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Land use and occupation in the municipality of Mossoro/RN (1998-2018)

Uso e ocupação do solo no município de Mossoró/RN (1998-2018)

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Abstract: The present work is related to the studies of landscape dynamics and aims to carry out a multitemporal analysis of land use and occupation in the municipality of Mossoro In the state of Rio Grande do Norte, Brazil, over a period of 20 years, in order to contribute to environmental planning and land use planning. The methodological procedures are based on bibliographical research, remote sensing techniques in Geographic Information Systems environment and multitemporal landscape analysis. The results allowed the spatialization of 13 classes of land use and occupation in the town and the understanding of their evolution over the analyzed period. It was possible to identify that the main changes are associated with the performance of anthropogenic agents and the productive dynamics of the municipality. The results obtained allow for broad application in the area of environmental planning, land-use planning, and environmental management.

Keywords: Landscape; Remote sensing; Mossoró.

Resumo: O presente trabalho está relacionado aos estudos da dinâmica da paisagem e tem como objetivo realizar uma análise multitemporal do uso e ocupação do solo do município de Mossoró/RN ao longo de um período de 20 anos, com fins de contribuição ao planejamento ambiental e ordenamento territorial. Os procedimentos metodológicos estão fundamentados em pesquisa bibliográfica, técnicas de sensoriamento remoto em ambiente de sistemas de informação geográfica e análise multitemporal da paisagem. Os resultados permitiram a espacialização de 13 classes de uso e ocupação do solo no município e a compreensão de sua evolução ao longo do período analisado. Foi possível identificar que as principais alterações estão associadas a atuação de agentes antropogênicos e à dinâmica produtiva do município. Os resultados obtidos possibilitam ampla aplicação na área de planejamento ambiental, ordenamento terrritorial e gestão ambiental.

Palavras-chave: Paisagem; Sensoriamento remoto; Mossoró.

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1. Introduction

The analysis of land use and occupation has become frequent in geographic studies and, most of the time, with the intention of understanding landscape dynamics of a given place in order to contribute to processes of environmental management and land use planning. Landscape is one of the key concepts of geographical science of great polysemy, as it has applications in several sciences: Geography, Arts, Architecture, among others. Its composition involves, in addition to the natural elements, that is, the natural landscape in Dokuchaev's conception (MAXIMIANO, 2004), elements resulting from human action in the environment, being understood as a global entity (BERTRAND, 2004). Currently, there is some consensus that the landscape is the product of the interaction between natural (physical, chemical and biological) and anthropic (society) components, each of which has its own dynamics that can be individualized (MEDEIROS, 2017). For Rodrigues (1998), it is a product established by the intervention of society in the environment.

This established product makes visible the landscape elements in consonance with the artificially created ones (FORMAN,1995) that, over a certain period, can explain the interaction mechanisms that formed it, besides exposing the level of changes implemented by anthropic action.

Thus, there are several optics of landscape analysis, from its vertical conception, where it seeks to understand the systemic flows related to its evolution and functioning, as well as the horizontal or geographic-spatial conception, where the focus of the analysis falls on the organization and spatial distribution of land use and occupation classes. The main application of landscape studies has focused on the analysis of sustainable development and environmental planning and land use planning (RODRIGUEZ et al., 2021).

In this way, the classification of land uses and occupation forms a fundamental basis for understanding the phenomena, due to the complexity of forms and elements distributed in space. This complexity, exposed mainly by the natural dynamics of an area and the anthropic actions, leads to an analysis where the classification and hierarchization, taking into account the scale to be worked on and the period (BERTRAND, 2004), are fundamental to understand the dynamics of the landscape.

The use of geotechnologies identified with remote sensing (JENSEN, 2009) has consolidated important methods for the analysis of the landscape, by using the instruments available for observation of the earth's surface. The satellite made it possible through its various optical resources to read the surface, providing an excellent ability to interpret natural and anthropic aspects to be classified by the images provided (LIU, 2007). These possibilities of observing the surface through images with spatial and spectral resolutions, processed by remote sensing (SR) techniques in specialized software, bring applications and classifications of elements from wider areas without the need to go all over it.

