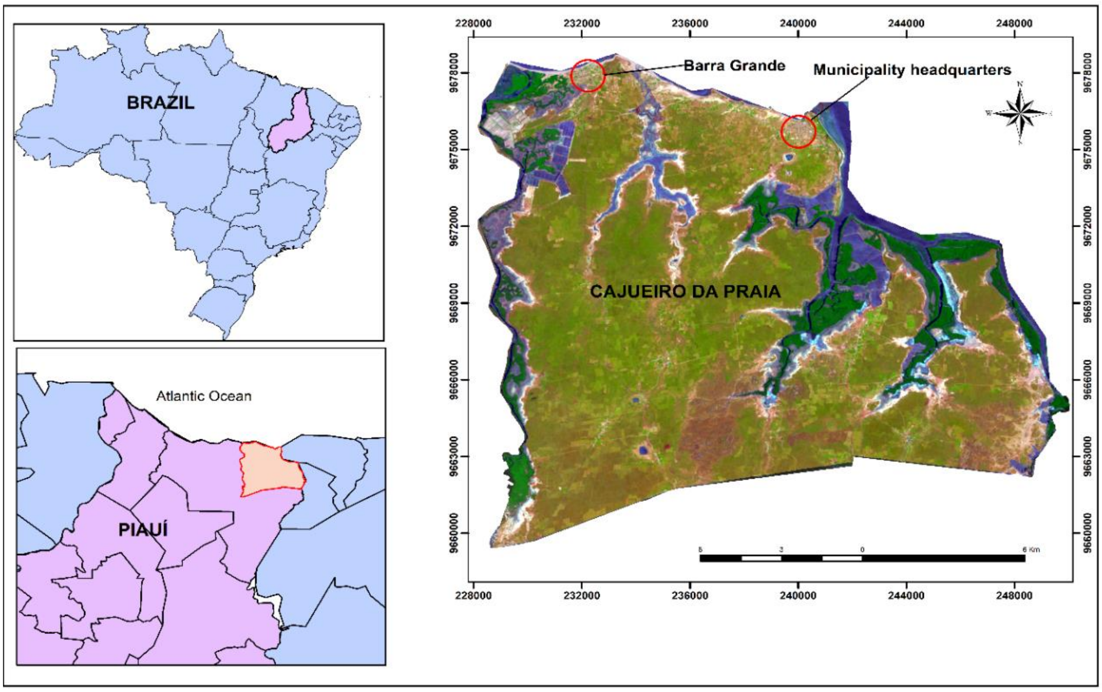
The municipality of Cajueiro da Praia, being located in the coastal region of the state of Piauí, is characterized by the occurrence of tertiary sediments from the Barreiras Group, and sediments from the Quaternary period, represented by dunes and alluviums. In the South, rocks from the Precambrian emerge (CPRM, 2006) (in Portuguese: Companhia de Pesquisa de Recursos Minerais).

MATERIALS AND METHODS

Mapping and dynamics of land use and land cover

The study consisted of two stages, the first related to the preparation of land use and land cover maps corresponding to two periods, one in 2000, and another 15 years later, in 2015. The second stage concerns the numerical and spatial crossing of resulting maps and the analysis of land use and land cover dynamics, based on the accuracy of the maps.

Figure 1 - Location of the municipality of Cajueiro da Praia, Piauí – Brazil.



Source: Imagem Landsat 8. Org .: by the Authors, 2019.

The proposed mapping of land use and cover of the municipality was performed using orbital images as basis. The classification of these images was performed in supervised mode, through the automated method of maximum likelihood estimation (the Maxver method), which is a general method FOR estimating parameters, especially in cases of normal distribution (JENSEN, 2009). Visual interpretation was also used to identify the classes.

LANDSAT 8 images, OLI sensor, and LANDSAT 5, TM sensor were used for mapping land use and land cover of the 2000 and 2015 years. The criteria for choosing the scenes were low cloud cover and capture during the dry season, facilitating the identification of the different soil covers.

Thus, to analyze the multitemporal evolution of land use in the municipality of Cajueiro da Praia-PI, it was used an orbital image of the LANDSAT 5 sensor TM series (orbit/point 219/62) from October 15, 2000 and another image of the LANDSAT series 8 OLI/TIRS sensors (orbit/point 219/62) was selected dated from October 9, 2015. It was also used to aid the construction of maps, 2014 *RapidEye* orbital images from July and August and July and September of 2012 obtained from the Ministry of the Environment (in Portuguese: MMA - Ministério do Meio Ambiente).

