Original Research Article

Spatial - temporal analysis of the use and soil cover in the Rio da Cruz microbasin of the semi-arid region of Paraíba, using remote sensing

ABSTRACT

The changes that occur in ecosystems are increasingly coming from anthropogenic actions. In microbasins, these changes become more noticeable and can be detected using remote sensing techniques. The Rio da Cruz microbasin, meso-region of Sertão Paraibano. Field visits were made to identify the vegetation cover and forms of land use. Then, satellite images of the three-year rainy and dry periods were used: 2001, 2009 and 2017. The following steps were performed, image processing: pre-processing; processing and post-processing. Seven classes were selected: Arboreal Caatinga, Arboreal Shrub Caatinga, Anthropized Caatinga, Pastures and Agriculture, Rocky Outcrops, Water Bodies and Buildings. The results demonstrated an advance of the antropic action in the areas near the bodies of water. The temporal analysis of the watershed of the River of the Cross allowed to verify the reduction of the Arboreal Caatinga and increase of the Arboreal Shrub Caatinga, Anthropized Caatinga and Pasture and Agriculture areas in the studied years. Remote sensing techniques and knowledge of the microbasin result in relevant information on the use and cover of the soil in years of regular precipitation and in conditions of greater precipitation, the arboreal vegetation is overestimated, making it difficult to identify anthropic areas during the rainy season.

***Keywords**: Anthropogenic action. Caatinga. Geotechnology. Satellite images.*

1. INTRODUCTION

The predominant vegetation in the semi-arid region of northeastern Brazil is the Caatinga, which extends for approximately 735,000 km², equivalent to 11% of Brazilian territory and 70% of the Northeast [1] . The term "caatinga" is of Tupi origin and means "white forest", due to the whitish and shiny appearance of the tree trunks devoid of leaves in the dry season that dominate the landscape [2]. The Caatinga is the name of the biome of this region, rich and complex in its biodiversity, nevertheless, its ecosystems are under the constant threat of the degradation. According to the [3], 46% of its area is deforested and subject to degradation processes, with the main causes being the cutting of native vegetation for the consumption of firewood and the production of charcoal for domestic and industrial purposes, as well as the conversion of land into pasture and agricultural plantations. As ecosystems are modified, the biodiversity of fauna and flora is reduced when noticing the disappearance of many native animal and plant species, increasing environmental problems and, consequently, compromising the natural balance.

The management of natural resources can be optimized through the monitoring of land use and land cover, allowing the planning and implementation of public policies based on the diagnosis of landscape changes [3]. For [4], the information generated by the multitemporal analysis using satellite images, considering the rainfall indices, helps in the monitoring of the soil, the vegetation and the watersheds, including the planning of actions to recover areas. According to studies conducted [5, 6] the use of Remote Sensing (SR) techniques to understand both ecological relations and the soil use and cover process has through the monitoring of anthropic activities and the knowledge of how the environmental impacts interfere in the semiarid regions of Northeast Brazil.

Among several studies that show the importance of using satellite images in the semi-arid region, we highlight those of [7], who analyzed the historical occupation process of the Cariris Velhos (PB) region; [8], who carried out a temporal analysis of land use and land cover in the State of Sergipe, and [9] that analyzed the changes in land use in Serra Talhada (PE). In studies involving water resources, the research developed by [10], whose objective was to support the existing information to facilitate the development of projects in the Natuba River (PE) subbasin, by [11], which helped to understand the anthropic effects caused in the Rio São Paulo (PE) basin, by [12], who mapped the alteration of the vegetation cover in the Rio sub-basin (PB) and by [6], who carried out a temporal analysis of soil cover changes in the São João do Rio do Peixe basin.

The microbasin of Rio da Cruz, located in the meso-region of Sertão Paraibano, has as its main reservoir the Capoeira dam, inserted between the municipalities of Mãe D'Água and Santa Terezinha (PB), which purpose is to supply water to the population and support the agricultural activities of rural communities in the municipalities of the region [13]. Changes in the landscape of the watershed are increasingly noticeable due to the use of their natural resources for the various activities. Considering that remote sensing techniques have been increasingly applied to ascertain the changes in the landscape and the absence of studies of space-time analysis in the watershed of the Rio de la Cruz and its ecological and economic importance for the region, this work aimed to perform a multitemporal analysis of soil use and cover in this watershed from Landsat orbital images in the rainy and dry periods of 2001, 2007 and 2017.

2. MATERIALS AND METHODS

2.1 Characterization of the Study Area

The research was developed in the microbasin (Figure 1) of Rio da Cruz, Meso-region of Sertão Paraibano, occupying an area of 739,40 km² (73,940 ha) of which 98% are inserted in the municipalities of Imaculada, Mãe D'água, Maturéia, Patos, Santa Teresinha , São José do Bonfim and Teixeira, and 2% in the state of Pernambuco in the municipalities of Brejinho and Santa Teresinha [14].