Given these technical possibilities, this study aims to understand the dynamics of the landscape from a multitemporal analysis of land use and land cover in the municipality of Mossoro, state of Rio Grande do Norte, over the period between the years 1998, 2008 and 2018 for the purpose of contributing to environmental planning and land use planning of the municipality.

2. Methodology

2.1 Brief characterization of the area

The municipality of Mossoro is located in the intermediate geographical region of Mossoro (IBGE, 2017) state of Rio Grande do Norte, being considered one of the most important municipalities in the state, both in terms of population (2nd most populous in the state) and economy. Located 257 km from the capital Natal, with a total territorial area of 2,100 km² (IBGE, 2018), it is one of the largest municipalities in Rio Grande do Norte, being the main municipality in the intermediate geographical region, considered the Capital of the Brazilian Semiarid (BRASIL, 2017).

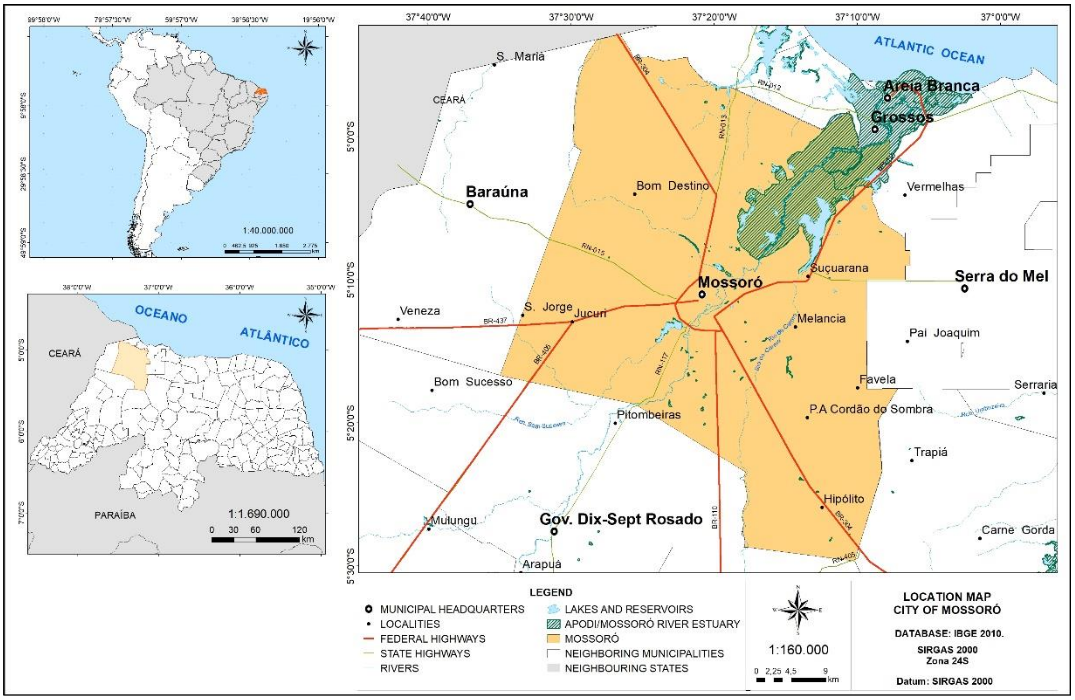

Figura 1 – Map of location of the municipality of Mossoro.
Source: prepared by the author from the IBGE database

With its entire area in the polygon of droughts, in the municipality of Mossoro predominates the semi-arid climate (NIMER, 1977), which has among 6 dry months (DINIZ and PEREIRA, 2015), with two well-defined seasons, one rainy and one dry. Rainfall is entirely influenced by the Intertropical Convergence Zone – ITCZ, with rainfall concentrated between the first 3 to 4 months of the year, and the rest of the year is dry (INMET, 2018). The annual rainfall averages are 672.5 mm/year (DINIZ and PEREIRA 2015). For these conditions, the predominant vegetation is the Caatinga, adapted to hydric stress in periods of drought and high annual solar radiation, because the Caatinga has, as one of its characteristics, the rapid formation of leaves during the rainy season and the loss of leaves (deciduous) during the dry season (ALMEIDA et al., 2009).

