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Spatial and Temporal Analysis of Land Use and Land Cover in the Microregion of Western Cariri of Paraíba

Análise Espaço-Temporal do Uso e Cobertura do Solo na Microrregião do Cariri Ocidental da Paraíba

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Abstract: This study aimed to analyze land use and land cover in the microregion of Western Cariri, in the state of Paraíba, to identify the changes that occurred in this area between 1989 and 2019. This study used land use and land cover data from 1989 to 2019. To this end, data from 1989, 2005, 2013, and 2019 were chosen, taking into account the precipitation closest to the region's historical average. In these 30 years, Paraíba's Western Cariri increased its pasture area by 42.87%, accumulating an increase of 351.7 km^2. In addition, there has been a reduction of more than half (51.33%) of the area covered by water bodies, caused by the prolonged droughts of recent years. A worrying fact is that 90.0 km^2 is made up of non-vegetated areas, corroborating studies that point to increased desertification in Western Cariri. It is also possible to observe the increase in population in this region, which brings even greater pressure to an already fragile ecosystem. With this, it is possible to conclude that the MapBiomas tool can be used in studies to monitor desertification in the country.

Keywords: Desertification; Brazilian semi-arid region; Caatinga; MapBiomas.

Resumo: O presente trabalho teve como objetivo analisar o uso e cobertura do solo na microrregião do Cariri Ocidental paraibano, a fim de identificar as mudanças ocorridas nessa área, no período de 1989 a 2019. Nesse estudo, utilizaram-se os dados de uso e cobertura do solo, referentes ao período de 1989 a 2019. Para tanto, foram escolhidos dados de 1989, 2005, 2013 e 2019, levando em consideração a precipitação mais próxima da média histórica da região. Nesses 30 anos, o Cariri Ocidental da Paraíba aumentou em 42,87% a área de pastagem, acumulando um aumento de 351,7 km^2. Além disso, ocorreu a redução de mais da metade (51,33%) da superfície de cobertura dos corpos hídricos, provocada pelas secas prolongadas dos últimos anos. Um dado preocupante é a constatação de que 90,0 km^2 são formados por áreas não vegetadas, corroborando os estudos que apontam para o aumento da desertificação no Cariri Ocidental. É possível, ainda, observar o aumento da população nessa região; o que traz uma pressão ainda maior para um ecossistema já fragilizado. Com isso, é possível concluir que a ferramenta do MapBiomas pode ser utilizada em estudos de acompanhamento da desertificação no país.

Palavras-chave: Desertificação; Semiárido brasileiro; Caatinga; MapBiomas.

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1. Introduction

The Brazilian semi-arid region has heterogeneous soil, topography, and vegetation (Araújo et al., 2018). Almost the entire region is located at low latitudes, close to the equator (between 5 and 10° S), thus triggering minimum temperatures of 15° C and maximum temperatures of 40° C, as well as irregular rainfall. There are two typical seasons in this area: a dry one, lasting seven to nine months, and a rainy one, which occurs over three to five months. The El Niño phenomenon, characterized by a warming of the waters of the Pacific Ocean, has corroborated the dry periods. These last an average of 4 to 6 years (Ab' Saber, 2007; Araújo, 2011; Barbosa et al., 2019).

In Paraíba, the Cariri Microregion (1989) is considered semi-arid, as it is one of the driest areas in the state, a factor that limits activities. The resident population is 129,316, of which 45,483 live in rural areas, corresponding to a contingent of 35.17% of the inhabitants (Brazilian Institute of Geography and Statistics, 2017), who depend on the environmental resources in the region that comprises Western Cariri. The suppression of vegetation due to deforestation and burning, the inappropriate use of the soil for human activities, and the occurrence of agricultural practices that are unsuitable for soil conservation are all cultural practices that compromise the lives of species by destroying their habitats.

The removal of vegetation occurs mainly to make way for pasture for animal feed and firewood production (Pinheiro et al., 2022). The most fertile soils are used for farming practices, among other human actions, further impacting the Caatinga Biome; leading to the loss of species, soil erosion, and desertification (Holanda et al., 2015). According to Travassos and Souza (2014), the phenomenon of desertification is a type of environmental degradation caused by the development of human activities and climatic variations and can occur in regions with arid, semi-arid, and dry sub-humid climates.