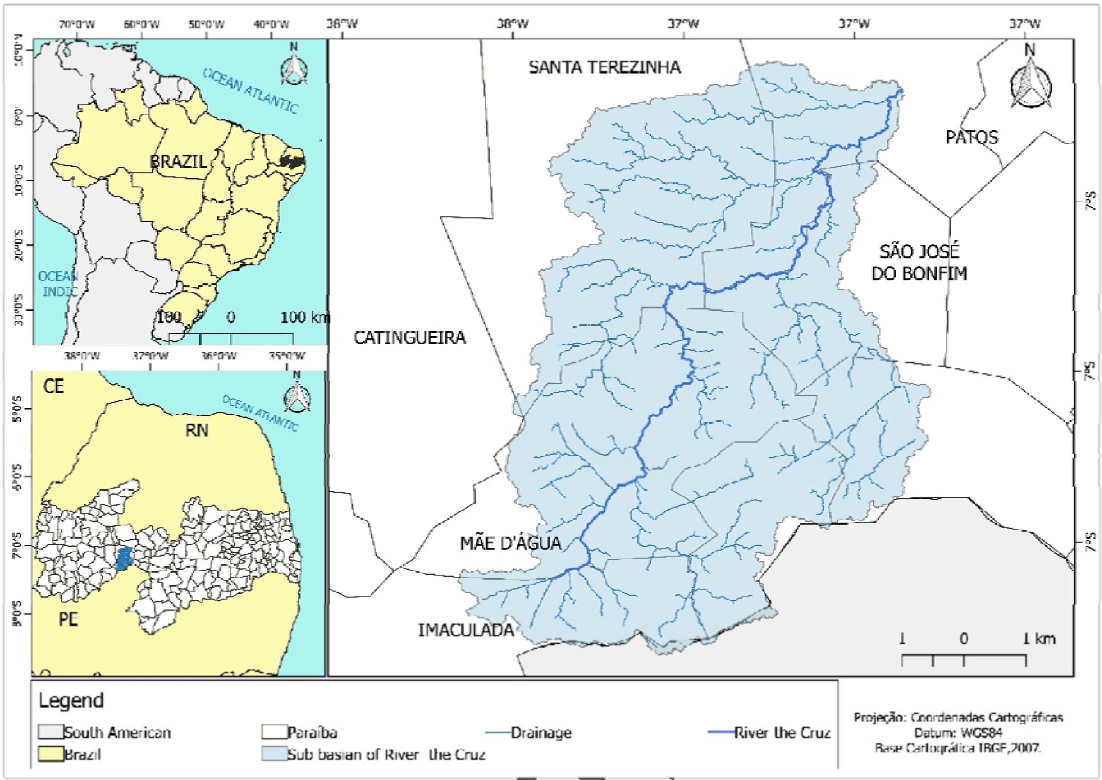


Fig 1. Location map of the Rio da Cruz watershed - PB / PE. Anjos (2018)

The microbasin is strongly influenced by the high intensity and short duration rains, characteristic of the semi-arid region [15]. The main river of the microbasin is called Rio da Cruz, it has its source in the municipality of Imaculada (PB), it is about 56 km and runs in the southwest-northeast direction (SW-NE), passing through the municipalities of Mãe D'Água, Santa Terezinha, São José do Bonfim and Patos, where it meets the Farinha River and forms the Espinharas River. The main reservoir is the Capoeira Dam with a capacity of 53,450,000 mm³ of water. It is located between the municipalities of Mãe d'água and Santa Terezinha (PB) [13].

The majority of the population of the municipalities of Imaculada, Mãe D'Água, Santa Teresinha, São José do Bonfim (PB) and Brejinho (PE) are in the rural area (Table 1). This population has its economic activities based on the agricultural exploration and animal husbandry, developed on the banks of the Rio da Cruz and the Capoeira Dam. The municipality of Patos-PB stands out because it concentrates a larger population in the urban zone, where the Rio da Cruz is with the Rio Farinha, making visible the impacts originated by the inadequate use of the banks and the river bed. [16] highlight the signs of degradation present in this river caused by agricultural production (planting forage species and animal husbandry) and the daily discharge of domestic effluents due to the absence of basic sanitation in the city of Patos- PB.

Table 1. Population of the municipalities that make up the Rio da Cruz watershed - PB / PE

Municipalities	Urban Population	Rural Population
Imaculada*	5.063	6.289
Mãe D'Água*	1.569	2.450
Matureia	3.857	2.082
Patos*	97.278	3.396
Santa Teresinha*	2.208	2.373
São José do Bonfim*	1.361	1.872
Teixeira	9.631	4.522
Brejinho - PE	3.386	3.921
Santa Teresinha - PE	6.876	4.115

* Municipalities where the main river of the microbasin, Rio de la Cruz, passes.