Geologically, the municipality of Mossoro is located on the Borborema Province. It is seated on the Potiguar Basin, which, according to Maia and Bezerra (2015), is the result of tectonic actions, climate and eustatic processes coming from the South American Plate.These processes occurred in the formation of the Potiguar Basin, during the Mesozoic, are associated with the separation of South America from Africa (MATOS 2000). With the deposition that occurred mainly during the Cenozoic (BEZERRA and VITA-FINZI, 2000), the alluvial sediments and eolic and marine deposits at the borders of the Brazilian coastline gave rise to the Barreiras Group (BARRETO et al, 2004). The lithostratigraphic units found in the municipality of Mossoro are configured as a variety of sediments, which can be grouped into: Jandaíra formation (Kj2), dated from the Cretaceous, originating from sedimentation on a shallow sea platform (TIBANA E TERRA, 1981), where the precipitation of calcium carbonate was able to settle, forming the various layers of limestone rock of this formation; and the Barreiras Group (ENb), which is configured as continental and marine terrigenous sediments, according to Arai, 2006; Suguio, 1999, of Miocene age, originating from erosion processes, after cyclic uplift of the South American platform at the end of the Cretaceous (CECERO, 1997).

The geomorphology of the municipality of Mossoro consists of several units, according to the most recent classifications carried out on a state scale, covering: fluvial-marine plain, fluvial plain, structural reliefs, coastal tablelands and Chapada do Apodi (ROCHA et al., 2009; MAIA, 2012; DINIZ et al., 2017). Another classification presents the units of the northern coastal tablelands, interior tablelands, Chapada do Apodi and part of the coastal plain framing them within the sculptural mold domain of the marginal sedimentary basins (DINIZ et al., 2017). According to Dantas and Ferreira (2010), the area of the municipality integrates the low plateaus of the Potiguar Basin and the coastal tablelands.

In the territory of the municipality, several activities are developed, such as oil, salt, irrigated fruit farming and marine shrimp farming. Some of these activities are historically installed in the municipality, favored by the natural conditions as well as its strategic location between two capitals, Natal/RN and Fortaleza/CE.

The process of installation and development of these activities associated with the growth of human settlements centers, both in urban and rural areas, has produced a landscape change, often generating significant environmental impacts, which needs to be better known in order to be able to subsidize environmental management and land use planning, aimed at maximizing its benefits and minimizing negative environmental impacts.

2.2. Methodological procedures

In order to carry out this work, bibliographic research was necessary, in addition to the processing of satellite images and the elaboration of statistical models in the laboratory. The bibliographic research used academic works published in specialized magazines, in addition to specialized books on the theme.

For the elaboration of the maps were used images from the satellite LANDSAT 5 sensor TM (Thematic Mapper), LANDSAT 7 sensor ETM + (Enhanced Thematic Mapper Plus) and LANDSAT 8 sensor OLI (Operational Terra Imager) in routes 63/64, orbit 224 available in the platforms of the USGS (United States Geological Survey) and the DGI/INPE (National Institute for Space Research) platform, from the following dates: the first scene is from March 1, 1998; the second, of March 13, 2008; and the last scenes are from March 13, 2018; all with a spatial resolution of 30 meters. Taking into account the image referring to March 1, 1998 in relation to the others from March 13, 2008 and 2018 to be different as there is no image for this date in the year 1998. In the pre-processing stage, a mosaic of the study area was made, due to it being divided into two LANDSAT scenes, and then they were submitted to atmospheric correction and radiometric correction techniques, in the SPRING 5.5 software. 6, reducing interference captured by the sensor, eliminating noise and geometric distortions. After this process, the scenes were submitted to the Linear enhancement method, controlling the gray levels of the image in the histogram of each channel (Red, Green and Blue).