The satellite images used have a spatial resolution of 30 meters, in the case of the LANDSAT series, and 5 meters in the case of *RapidEye*. The study area was covered for accuracy, verification of the different uses and land coverings were compared to those identified on the map. For the analysis of land use and coverage changes, the maps of the two different dates (2000 and 2015) were overlaid.

In the *Arcgis* 10.2 software, a tool was used to allow supervised image classification for the construction of the usage and coverage map. This classification is based on the use of algorithms to determine the pixels that represent reflection values for a given class (CÂMARA *et al.*, 1996).

Accuracy of land use and land cover map

To reduce the error associated with the statistical data, the index *kappa* (κ) was used, which is derived from the error matrix, a data that measures the degree of agreement of the elements, thus generating an aspect of reliability and precision of classified data. The kappa index is calculated according to Equation 1 (PERROCA; GAIDZINSKI, 2003):

$$\kappa = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} x_{+1})}{N^2 - \sum_{i=1}^{r} (x_i + x + x_i)}.$$

Where, κ indicates the concordance index, N is the number of observations (sample points); r is the number of lines in the error matrix; x_{ii} are the observations in the row i and column i; x_{i+} is the marginal total of the line i; x_{+1} is the marginal total of the column i.

For the analysis of κ, it is important to know that it varies in the range from 0 to 1 that is, the closer to 1, the better will be the quality of classified data. Fonseca (2000) suggests a classification for κ values (Table 1).

Table 1. Index-performance ratio κ

Index κ	Performance
< 0	Very Bad
$0 < \kappa \leq 0.2$	Bad
$0.2 < \kappa \leq 0.4$	Moderate
$0.4 < \kappa \leq 0.6$	Good
$0.6 < \kappa \leq 0.8$	Very Good
$0.8 < \kappa \leq 1.0$	Excellent

Source: Fonseca (2000).

RESULTS AND DISCUSSION

The classification made in the municipality of Cajueiro da Praia allowed the definition of nine classes of land use and land cover: urban area, continental water bodies, sandy cord/sandbank, wetland area, exposed soil, vegetation I (mangrove), vegetation II (restinga), vegetation III (caatinga) and vegetation IV (carrasco) (Chart 1).

In the analysis and production of the map, no crops were identified given the 30-meter resolution of the LANDSAT images and the size of the cultivated areas. This type of use is associated with caatinga vegetation, carrasco and exposed soil.

The soil class considered the exposed soil present on the roads, as well as regions close to water bodies and urban areas. The wetland class, on the other hand, occurs at various points on the map, mainly due to the existence of a considerable amount of water bodies in the municipality.

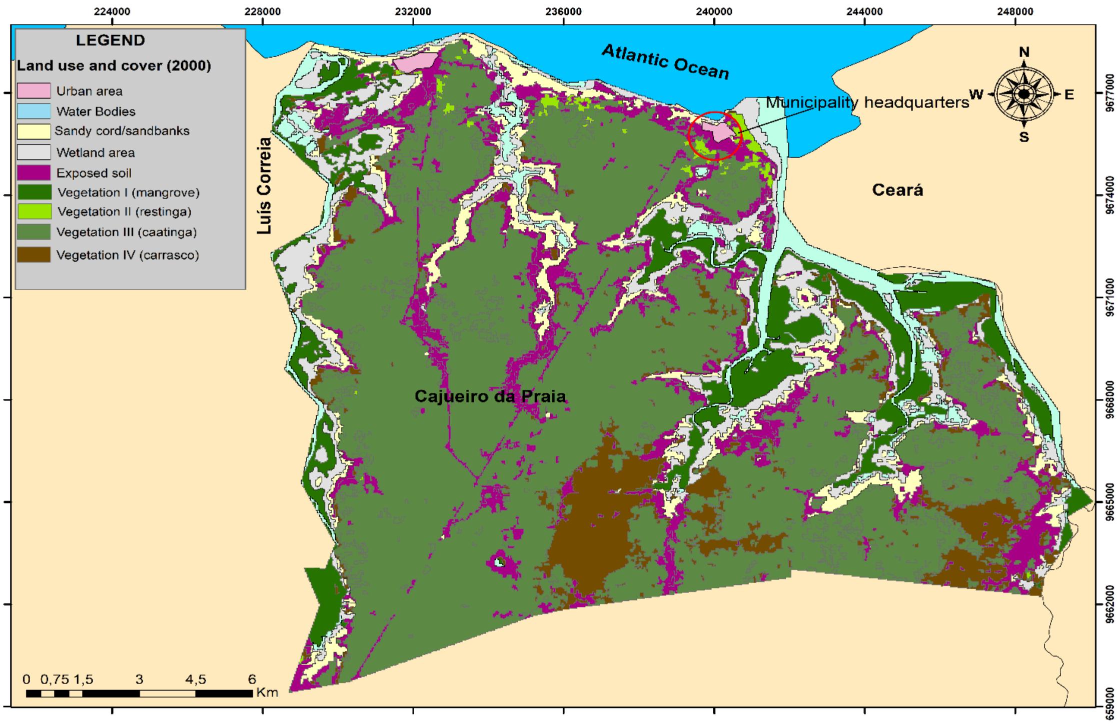
Chart 1 - Relationship between classes and description used in the land use and cover map in the municipality of Cajueiro da Praia, Piauí - Brazil .