The climate of the study area, according to [17] is of the type Bsh, of low latitude and altitude, semi-arid with summer rains. The average annual rainfall is 700 mm, concentrated in the first four months of the year, with average daily temperature variations between 23º to 30ºC [18].

2.2 Precipitation Record

The records of accumulated rainfall of 2001, 2009 and 2017 were acquired and analyzed in the municipalities belonging to the microbasin (Figure 2). Precipitation in the semi-arid region is a determining factor for image classification, as it directly influences the vegetation behavior and consequently the identification of the targets.

Fig. 2. Graphical representation of cumulative precipitation (mm) of the studied periods (2001, 2009 and 2017) of the municipalities that compose the Rio da Cruz watershed.

2.3 Characterization of Vegetation and Soils

The predominant vegetation is the open tree shrub hyperxerophilic caatinga, due to the exploitation of wood and non-timber products, and the conversion of land to agricultural crops and animal husbandry. Soils are the result of the weathering of crystalline rocks, mostly Red-Yellow Podizolic of clayey composition, and some stretches of alluvial Latosols [19].

2.4 Acquisition of images, image processing and generation of map layout

Field visits were initially made to know the area and collect data from the microbasin to support the classification of land use and cover. The satellite images were obtained from the United States Geological Survey [20] from the Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) / TIRS (Thermal Infrared Sensor) and dry of the years 2001, 2009 and 2017, with orbit 215 and point 65, spatial resolution 30 m and colored compositions in the bands used for the mapping of the microbasin (Painting 1; Figure 4). For the identification of the microbasin in the image, we used the vector file of delimitation performed by [14].

Table 2. Images of the Landsat satellite for the years and months studied

Satellite / Sensor	Year	Rainy Season	Dry Period
Landsat 5 /TM	2001	15/05/2001	22/10/2001
Landsat 5 /TM	2009	19/04/2009	15/12/2009
Landsat 8 /OLI	2017	24/04/2017	05/12/2017

For the identification of the microbasin in the image, we used the vector file of delimitation performed by [14] and (Figure 3) the composition helps in identifying the class, in supervised classification with in loco collections.

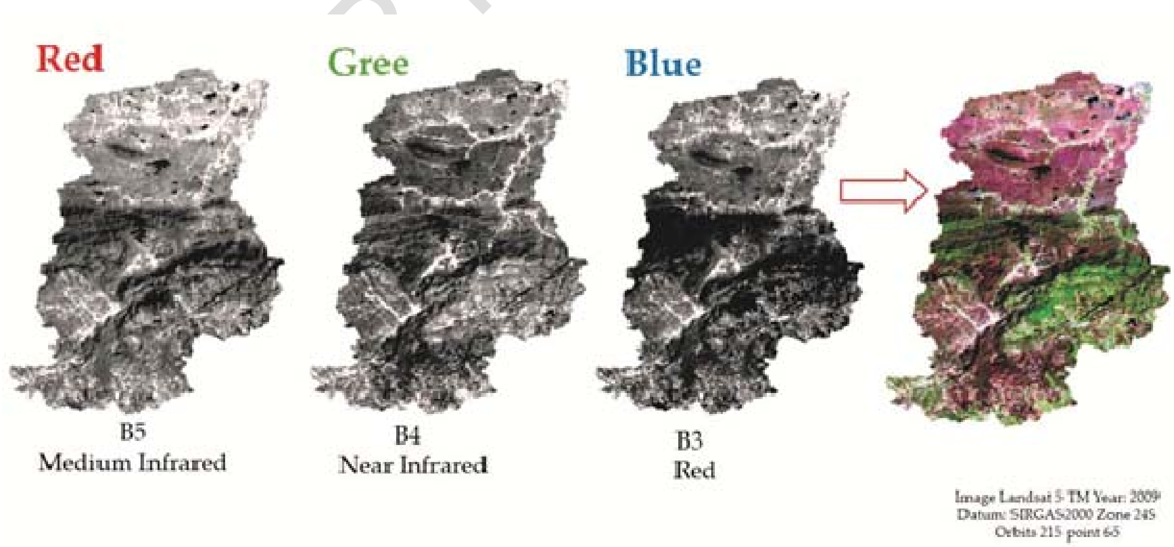


Fig. 3. Colored composition of the three bands of the Landsat 5 sensor TM

2.5 Analysis and interpretation of orbital images

Analyzes of land use and land cover classes were carried out, river basin, according to the flowchart of (Figure 4), being compared with studies carried out in other microbasins, especially in similar periods, and the impacts generated in the areas studied.