After pre-processing the images, the extraction of the NDVI, SAVI, and NDWI indexes was started; they were processed in a GIS environment using ArcGis 10.2© software, using the image fusion method. After this process, thematic maps of land use and occupation were created using the Image Analyst tool, using the Euclidean distance classification method, given by the formula:

$$D(x, m) = (x^2 - m^2)^{1/2}$$

Where: D=distance
x = pixel being tested;
m = mean of a grouping

This consisted in associating a pixel to a certain class (GAUCH, 1982; BORGES et al., 2007), in which the extraction within the software took place through the Image Analyst tool, selecting the pixel or grouping of pixels in the class determination. This process was repeated 6 times until reaching a satisfactory result. At the end of the classification, the maps were generated in the ESRI ArGis 10.2© software, where the vectorizations for the land use and occupation classification were made as a result of the indices generated, these being important means of acquiring attributes for this purpose.

After this process, area calculations were performed using the calculate geometry tool in the software, where the dimension of each land use and occupation class, in hectare, was extracted. The next step was to tabulate the data and create graphs and tables, using Windows Office Excel 2010 ©, for their presentation and statistical representation.

Within this construct, the land use and occupation classes were defined based on the Land Use Technical Manual (IBGE, 2013), adapting them to the elements identified and mapped in the study area. Thus, the classes were chosen from the objects individualized in the most recent image, which are the following: irrigated agriculture, rainfed agriculture area, shrimp farming activity, petroleum activity, saline activity, urban areas, settlements, mining areas, dense arboreal shrubby caatinga, open shrubby arboreal caatinga, riparian forest, water bodies and exposed soil.

After the classification process, the field stage was carried out, which aimed to verify the classified areas if they correspond to what was presented in the image processing. With this done, the effectiveness was identified in 95% and the rest was edited to match what was visualized in the field.

3. Results and Discussion

The results related to the mapping of land use and occupation in the municipality of Mossoro, for the years 1998, 2008 and 2018 are presented in figure 2, 3 and 4, in addition to the quantitative data exposed in table 1. With this, it is possible to identify the main changes in land use and occupation, which are important for understanding the dynamics of the landscape over the analyzed period.