With technological advances, the use of fast, simple, and free alternatives (such as the data from the MapBiomas project) can help with diagnoses that help detect environmental problems. It is possible, for example, to assess the progress of phenomena such as desertification. The MapBiomas project aims to advance the understanding of the dynamics of land use and occupation in Brazil by developing and implementing reliable, fast, and low-cost methods to generate annual maps of land use and land cover from 1985 to 2021 (MapBiomas, 2023). Data from Google Earth Engine (GEE) and the foundations of the Google platform are used to develop this program. Google Earth Engine is a platform that combines catalogs of petabytes of satellite images with geospatial data sets, allowing for the detection of changes, mapping of trends, and quantification of possible differences in the Earth's surface (GEE, 2022). However, MapBiomas data is mostly used to analyze land use and land cover on a continental scale, it is still rarely applied on a regional scale.

With this in mind, this study aimed to analyze land use and land cover in the micro-region of Western Cariri, in the state of Paraíba, to identify the changes that occurred in this area between 1989 and 2019.

2. Methodology

The Western Cariri micro-region is made up of 17 municipalities, covers an area of approximately 6,983.6 km^2, and is located in the south of the middle third of the state of Paraíba, approximately 140 km from the state capital, João Pessoa (Figure 1). The period in which almost 70% of the rainfall is concentrated is from February to May (Nimer, 1979). According to the Köppen classification, the region's climate is BSh, hot semi-arid, with average annual temperatures above 25°C and average annual rainfall of around 600 mm (Alvares et al., 2013). Its vegetation is made up of hyper xerophilous Caatinga, adapted to these adverse conditions.

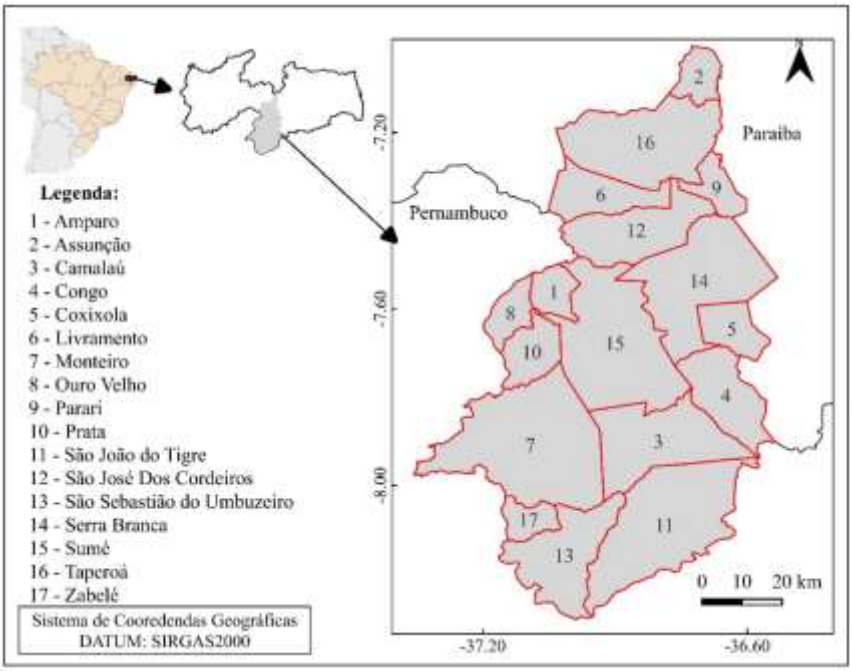

Figure 1 – Location map of the municipalities of Western Cariri in Paraíba
Source: Data from this study.