CLASSES OF LAND USE AND COVER	DESCRIPTION
Urban area	Man-modified spaces for various uses, especially construction work.
Water Bodies	It comprises the main water courses in the region, such as the Arraia River, Camurupim, Carmelo, Carpina, Ubatuba, as well as several lakes and ponds.
Sandy cord/sandbanks	It comprises an elongated strip of sand close to the beach line. In this case, it also corresponds to sandbanks located in areas of wetlands.
Wetland area	It comprises seasonally flooded areas, some used in shrimp farming.
Exposed soil	It corresponds to the areas where all the vegetation cover of the soil has been removed, mainly for anthropic use.
Vegetation I (mangrove)	Transition vegetation between terrestrial and marine environments, composed of species that are typical of these places.
Vegetation II (restinga)	Common vegetation in coastal areas, located especially in sandy and saline terrain, close to the sea. It can vary between herbaceous, shrub and tree.
Vegetation III (caatinga)	Typical vegetation formation in regions with low rainfall, strong shrubs with twisted branches and deep roots
Vegetation IV (carrasco)	Vegetable formation that includes shrubby caatingas of stony soils, scrub (secondary vegetation) and areas of open vegetation with small shrubs

Org.: by the Authors, 2019.

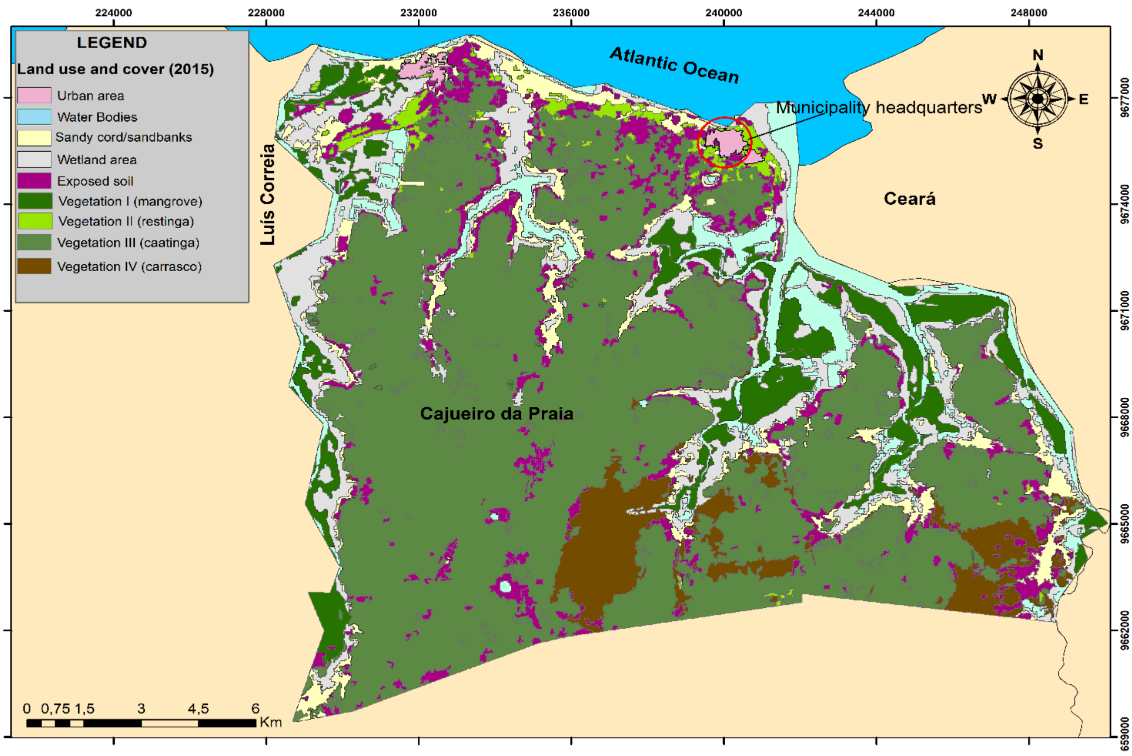
These classes provided the identification of the dynamics of land cover, in the proposed period, 2000 and 2015, favoring the segregation of vegetation and other types of land cover. The multi-temporal classification of soil cover was confirmed as an important environmental monitoring tool, allowing the spatialization of the identified classes in different years, as shown in figures 2 and 3.