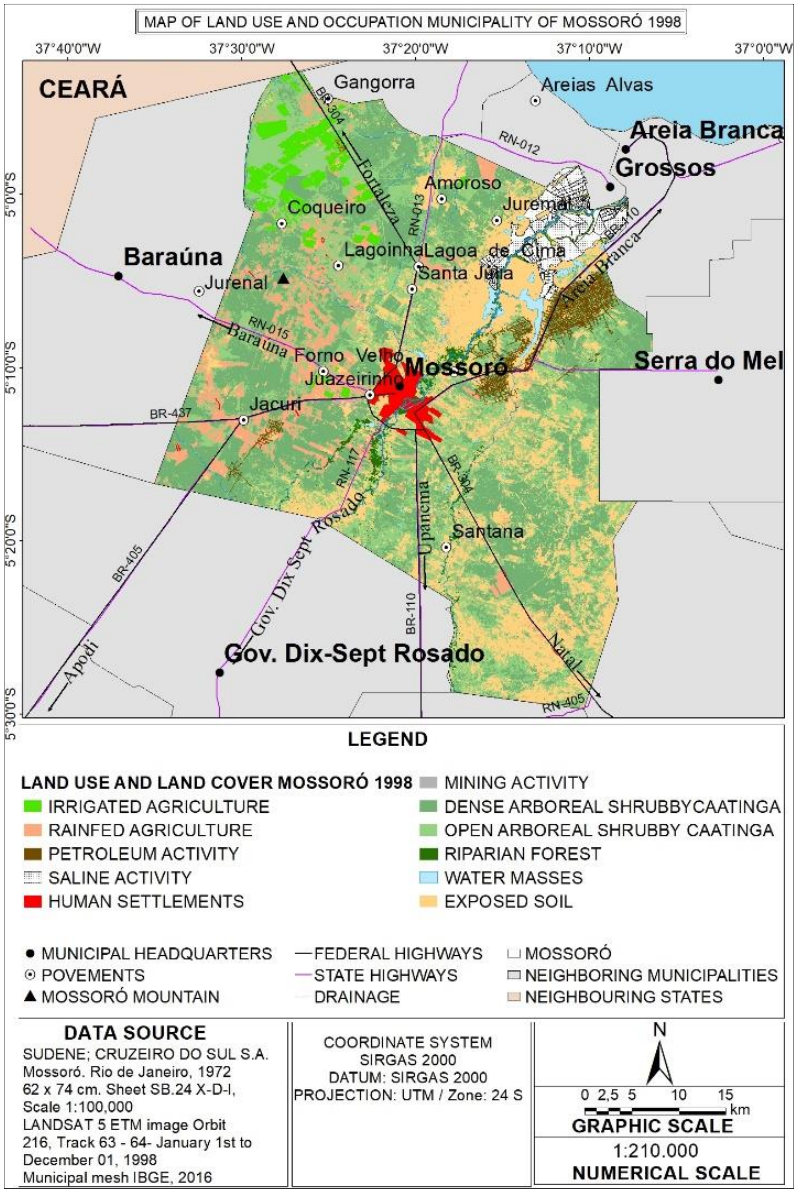

Figure 2 – Land use and occupation map, year 1998.
Source: authors (2020).

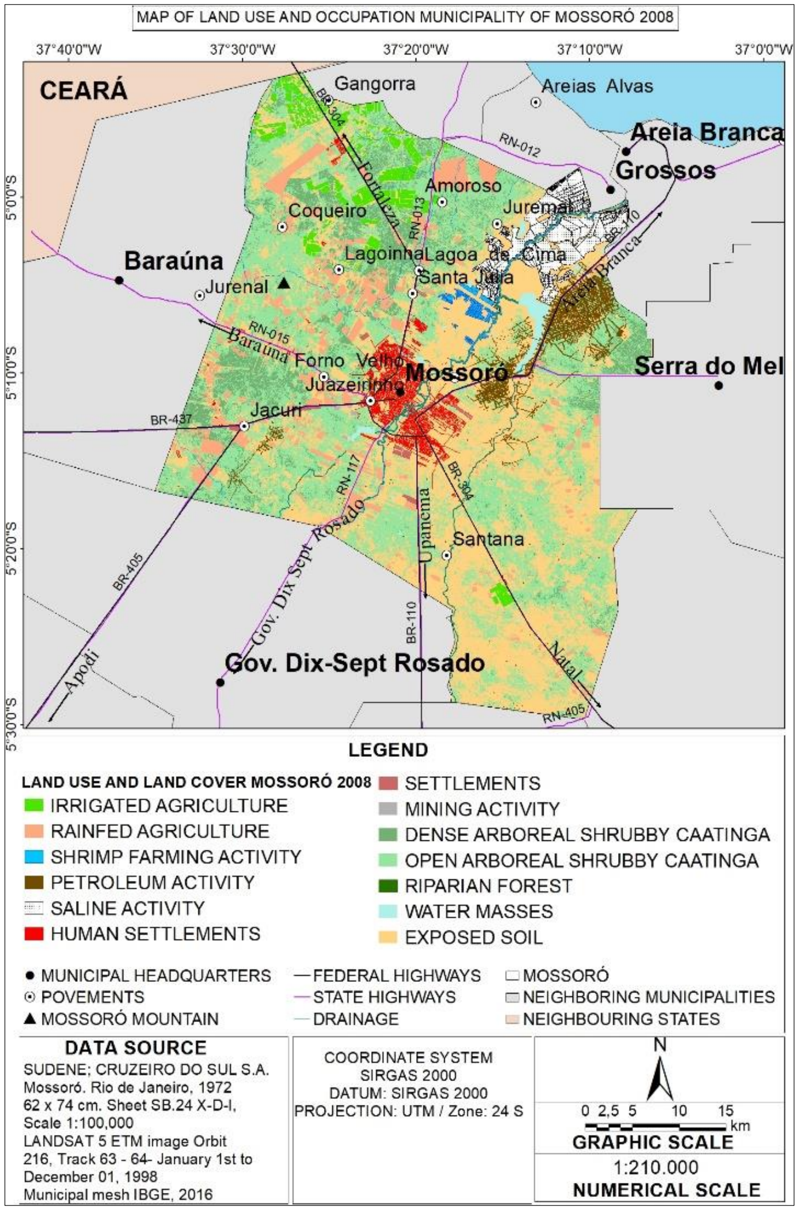

Figure 3 – Land use and occupation map, year 2008.
Source: authors (2020).