For the temporal analysis of changes in land use and land cover in the study area, we used data from the MapBiomas 7.0 project (Annual Mapping of Land Use and Land Cover in Brazil), which emerged in 2015 from a technical cooperation agreement with Google Earth Engine (MapBiomas, 2023). The results obtained through the MapBiomas platform are evaluated in terms of the quality of the mapping carried out, in which accuracy analysis is the main form of evaluation. According to the data obtained from the platform, the overall accuracy for each use and cover class for all the years of the 7.0 collection, at level 1, is 91.3%. For levels 2 and 3, it is 87.9% (MapBiomas, 2023).

The vector file delimiting the Western Cariri region of Paraíba was obtained from the IBGE website and uploaded to the Google Earth Engine platform. This allowed access to the products developed by MapBiomas. Among the collections available on the platform, we collected land cover and land use data in matrix format, with a pixel size of 30 meters, and satellite image mosaics for each year of the historical series for a given location, where each mosaic can have up to 105 layers of information with spectral bands, fractions, and indices. These can be accessed directly on Google Earth Engine (MapBiomas, 2023).

This study used land use and land cover data from 1989 to 2019 (30 years). Data from four different years (1989, 2005, 2013, and 2019) were chosen for analysis. To choose these periods, we took into account the years that had rainfall closest to the historical average for the Western Cariri region of Paraíba (Souza et al., 2015b), as shown in Table 1.

Table 1 – Precipitation history of Western Cariri, Paraíba

Year	Precipitation (mm)	Historical average (mm)	Variation from historical average (mm)
2021	430.7	611.0	-180.3
2020	770.5	611.0	159.5
2019	552.3	611.0	-58.7
2018	516.3	611.0	-94.7
2017	307.4	611.0	-303.6
2016	305.2	611.0	-305.8
2015	313.1	611.0	-297.9

Source: AESA (2023).

The MapBiomas classification system itself presents a class division and color palette of the features that were mapped by the program. The correlation of the classes adopted by the project was based on the classes used by the IBGE, the Intergovernmental Panel on Climate Change (IPCC), and the Food and Agriculture Organization (FAO). Table 2 shows the classes that were mapped in the study area.

Table 2 – Classes and description of the legends used in MapBiomas collection 7.0

Classes	Description	Color
Forest Formation - Dense arboreal Caatinga	Vegetation types with a predominantly continuous canopy - Seasonal Forested Savannah, Semideciduous and Deciduous Seasonal Forest.	
Savannah Formation - Open shrubby Caatinga	Vegetation types with a predominance of semi-continuous canopy species - Wooded Seasonal Savannah, Wooded Savannah.	
Grassland Formation - Caatinga	Vegetation types with a predominance of herbaceous species (Park Seasonal Savannah, Grassy Savannah, Park Savannah, Grassy Savannah) + (flooded areas with a network of interconnected lagoons, located along watercourses and in areas of depressions that accumulate water, predominantly herbaceous and shrubby vegetation).	
Pasture	Areas of grassland, predominantly planted, linked to agricultural activity. Areas of natural pasture are predominantly classified as grassland, which may or may not be grazed.	
Mosaic of Uses - Caatinga	Areas of agricultural use where it was not possible to distinguish between pasture and agriculture.	
Urbanized Area	Areas with a significant density of buildings and roads, including areas free of buildings and infrastructure.	
Other non-vegetated areas - Caatinga	Areas of non-permeable surfaces (infrastructure, urban expansion or mining), not mapped in their classes.	
Rock Outcrop - Caatinga	Rocks naturally exposed on the earth's surface, without soil cover, often with partial presence of rupicolous vegetation and high slopes.	
River, Lake and Ocean	Rivers, lakes, dams, reservoirs and other bodies of water.	
Other temporary crops	Areas occupied by agricultural crops of short or medium duration, generally with a vegetative cycle of less than a year, which, after harvesting, require new planting to produce.	

Source: Adapted from the MapBiomas 7.0 database (2023).

QGIS 3.22.10 software was used to make the maps and calculate the areas of the classes determined for the Western Cariri micro-region. The data was imported into Excel software and the values obtained were used to make the data table.

3. Results and discussion

Analyzing the data made available by MapBiomas for the years 1989 to 2019, it was observed that in Western Cariri there is practically no forest formation left, formed by dense arboreal caatinga (1.4 km^2 which is equivalent to 0.02%). In addition, only 58.69% (4,098.5 km^2) of its territory is covered by open woody caatinga. As the predominant class of land cover and land use, the area occupied by this class showed a variation of 3.7%, remaining little changed over the 30 years studied (Table 3).