Figure 2 - Land use and cover of Cajueiro da Praia, Piauí - Brazil (2000).



Org.: by the Authors, 2019.

Figure 3 - Land use and cover of Cajueiro da Praia, Piauí - Brazil (2015).



Org.: by the Authors, 2019.

Table 2 shows the areas of the 2000 and 2015 classes in km² used in the preparation of the dynamics of use and cover, as well as their respective symbols.

Table 2 - Classes of land use and cover maps

Classes	Symbology	2000 km²	2015 km²
Urban area		0.736027	1.362982
Water Bodies		12.4133	16.72976
Sandy cord/sandbanks		15.07397	14.71903
Wetland area		21.78071	29.41596
Exposed soil		30.27502	20.76829
Vegetation I (mangrove)		21.77709	19.86575
Vegetation II (restinga)		1.707221	4.124797
Vegetation III (caatinga)		148.2258	150.0326
Vegetation IV (carrasco)		20.21495	15.18491
Total ≅		**272.20**	

Org.: by the Authors, 2019.

Accuracy of land use and land cover map

The confusion matrix makes a correlation between rows and columns, where the columns represent the field truth while the lines participate as predicted classes. It is noted that both in the classification of the year 2000 and in the year of 2015 they obtained a satisfactory index κ, qualitatively classified as "excellent", according to Table 1. The κ value was higher for the 2015 map, indicating better accuracy (Tables 3 and 4). All classes of land use and coverage had a high level of accuracy in the classification, indicating the Maxver method as efficient in the supervised classification.

Table 3. Classification confusion matrix (LANDSAT 2000 image)

Index κ (year 2000) = 0.82

CLASSES	Veg. man.	W. bodies	S. Cord	W. area	E. soil	Veg. rest.	Veg. caat.	Veg. car.	Grand Total
Veg. man.	6								6
W. bodies		3							3
S. cord			4						4
W. area				3		1			4
E. soil	1				6		1		8
Veg. rest.						3			3
Veg. caat.					1		7		8
Veg. car.		1		1				1	3
Grand Total	7	4	4	4	7	4	8	1	**39**

Org.: by the Authors, 2019. **Abbreviations:** Veg. man.: mangrove vegetation; W. bodies: water bodies; S. cord: sandy cord; W. area: wetland area; E. soil: exposed soil; Veg. caat.: caatinga vegetation; Veg. car.: carrasco vegetation.

Table 4 - Classification confusion matrix (LANDSAT 2015 image)

Index κ (year 2015) = 0.91									
CLASSES	**W. bodies**	**Veg. man.**	**S. Cord**	**W. area**	**E. soil**	**Veg. rest.**	**Veg. caat.**	**Veg. car.**	**Grand Total**
W. bodies	8								8
Veg. man.		7							7
S. Cord			4						4
W. area	1			4					5
E. soil					3				3
V. rest.						5			5
Veg. caat.							3	1	4
Veg. car.							1	2	3
Grand Total	9	7	4	4	3	5	4	3	**39**

Org.: by the Authors, 2019. **Abbreviations:** W. bodies: water bodies; Veg. man.: mangrove vegetation; S. cord: sandy cord; W. area: wetland area; E. soil: exposed soil; Veg. caat.: caatinga vegetation; Veg. car.: carrasco vegetation.