Eleven classes of land use and occupation were identified for the year 1998 and 13 classes for the years 2008 and 2018. As identified in table 1, these classes were;

Table 1 – Classification of land use and occupation in 1998, 2008 and 2018. Source: Authors (2021

CLASSES OF USE	1998		2008		2018	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Irrigated agriculture	41.39	1.97	58.73	2.80	87.79	4.18
Rainfed agriculture	146.94	7.00	113.51	5.40	70.36	3.35
Petroleum activity	2.78	0.13	8.37	0.40	8.63	0.41
Saline activity	72.49	3.45	79.44	3.78	79.41	3.78
Shrimp farming activity	Not identified		6.88	0.33	15.90	0.76
Mining Activity	1.09	0.05	1.15	0.05	1.40	0.07
Human settlements	30.80	1.47	81.11	3.86	103.46	4.93
settlements	Not identified		3.75	0.18	11.73	0.56
Dense arboreal shrubby caatinga	630.43	30.02	168.29	8.01	763.19	36.34
Open shrubby arboreal caatinga	620.90	29.56	738.94	35.18	654.81	31.18
Riparian Forest	12.31	0.59	11.66	0.56	7.75	0.37
Water masses	13.86	0.66	18.14	0.86	9.80	0.47
Exposed soil	527.18	25.10	810.20	38.58	285.94	13.62
TOTAL	**2,100.17**	**100.00**	**2,100.17**	**100.00**	**2,100.17**	**100.00**

Source: authors (2020).

Irrigated agriculture, an activity that was boosted from the 1990s and through the 2000s (HESPANHOL, 2016) is concentrated in the northwest portion of the study area. In 1998, this class occupied 1.97% of the area of the municipality, having had a continuous growth over the period studied, rising to 2.8% in 2008 and 4.18% in 2018, which represents an increase of around 112% in occupied area over the 20 years analyzed. As it is an activity that demands deforestation and the use of different inputs, such as water, pesticides and fertilizers, the growth of this activity implies several negative environmental impacts. With regard to water consumption alone, irrigation has been responsible for capturing almost 50% of raw water in springs in Brazil, being the activity that consumes the most water in the country (ANA, 2021).

Rainfed agriculture, more traditional due to climate limitations, presented a continuous reduction over the years. With a 7% occupation of the area in 1998, it reduced this participation to 3.35% in 2018, that is, a reduction of more than 50% in the occupied area. This change may have several explanatory hypotheses, among them agricultural abandonment or rural exodus, given the increase in areas of human settlements and settlements, especially due to urban expansion; and/or the transformation of parts of the rainfed areas into irrigated areas, in view of the growth of irrigated agriculture throughout the period.

The petroleum activity also showed growth over the analyzed period, which was more significant between 1998 and 2008, when the activity had an increase of 201% in occupied area, from 2.78 km² to 8.37 km². From 2008 to 2018, the area occupied by the activity had a significant deceleration in growth (less than 10%), perhaps due to the reduction of investments, especially public ones, in the expansion of this activity in the Potiguar Basin lands, quite explored since the 1970s (ROCHA, 2013). Currently, in addition to no new investments in this area in the municipality, there is a strong disinvestment, mainly in Petrobras' production areas. Deactivation of production units and transfer of personnel to production areas focused on the pre-salt was the tonic experienced in recent years in the municipality and in the entire Potiguar Basin area, with a strong impact on the economic dynamics that once had its redemption in oil.