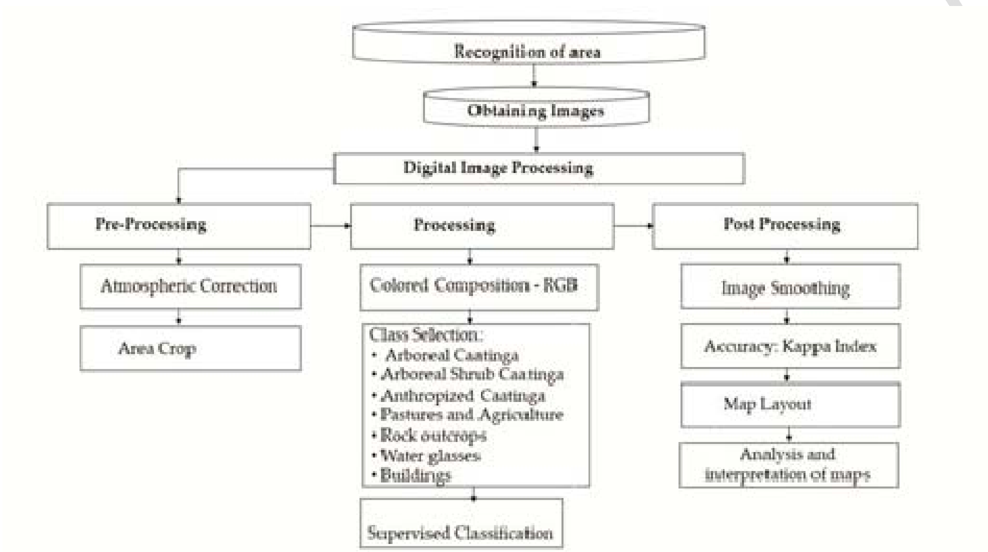


Fig 4. Flowchart of methodological procedures

In the digital processing of the images, the pre-processing was carried out where the atmospheric corrections were performed using the QGIS software v.2.14.21 Long Term Release Repository (LTR) in the Semi-Automatic Classification Plugin (SCP). The atmospheric interference, estimated from the digital numbers (ND) of the satellite images using the MTL extension metadata files using the Dark Object Subtraction (DOS) method [21] was corrected. In the processing, RGB color compositions were performed with the Landsat 5 TM (R5G4B3) and Landsat 8 OLI (R6G5B4) bands, with a scale of 1,100,000 images. Areas were selected from the field visits and seven classes of use and land cover: 1) Arboreal Caatinga 2) Arboreal Shrubl Caatinga characterized by the dominance (about 60%) of shrubs and few trees; 3) Anthropized Caatinga, herbaceous vegetation characterized by the absence of arboreal individuals and predominance of herbs and shrubs; 4) Pastures and Agriculture on riverbanks; 5) Rock outcrops; 6) Bodies of water and 7) Buildings. The classification was supervised using the Maximum Likelihood algorithm.

For the post-processing, the image smoothing was started with the aggregation of isolated pixel values that did not correspond to the peripheral areas with the majority values of the images. The accuracy (reliability) of the classification was verified using the Kappa concordance index that varies from poor to excellent according to the level of proximity between image representation and field reality. This index is recommended for using all cells in the matrix rather than just the diagonal elements [22]. The layout of these maps containing all the cartographic elements essential to its location (coordinates, scale, origin of images, legend). The maps were generated in the Universal Transverse Mercator projection (UTM) and the Datum SIRGAS 2000, zone 24 south.

3. RESULTS

The agreement of the classification of the supervised images, the use and the cover of the ground of the microbasin of the Rio da Cruz based on the images in all supervision resulted in values of Kappa concordance indices of 0.80 (2001), 0.55 (2009) and 0.95 (2017) for rainy periods. For the dry periods, the values for this index were 0.86, 0.86 and 0.96, respectively.

It was verified that these rates ranged from good (0.55 in 2009 in the rainy season) to excellent in the other years and periods studied, (indexes above 0.80) [23]. The agreement for the rainy season of 2009 was inferior to the others due to the presence of clouds in the areas and the excess of biomass present in the vegetation, resulting from the high precipitation indexes recorded in the area (1335.50 mm). These factors caused differences between the pixels classified in the images.

During the three years studied, it was verified that the average annual rainfall in the Rio da Cruz watershed was 656.88 (2001), 1335.50 (2009) and 782.43 mm (2017). The high precipitation registered in 2009 can be attributed to the La Niña phenomenon. The Figure 5 shows the distribution of land use and land cover classes in the watershed of Rio da Cruz over the years (2001, 2009 and 2017) and periods studied (rainy and dry). It is verified that in 2009 when a greater rainfall occurred (1335.50 mm), the identification of the vegetation classes was compromised by the volume of biomass, making it impossible to distinguish the different classes of Caatinga established (Arboreal Caatinga, Arboreal Shrub Caatinga and Anthropized Caatinga) in the satellite images, since the values of the pixels were very close. On the other hand, in the years 2001 and 2017 it was possible to differentiate all classes in the rainy and dry periods.

The values described in Table 3 refer to the areas (km²) and the coverage percentages of each class of land use and cover in the Rio da Cruz watershed, with an increase in the areas of Pastures, Agriculture and Anthropized Caatinga in both periods and reduction in the areas of Arboreal Caatinga and Arboreal Shrub Caatinga.