The confusion matrix allowed assessing the level of accuracy within each class, making an association between the field truth and the classification obtained by the method used.

Analysis of the 2000 land use and land cover map

From the 2000 matrix and map it was verified total accuracy for the classes mangrove vegetation, water bodies, sandy cord and restinga vegetation.

Among the points that obtained confusion, the carrasco vegetation stands out, which is a differentiated region from the surrounding vegetation, especially due to the geology and geomorphology of that area. The confusion occurred with the water and wetland area, probably due to the type of reflection that occurred between these classes in the production of the image.

When analyzing the 2000 land use and land cover map, the dominant caatinga vegetation occupies the largest area of the municipality. In the fieldwork, it was observed that caatinga occurs in different densities, with closed trees and open shrubby vegetation.

Carrasco vegetation gains prominence in the middle of a large caatinga. This term has been used to designate different types of vegetation in northeastern Brazil and outside of it, covering shrubby caatingas of stony soils, capoeiras (secondary vegetation) and areas of open vegetation with small shrubs (ANDRADE-LIMA, 1978). There is no consensus about carrasco, whether it is an ecotonal vegetation between the caatinga and the cerrado (savannah), some type resulting from the degradation of the cerradão (savanna woodland), or a fossil vegetation, representative of past environmental conditions (ARAÚJO *et al.*, 1999).

Another relevant point in this map is the exposed soil. It gains prominence beyond the regions close to urban areas, also in the extension of the highway, which is evidenced in the map of the year 2000 by a diagonal line that cuts the municipality from south to north towards coastal area. This class is also observed in the vicinity of water bodies, probably due to washing and erosion that occurs in the periods of flooding and subsequent drought.

Analysis of the 2015 land use and land cover map

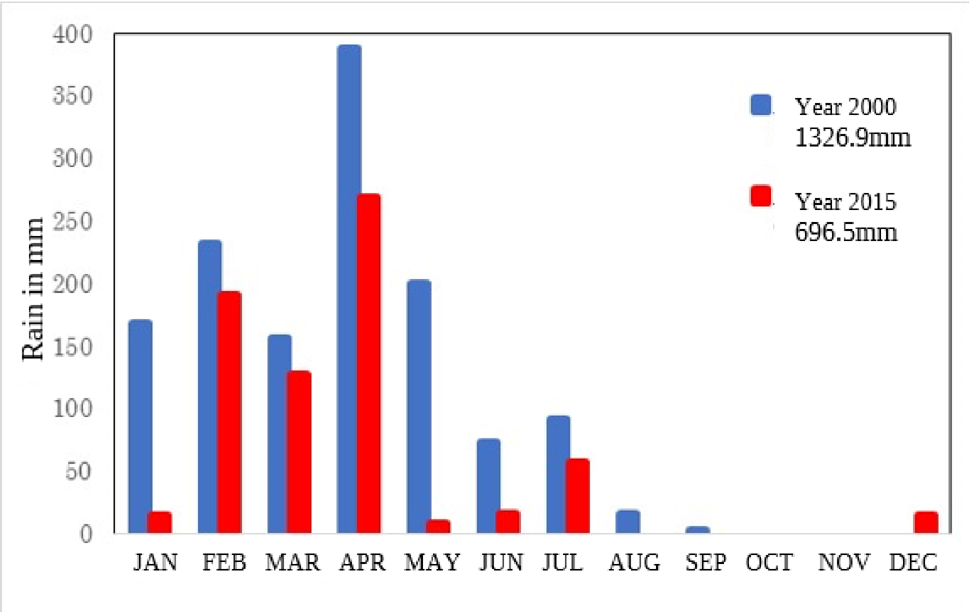
The mangrove vegetation is extensive in the study area (19.87 km^2), it occurs in the region bathed by the rivers Camurupim, Carpina, Carmelo, Ubatuba and Arraia. It is an area that deserves attention, as it has potential to the implementation of shrimp farming. The land use and cover change showed a decrease in the mangrove vegetation area that have been replaced by artificial water bodies, usually rectangular, which are shrimp farms.