With regard to saline activity, it is important to highlight that it is a secular activity, initially installed on the banks of the Apodi-Mossoro river estuary, starting from its mouth and entering the entire estuarine influence zone and expanding in order to occupy almost all of the fluviomarine plain between the municipalities of Areia Branca, Grossos and Mossoro. Over time, this activity has remained relatively stable in terms of occupied area. Medeiros (2017) identified this when analyzing the municipality of Areia Branca. With an occupied area of around 72.49 km² in 1998, from 2008 onwards a small increase in this activity of less than 10% of the previously occupied area can be seen, remaining stable for 2018. This growth is justified by a possible environmental licensing of new areas, often in Permanent Protection Areas, which motivated public civil action by the Federal Public Ministry (DE FATO, 2019).

Another activity that started to occupy areas of the fluviomarine plain and areas of estuarine influence, often contiguous to the areas of the salt pans, was the activity of marine shrimp farming. Introduced in the 2000s, with rapid growth in mangrove areas in the estuaries of Rio Grande do Norte, this activity was present in 2008 in Mossoro, occupying 6.88 km² of the area of the municipality. In 2018, there was an occupied area of more than 131% compared to the previous decade. It is an activity responsible for significant negative environmental impacts, mainly due to the development of the cultivation of exotic shrimps, such as *Litopenaeus vannamei sp*., the predominant species, and the use of inputs that can compromise the environmental quality of the ecosystem where it settles. This reinforces the need for special attention in the planning and land-use planning process of the municipality.

Present since the 1970s, the mining activity classified here is strongly associated with the extraction of limestone rocks for the production of lime and cement. Petroleum activity was not considered in this class, given that it has its own dynamics and particular behavior in the landscape.In the case of the activity treated here, its growth has been negligible in terms of area, with a growth of 28% being observed over the entire period analyzed. This may have several reasons, among which are some limitations from the environmental point of view for the expansion of this activity, mainly due to the fact that, in many cases, the explored areas are close to the limits with caves, which are protected by law. Moreover, it is worth mentioning the installation of a federal integral protection unit, the Furna Feia National Park, in areas of the municipalities of Mossoro and Baraúna, which aims at the preservation of several caves in this locality and which has some cement production units in its damping zone. Another possible justification is the similarity of the spectral response of some of these areas with the exposed soils, a category that will be the object of a posteriori analysis.

Human settlements represent the areas occupied or artificialized as a result of human constructions.They encompass both rural and urban areas, however, their significant growth over the analyzed period, which corresponded to more than 236% when compared to 1998, is mainly due to urban expansion. From 2008 onwards, the first closed horizontal condominiums in the municipality were identified, intensification of urban verticalization, the installation of shopping center and, more recently, a significant area that started to be occupied by new settlements for the edification of planned neighborhoods.It should be noted that much of the areas found as settlements and urban areas, especially from 2008 had a growth of 212.8% between 2008 and 2018, are mostly intended for this type of urban expansion. The evolution of these human activities is marked by a more accentuated scale resulting from the economic moment experienced by the municipality, especially in the early 2000s (OLIVEIRA, 2017; PEQUENO and ELIAS, 2010).

It is true that the evolution of these activities, especially those related to urban expansion, is associated with the occupation of green areas, usually in areas bordering rural areas, which implies deforestation, removal and soil disturbance that generate other direct and indirect impacts that, as a rule, contribute to a greater environmental imbalance due to generalized degradation. Considering this reduction in green areas, it must be deduced that the impacts, especially associated with thermal comfort, are significant. However, it is necessary to analyze the changes related to the vegetation cover of the municipality for conjectures and hypotheses.

In this case, throughout the analyzed period, the total vegetation cover corresponded to 60.17% of the municipal territory in 1998 – including the classes of caatinga and riparian forest –, reducing to 43.75% in 2008 and increasing again to 67 .89% in 2018. This makes it clear that vegetation cover is the most significant class in the municipality 's landscape, in terms of occupied area. However, this data in itself does not reflect the environmental conditions or the various possibilities of changes and impacts related to the environment. It is necessary, for example, to analyze the degree of connectivity and fragmentation of this class to better understand its implication in the landscape and for the environmental balance, which will not be the object of this study.