Table 3. Areas and percentages of the land use and cover of the Rio da Cruz watershed from the years 2001, 2009 and 2017 in the rainy and dry periods

Classes	**Rainy Season**					
	2001		**2009**		**2017**	
	Area (km²)	**%**	**Area** (km²)	**%**	**Area** (km²)	**%**
* Arboreal Caatinga	221,1	29,9	407,1	55,1	105,1	14,2
Arboreal Shrubl Caatinga	111,0	15,0	99,6	13,5	133,6	18,1
continuation						

Anthropized Caatinga	273,6	37,0	73,0	9,9	337,2	45,6
Rock outcrops	35,3	4,8	36,4	4,9	33,8	4,6
Water Bodies	2,4	0,3	7,5	1,0	0,4	0,1
Pastures and Agriculture	92,4	12,5	3,9	0,5	123,2	16,7
Buildings	3,5	0,5	4,8	0,6	6,1	0,8
Clouds and Shadows	0,0	0,0	107,1	14,5	0,0	0,0
	Dry Period					
* Arboreal Caatinga	90,9	12,3	151,3	20,5	61,7	8,3
Arboreal Shrubl Caatinga	136,1	18,4	80,5	10,9	83,1	11,2
Anthropized Caatinga	306,9	41,5	272,9	36,9	351,1	47,5
Rock outcrops	38,6	5,2	43,5	5,9	36,6	4,9
Water Bodies	1,4	0,2	6,2	0,8	0,3	0,0
Pastures and Agriculture	161,0	21,8	179,4	24,3	200,5	27,1
Buildings	4,6	0,6	5,6	0,8	6,1	0,8
Clouds and Shadows	0,0	0,0	0,0	0,0	0,0	0,0
Total	739,4	100,0	739,4	100,0	739,4	100,0

* Approximate area of the arboreal caatinga in the rainy period of the year 2009 is 163,0 km.

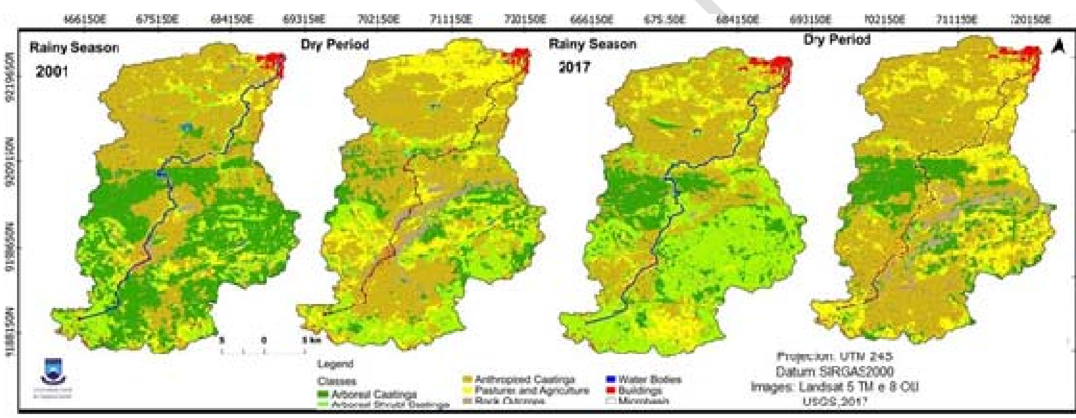
For the purposes of comparison, only 2001 and 2017 were considered, given the precipitation that occurred in 2009, higher than expected, not representing the normality of the region's rainfall index. When analyzing the use and cover of the soil of all the classes in Figure 5, the strong exploitation of the tree vegetation and the intensity of the use of the soil in the microbasin of the Rio da Cruz is evident.

In the Caatinga Arborea class, it was observed that in the rainy season there was a reduction of 52.5% of the vegetation cover in the microbasin area: 221.1km² and 105.1km² in 2001 and 2017, respectively (Table 3). In these years increases of 20.36% were observed in the Arboreal Shrub Caatinga class (111.0 km² for 133.6 km²), 33.34% in the Pastures and Agriculture class (92.4 km² for 123.2 km²) and 23.25% (273.6 km² and 337.2 km²) in the Anthropized Caatinga class (Table 3).

Observing vegetation behavior in 2001 and 2017 in Figure 6, it was verified that the classes presented distinct areas in the rainy and dry periods, and can be explained by the physiological behavior of the vegetation of the Caatinga. The vegetation reflects the biomass stimulated by the budding process, showing the canopy of trees and forming, even if discontinuous, the upper canopy characteristic of this vegetation, making more noticeable the Arboreal Caatinga class and the form of occupation of the areas in general. In years of normal precipitation, in the dry period, with the increase of water deficiency, the deciduous process occurs (loss of leaves of most Caatinga species), as a response to soil water restriction decreases vegetation reflectance.