For 2015, the error matrix showed that wetland, restinga and carrasco vegetation had a small confusion in the classification when compared to classes identified in the field study. All other classes had 100% correct answers, this is mainly due to the better quality of the image generated by the LANDSAT 8 satellite.

In 2015, it was observed that the exposed soil was spatially more dispersed, except for a concentration in the coastal region, probably due to the growth of tourism near the beaches.

The water bodies expanded 35% in 2015, as a result of the expansion of shrimp farming and natural accumulation of tidal waters. In 2015, it rained proportionally only 52% of what it rained in 2000 (Figure 4), at the nearest weather station, which is Parnaíba, Piauí - Brazil. Therefore, the precipitated volume is not the factor responsible for the increase in water bodies from 2000 to 2015.

Figure 4 - Rainfall in the years 2000 and 2015 from the Parnaíba weather station.



Source: INMET (2020). Org.: by the Authors, 2020.

After studying each year, an analysis was made of the dynamics of land cover in which it was possible to perceive the process of change in land cover over time, showing the different uses of soil in geographic space.

Dynamics of land use and cover in the years 2000 and 2015

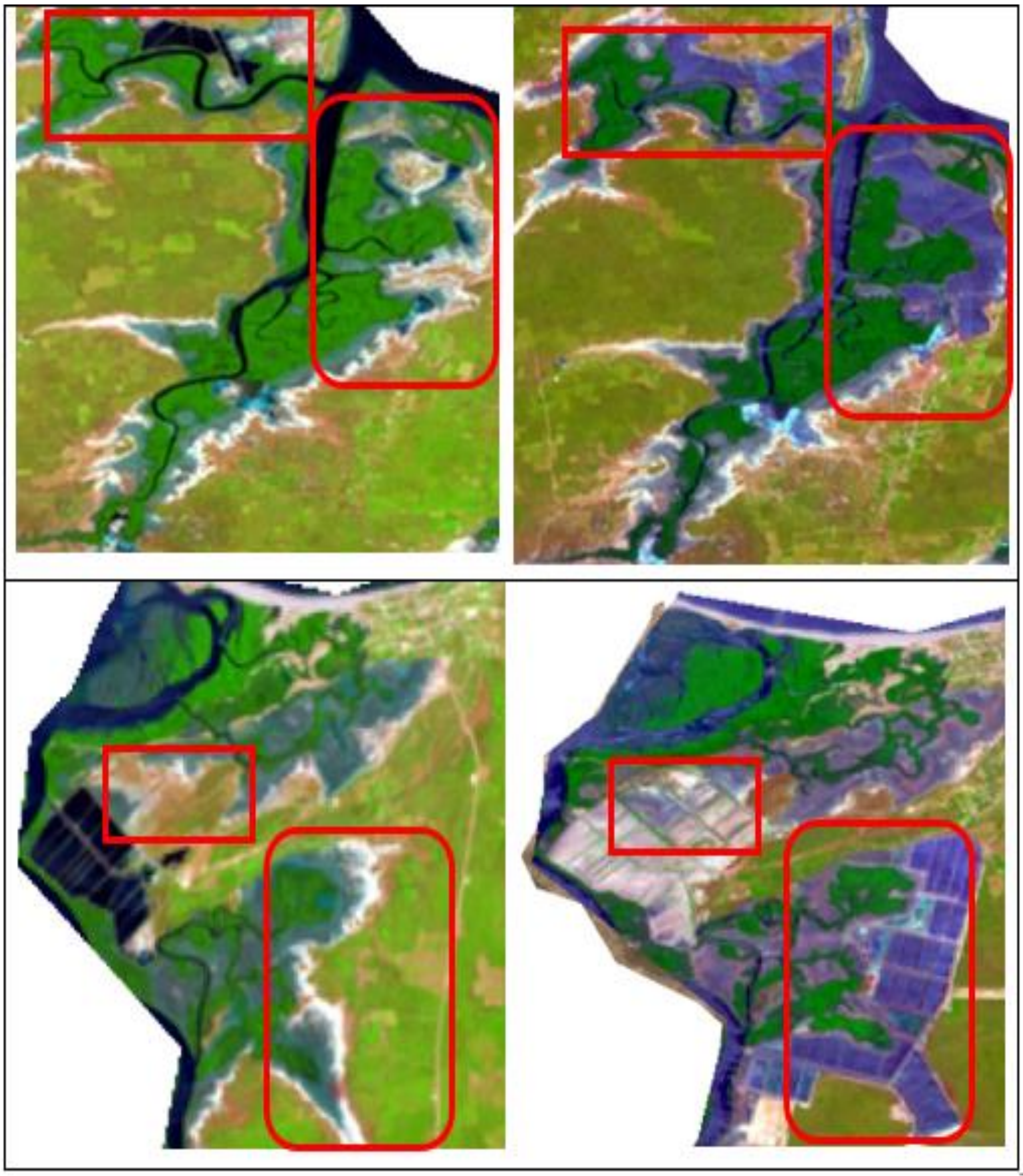
Given these dynamics, it was noted that from 2000 to 2015 there was a recovery of the caatinga vegetation areas (54.45% to 55.12%) and reduction of mangrove area (8.0% to 7.30%).