From the point of view of the reduction observed between 1998 and 2008 is associated with the dense arboreal shrubby caatinga, which had a decrease of about 73% in area occupied. Part of this is probably due to the transformation into open arboreal shrubby caatinga, since this class recorded an increase of almost 20% in the same period, as well as the increase in the exposed soil area, which increased from 527.18 km² to 810.20 km². In the period from 2008 to 2018, however, a recovery of the dense arboreal shrubby caatinga class is observed, which now occupies 36.34% of the municipal territory, being the most representative among the categories related to vegetation cover. This recovery may also be associated with the decrease in exposed soil areas, which fell to 285.94 km² in 2018. The class related to open shrubby arboreal caatinga has a slight reduction in 2018, when compared to 2008, but throughout the entire period there is an increase of around 5%, which can confirm the thesis that areas of exposed soil started to be occupied by this type of vegetation cover. If one considers that the exposed soil may be the result of the spectral response of the dry caatinga, this may be even more justified. These are hypotheses that are presented but need to be validated at another time by other studies with such objectives.

As for the riparian forest, which has an important environmental and ecological function, a continuous reduction can be seen throughout the period, with something around 5.3% in 2008 and 38% in 2018 of loss in terms of occupied area. This may be related to the expansion of human activities along and on the bank of the Apodi-Mossoro river and, in some cases, to some type of environmental crime, given that a good part of this riparian forest is, most likely, in a permanent protection area, as provided for in Law No. 12,651/2012 (BRAZIL, 2012).

The water masses, in turn, oscillated throughout the period, increasing the area occupied in 2008 and reducing in 2018. Taking 1998 as a reference year, the total reduction was almost 30%. However, considering that we are in a semi-arid climate area where the main surface springs are of a temporary nature, where the volume of water masses are associated with rainfall regimes and, considering that the last years (2012-2018) were marked by drought severe, this reduction may be associated with this factor.

In summary, the 5 activities that most predominate in the landscape of the municipality in 2018 are, in descending order of occupied area: dense shrubby arboreal caatinga, open shrubby arboreal caatinga, exposed soil, human settlements and irrigated agriculture. However, the activities that had the most increase in terms of occupied area, throughout the analyzed period, were: human settlements (235%), petroleum activity (210%), irrigated agriculture (112%), mining activity (28%), and dense shrubby arboreal caatinga (21%). The activities listed are quite dependent on large areas, generating direct impacts plus a series of indirect impacts that imply significant changes in the ecological functions of the landscape, which need to receive special attention in the territorial planning processes aimed at a more efficient municipal environmental management.On the other hand, the use categories with the greatest reduction are more associated with nature, such as riparian forest (-37%) and water masses (-29%) or traditional activities, such as rainfed agriculture (-52%). The main exception is the exposed soil, which had a -45% reduction over the analyzed period.

4. Final Considerations

With this study it was possible to identify that the main alterations in the landscape of the municipality of Mossoro involve the direct interaction between natural and anthropic components, being, however, the anthropic components the main agents of transformation in the landscape throughout the analyzed period. Such transformations can lead to a picture of environmental degradation that needs to be known, given the environmental impacts generated by that dynamic that must be considered in public policies for environmental management at the municipal level.

The results of the analysis of land use and occupation over the period studied, both in quantitative terms and in terms of spatialization of the phenomena, provide data of great use for application in environmental planning and territorial planning with the aim of promoting sustainable development.

This study is relevant for future analyzes on vegetation, urbanization, environmental conservation as it presents the process and evolution of determining factors that are established by human activities on the environment, in addition to technical and methodological procedures for obtaining data for application in other areas of research.

It was also presented in this work that human factors were fundamental in the construction of the landscape that was identified, as well as leaving open other agents as possible modelers of the landscape in the municipality of Mossoro.

The use of remote sensing and GIS confirmed, once again, the relevance of these techniques and tools for spatial analysis both for the study of the landscape and for their application in the scope of territorial public policies, in this case, applied at the municipal scale. Therefore, they are very useful for environmental monitoring studies based on previous diagnoses.

In this way, the study contemplates the objectives established when it exposes the configuration of land use and occupation in the municipality of Mossoro during the 20 years, from the samples of the years 1998, 2008 and 2018, it showed how the productive interactions of society were constituted in relation to the environment and the changes that this interaction caused during this period.

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