When comparing the areas and percentages of increase and reduction of classes from dry to rainy, it was verified that only the Arboreal Shrub Caatinga did not maintain the pattern verified in the other classes in the rainy season, since a reduction of 38.94% (136.1 km2 for 83.1 km2). This decrease was caused by the substitution of the use of this area for crops and livestock, confirmed in loco by the increase of 24.53% in the pastures and agriculture class (Figure 6B, F; Table 3).

Fig. 5. Use map and soil cover of the Rio da Cruz watershed from 2001 and 2017. Anjos (2018)



In general, there is the exploitation of native tree vegetation for various purposes, such as energy production for domestic and industrial use, timber for rural construction (sticks, stakes, mourões, etc.), sawmill for the manufacture of furniture and civil construction, in addition to non-timber forest products (fruits, oils, fibers, resins, etc.). In all of these conditions, there is a predominance of the extractive model and its negative consequences on soil, biodiversity, decharacterization of natural landscapes and, above all, silting and deterioration of rivers, lakes and reservoirs.

These statements were observed in the microbasin of the Rio da Cruz, since the use of the soil and vegetation cover of this area demonstrates the lack of knowledge of the negative effects of anthropic actions on the environment, especially the removal of native vegetation, favoring erosion and loss of soil fertility, silting of watercourses, among others, thus increasing areas of Anthropized Caatinga, culminating in processes that lead to risks for their survival.

Figure 7 shows images of soil use and cover in the rainy and dry periods according to the classes established in the Rio de la Cruz watershed mapping. The difference between the landscape in the Arboreal Caatinga and Arboreal Shrub Caatinga between rainy and dry periods, the use of pasture and agricultural crops, as well as the degradation present in the areas, especially in the Anthropized Caatinga, due to the exposure of the ground.