Another point that drew attention was the increase in water bodies over the years, some elements that presented themselves as other aspects in the year 2000, in 2015 appear as water, as is the case of the sandy cord (11.43%), wetland area (25.17%), exposed soil (3.42), mangrove vegetation (6.20%), as previously mentioned, this is mainly due to the increase in tanks used in the technique of shrimp farming in ponds, as shown in Figure 5 .

Apicuns and salgados are the areas where the greatest conversion to shrimp farming occurred. . Figure 5 shows the evolution of this type of business in the city, because they support features such as flat surface topography, imminent source of supply, sea water in quantity and quality in addition to the low economic value of purchase of land due to large salinity conditions and risk of flooding (ALBUQUERQUE *et al.*, 2015).

The classes of land use and coverage changes are defined in Table 2, and described in Chart 2.

Figure 5 - Satellite images of the temporal relation between areas of water bodies in Cajueiro da Praia



Source: LANDSAT Images (2000 and 2015). Org.: by the Authors, 2019.

Chart 2 – Description of the classes of land use and cover changes.

CLASSES	DESCRIPTION
Expansion of urban area	Corresponds to the classes that have undergone changes over the years, transforming into an urban area in 2015
Preservation of vegetation	Indicates how much each vegetation has been preserved over the years
Expansion of water bodies	It deals with the increase in the quantity of water bodies from the relation with other classes
Maintenance of exposed soil	Identifies how much exposed soil has remained as compared to the two years studied
Preservation of the wetland area	Percentage of area that has remained wet over the years
Expansion of the sandy cord	Identifies the classes that suffer changes and that in 2015 appear with sandy aspects

Org.: by the Authors, 2020.

It is important to clarify that only the data that obtained a percentage greater than one was included in the caption, in order to facilitate the analysis of some of the main points identified in the table.

As noted in the dynamics table (Table 5), the urban area also increased because about 44.29% of the exposed soil in 2000 is presented as an urban area in 2015, also covering a portion of the sandy cord, caatinga and restinga vegetation, in addition to other points, in a less expressive way.

Table 5 - Land use and land cover dynamics in Cajueiro da Praia, Piauí - Brazil, in%.

Classes/ Caption		Year 2000 U. area	W. bodies	S. cord	W. area	E. soil	V. man.	V. caat.	V. rest.	V. car.
2015	U. area	44,93	0,00	3,06	0,41	44,29	0,28	2,57	3,80	0,67
	W. bodies	0,00	51,11	11,43	25,17	3,42	6,20	1,72	0,00	0,96
	S. Cord	0,60	2,31	52,10	4,30	34,24	0,30	4,50	0,26	1,38
	W. area	0,00	10,32	15,28	54,10	7,51	5,67	3,00	0,12	3,99
	E. soil	0,04	0,01	2,17	0,91	48,53	1,03	39,89	1,81	5,61
	V. man.	0,00	2,06	0,16	3,00	0,16	94,03	0,00	0,00	0,58
	V. caat.	0,00	0,05	0,19	0,06	5,88	0,05	90,20	0,22	3,35
	V. rest.	0,64	0,03	3,02	2,23	33,49	0,65	37,84	21,20	0,90
	V. car.	0,00	0,00	0,41	0,38	10,11	0,14	7,75	0,01	81,21

Source: Data generated from Arcgis 10.3 software. Org.: by the Authors, 2020. **Abbreviations:** U. Area: urban area; W. bodies: water bodies; S. cord: sandy cord; W. area: wetland area, E. soil: exposed soil; V. man.: mangrove vegetation; V. caat.: caatinga vegetation; V. rest.: restinga vegetation; V. car.: Carrasco vegetation.
(orange) = Expansion of urban area; (yellow) = Preservation of vegetatio; (blue) = Expansion of water bodies; (red) = Maintenance of exposed soil; (green) = Preservation of the wetland area; (purple) = Expansion of the sandy cord.