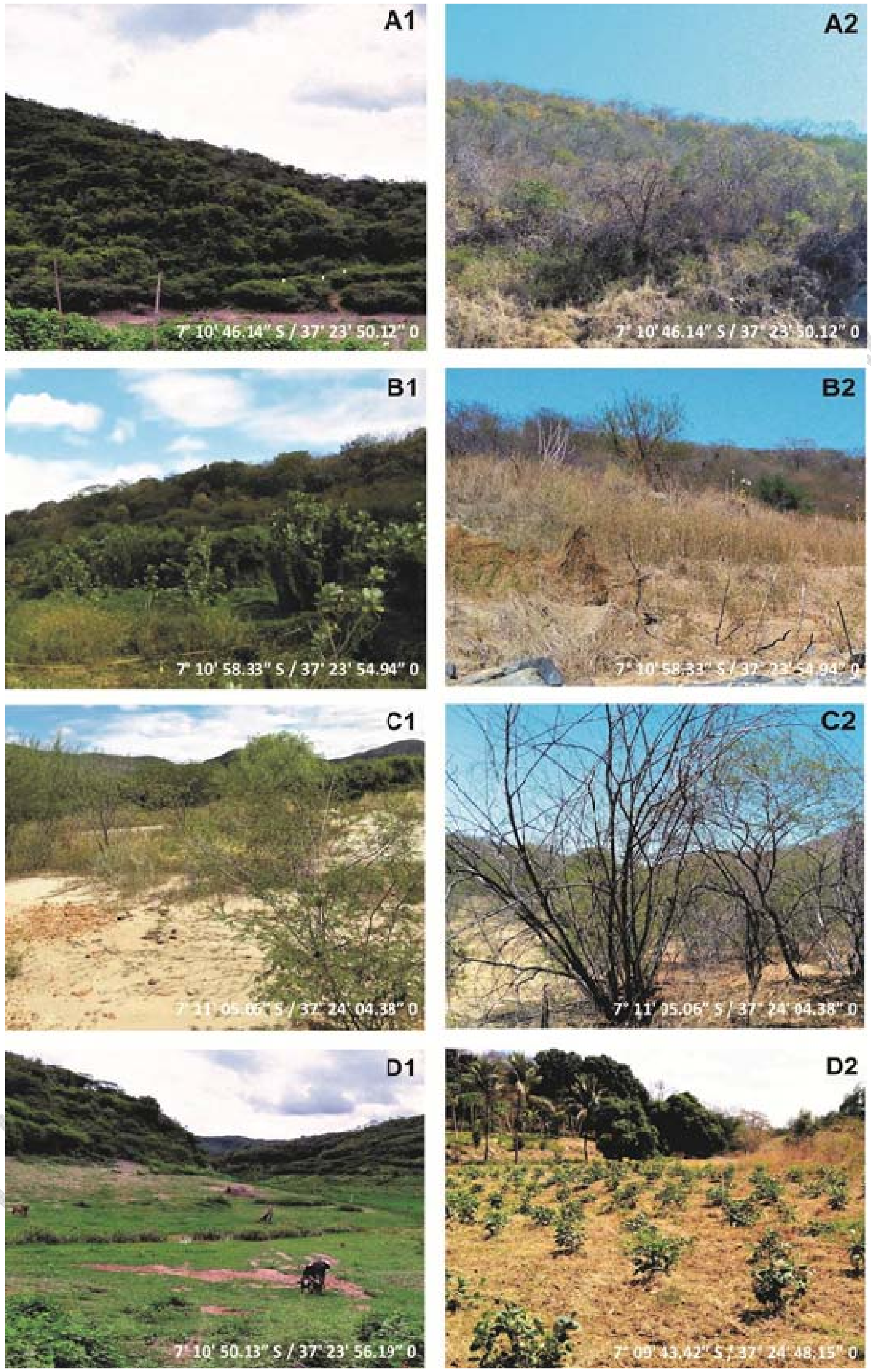


Fig. 6. Images of the classes of use and soil cover of the Rio de la Cruz watershed in the rainy and dry periods, respectively. Arboreal Caatinga (A1, A2); Arboreal Shrubl Caatinga (B1; B2), Anthropized Caatinga, (C1; C2); Pastures and Agriculture (D1, D2).

As expected, the waterbodies class was most evident in all rainy periods, as verified by the surface waters of the streams and reservoirs supplied by the precipitation occurred in the region (Figure 6A, E, Figure 8D). This class may vary according to the precipitation indices that provide a larger volume of water in the watershed.

Analyzing the data in Table 3, there is a reduction of 83.33% in the rainy season and 78.57% in the dry period for the years 2001 and 2017. This behavior is a reflection of precipitation of previous years that precede those of this study, which favor or not a greater accumulation of surface water and that can be strongly influenced by the El Niño and La Niña phenomena.

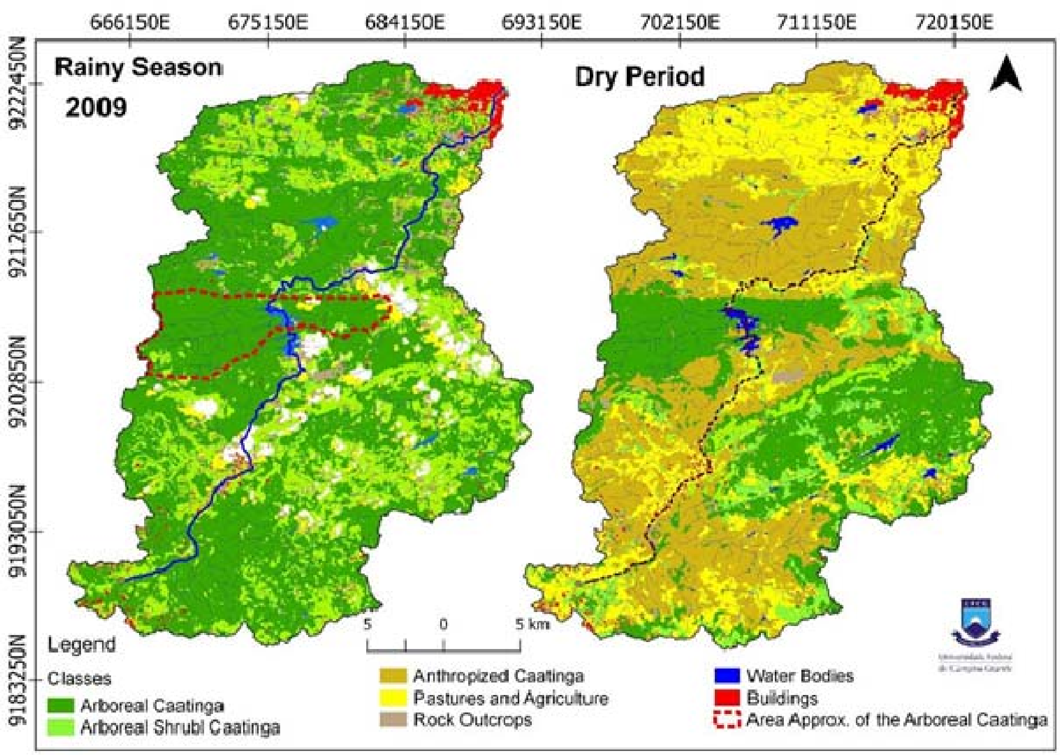


Fig. 7. Use and land cover map of the Rio da Cruz watershed of the year 2009. Anjos (2018).

The identification of vegetation classes for the year 2009 in the rainy season (Figure 8C) was compromised by the biomass volume of the vegetation, making it difficult to distinguish between the established classes (Arboreal Caatinga, Arboreal Shrub Caatinga, Anthropized Caatinga and Pastures and Agriculture). In satellite images, pixel values were very similar, specifically in the near infrared bands where the vegetation reflects a large amount of energy which is directly related to the biomass produced. From the information obtained in the Arboreal Caatinga class in the rainy season of 2001 and 2017, an average area of 163.10 km2 was estimated for this class (Table 3).

It is interesting to highlight the influence of the climatic conditions, and in particular in this study, the rainy season of 2009, on the vegetation of the semiarid, which maintained its foliage for a longer period, benefited by the humidity in the soil due to the high rainfall index recorded in the region (Figure 7, D, Table 3).

According to [24], this phenomenon causes changes in the precipitation of northeastern Brazil, especially in the semi-arid region, when the occurrence of rains is accentuated, characterizing the average index normally recorded. La Niña, according to [25], contrasts with El Niño, which accentuates the low rainfall levels, causing droughts in the semi-arid region, as in 2001 (656.88 mm), which was below of the region, which ranges from 700 to 750 mm [13].

In research,[26 - 25], it has been proven that precipitation in the semi-arid region is determinant and directly interferes in the vegetation response and in the hydrological cycle. The rainy season triggers the phenological processes of tree species directly influencing all phases (leaf bud budding, flowering, fruiting, seed dispersal and seed bank and seedling bank formation) and also enables the development of the herbaceous and shrub strata of in order to favor the seasonal cycle to which the species of this region are submitted.

The results of this study are similar to those obtained through the temporal analysis of the vegetation cover carried out by [27], in the years 1987 and 2004 in the municipality of Boa Vista-PB, where Caatinga occurs with similar characteristics to the present work. The authors identified an increase in the class of sparse vegetation (Anthropized Caatinga) from 26.80% in 1987, to 35.82% in 2004, elucidated by the disordered vegetation suppression for pasture and agriculture. It is evident the non-length of the Forest Code, which establishes 50 m of Permanent Preservation Area (APP) for water courses with a width between 10 m and 50 m [28].

[29], in studies carried out in the Saco River basin in Santa Luzia - PB, observed that the Arboreal Caatinga, located in mountainous and steep relief, presented 100% of its preserved vegetation. The authors emphasized that the natural conditions of relief favored the maintenance of native vegetation due to the difficulty of the exploitation of these lands for pasture and agriculture. It is important to note that even if tree vegetation is not on the river banks, in the 50 m of APP, its preservation is essential to prevent soil erosion in adjacent areas and provide the other environmental benefits.

According to[30], tree vegetation is frequently being withdrawn, causing negative impacts on the river basins. [31] emphasize that the suppression of this vegetation is due to the fact that they occupy fertile lands along the banks of the water courses and reservoirs being exploited, thus allowing the use of the areas for agropastoral purposes.[Souza and[7]also add that the replacement of native vegetation cover causes negative impacts on the environment and generates high environmental and economic costs. The absence of land use planning in a given area causes negative impacts on biodiversity, and it is increasingly important to know how the occupation process occurred in order to estimate the degree of degradation to which the tree vegetation was submitted [32].

[33] observed in the municipalities of Serra Branca and Coxixola, in Paraíba over a period of 17 years, soil exhaustion and vulnerability to degradation caused by the removal of vegetation cover and pasture and agriculture substitution. [34] point out that the small farmer does not have the infrastructure to cope with the long periods of drought, being dependent on the natural resources of the Caatinga, when logging is one of the main economic activities. In the present study, the increasing demand of land for exploitation by the mainly rural population of the municipalities of this microbasin results in the removal of the tree cover.

[6] verified that in a period of 30 years (1980 to 2007) in Northeast Brazil, the rural exodus surpassed half a million people. This fact, from the environmental point of view, allowed the recomposition of the native forest, like the Peixe River Basin. These authors consider that

this evasion in the rural area benefited the recomposition of native vegetation in the Peixe River basin, in the Alto Sertão da Paraíba. In contrast, according to the 2010 population census, in the last 10 years only 40,000 people have done this migration [35], which justifies a strong pressure on the natural resources of the caatinga.

According to [24]; These results suggest that there is a significant change in the volume of precipitated water, positively or negatively influencing the amount of water accumulated. According to [26], in the studies carried out in the Taperoá River basin - PB in 2009, the exceptional rainfall period was confirmed, contributing to the uniformity of soil moisture conditions and stabilization of plant mechanisms, favoring a woody biomass gain from the Caatinga of 53.8%.

4.CONCLUSIONS

Remote sensing techniques and knowledge of the watershed result in relevant information on land use and cover in years of regular rainfall in the region. The studies carried out in the two distinct seasons make visible the water, vegetation and soil targets and serve as the basis for the elaboration of mapping projects that involve the use and soil cover of micro-basins in the mesoregion of the Paraiba sertão in different periods.

In years of higher precipitation the biomass of the tree vegetation overestimates the vegetation classes, making it difficult to identify the vegetation cover of the soil and the anthropic areas in the rainy season. The temporal space analysis of the Rio da Cruz microbasin, through the classification of land use and land cover, indicates an advance of the anthropic action associated with climatic conditions, mainly in the river banks, with the reduction of the Arboreal Caatinga and increase of the Arboreal Shrub Caatinga, Anthropized Caatinga and Pasture and Agriculture areas.

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