The urban area of the municipality was still small in 2015 (1.36km²), but a significant growth was observed in the studied period (84%). Monitoring and planning of urban area is important for orderly growth. The population was 6,122 inhabitants in 2000 and 7,510 in 2015. Poultry grewless than the urban area, probably due to the structure built to support tourist activity, including hotels, inns, restaurants and other buildings for services.

The sandy cord has also undergone a significant change over the years. The analysis showed that 34.24% of the exposed soil in 2000 was a sandy cord on the most recent date. Some factors may have influenced this change, such as the intensity of erosion, human activities such as construction works in dunes or even climate change.

The wetland area plays an irreplaceable social and economic role, as it contains floods that allow the recharge of aquifers, in addition to retaining nutrients, purifying water and stabilizing coastal areas (MMA, 2007). In 2000, this area corresponded to approximately 21,780 km². In 2015, it was 29,415 km². This growth is also due to the influences of shrimp farming.

The mangrove vegetation, which corresponded to 8.00% of the total area of the municipality, reduced to 7.30%. Although it seems to be a small loss, it is an area constantly threaten due to the increase in shrimp tanks. This demonstrates that the decrease is progressive and that it can continue over the years with a possibility of significantly damaging this vegetation.

As for the exposed soil of the region, it is more concentrated in the regions close to the urban area and to water bodies, however, random points throughout the territory are observed. A point that can be associated with the reduction of its total area over these years from approximately 30.275 km² to 20.768 km² is the change in the size of the caatinga vegetation area, as noted in table 5. Part of the exposed soil may be related to soils used for annual crops, but in fallow, without vegetation cover, because to the images being from the dry season..

The caatinga vegetation has the highest total percentage of the municipality, 55.12% of the total territory of Cajueiro da Praia is situated within this class. Among Brazilian biomes, the Caatinga is the least known botanically, the most numerous families in terms of endemic species are leguminous (80) and cactaceous (41). Of these, several are in danger of extinction (MMA, 2002). This biome is one of the least protected by the conservation units and integral protection.

Another vegetation identified in the study is restinga, it varies between herbaceous, shrub and tree common in coastal areas. This vegetation showed only 21.20% of preservation between the two dates. Despite corresponding to 1.52% of the total area of the territory, it had a significant growth since the year 2000 when its area corresponded to only 0.63%, this variation is directly related to the state of the dunes and the sandy cord (MMA, 2010).

The carrasco vegetation, unlike restinga, had a drop in its total occupation area. In the year 2000, this vegetation corresponded to 7.43% of the total territory of the municipality, in 2015 it represented only 5.58%, according to the dynamics. This variation is directly related to exposed soil and caatinga vegetation. It is an area surrounded by these two classes that, according to the dynamics table, have been directly influenced over the years.

CONCLUSION

The classes of land use and cover identified in the region were water bodies, urban area, wetland area, sandy cord, exposed soil, restinga vegetation, caatinga vegetation, carrasco vegetation and mangrove vegetation, changes occurred either in growth or reduction in terms of area in the studied time interval.

The temporal dynamics of land use and cover showed that, on average, the vegetation maintained some stability between the years 2000 and 2015, but it also showed that the water had a significant increase, indicating the expansion of aquaculture.

The mapping of land use and coverage changes in the study area is a tool that can be applied to the territorial management of the municipality.

ACKNOWLEDGEMENTS

We thank Piauí Research Support Foundation - FAPEPI (in Portuguese: Fundação de Amparo à Pesquisa do Piauí) for the payment of a scholarship to the first author. We thank the National **Council for Scientific and Technological Development - CNPq (in Portuguese: Conselho Nacional de Desenvolvimento Científico e Tecnológico) for financing the proc project.** 443176/2014-0 and by the scholarship of the second author proc. 301254/2017-6. We also tank the Geomatics and Soils and Sediments laboratories at the Federal University of Piauí - UFPI.

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