Table 3 – Values of land use and land cover classes in Western Cariri, Paraíba

CLASSES	1989		2005		2013		2019		Variation
	km²	%	km²	%	km²	%	km²	%	1989 - 2019
Forestry training	1.2	0.02	1.4	0.02	1.2	0.02	1.4	0.02	**12.93%**
Savannah Formation	3.950.8	56.57	4.001.9	57.30	4.179.4	59.87	4.097.1	58.67	**3.70%**
Countryside formation	22.6	0.32	22.5	0.32	22.9	0.33	23.0	0.33	**1.80%**
Pasture	820.5	11.75	1.115.6	15.97	1.075.3	15.40	1.172.2	16.79	**42.87%**
Mosaic of Uses	2.053.4	29.40	1.683.4	24.10	1.600.4	22.92	1.556.4	22.29	**-24.21%**
Urbanized Area	6.0	0.09	11.9	0.17	15.3	0.22	21.6	0.31	**258.87%**
Non-vegetated areas	85.7	1.23	92.8	1.33	65.4	0.94	90.0	1.29	**5.01%**
Rock outcrop	-	-	-	-	-	-	0.03	0.00	**100.00%**
River and Lake	43.3	0.62	54.0	0.77	20.6	0.30	21.1	0.30	**-51.33%**
Temporary crops	-	-	0.2	0.00	0.7	0.01	0.7	0.01	**100.00%**
TOTAL	**6.983.6**	**100.0**	**6.983.6**	**100.0**	**6.983.6**	**100.0**	**6.983.6**	**100.0**	

Source: Adapted from the MapBiomas 7.0 database (2023).

To understand the absence of dense arboreal caatinga in this region, Souza and Souza (2016) point out that, during the process of occupation of Cariri, the use of fires during the expansion of agriculture and for the renewal of pastures considerably modified the vegetation cover of the caatinga. The authors also point out that severe droughts and the removal of wood for various purposes have had even more devastating effects. For Travassos and Souza (2014), in addition to the relationship between land use and desertification, another worrying fact is that the soils of the Cariri region of Paraíba have been transmuted over time as a result of successive deforestation. Allied to this is the action of erosive agents, causing a great deal of damage to its original natural characteristics.

The second class, with the largest area of land use and occupation, is the Mosaic of Uses, formed by areas of agricultural use, which showed a 24.21% reduction in its occupied area. With this data, four Use and Coverage maps were produced for the Western Cariri region of Paraíba, based on the 1989, 2005, 2013, and 2019 time periods (Figure 2).

According to MapBiomas, the year 1989 showed the following predominant classes: Savannah Formation, which is formed by a preponderance of Caatinga-steppe, has a shrubby-arboreal stratum and covers an area of 3950.8 km², equivalent to 56.57% of the total area (Table 3); and Mosaic of Uses, which is formed by areas of agricultural use and covers 2,053.4 km², equivalent to 29.40% of the area of Western Cariri (Table 3).

In 2005, the land cover of areas previously used for farming (Mosaic of Uses) was replaced. This represents a reduction of 18.02% (370.08 km^2). With this, they are now occupied only by livestock, with an increase of 35.96%, occupying 1,115.6 km2 of Western Cariri that year (Table 3). In addition, there was an increase in the population of this micro-region, in which the area occupied by urban infrastructure almost doubled, with an increase of 5.9 km^2 compared to 1989 (Table 3).

One of the main highlights of the Land Use and Land Cover analysis for 2013 is the 228.7 km^2 increase in the area of Caatinga, as well as the 29.05% increase in urban areas. On the other hand, there was a 61.81% reduction in areas covered by water (Table 3). This occurred because, from 2012, Western Cariri was hit by a prolonged drought, which lasted until 2018, as observed by Diniz et al. (2020). This drought was one of the worst in the last 50 years, which reduced all the water reservoirs in this region to the level of a public calamity.

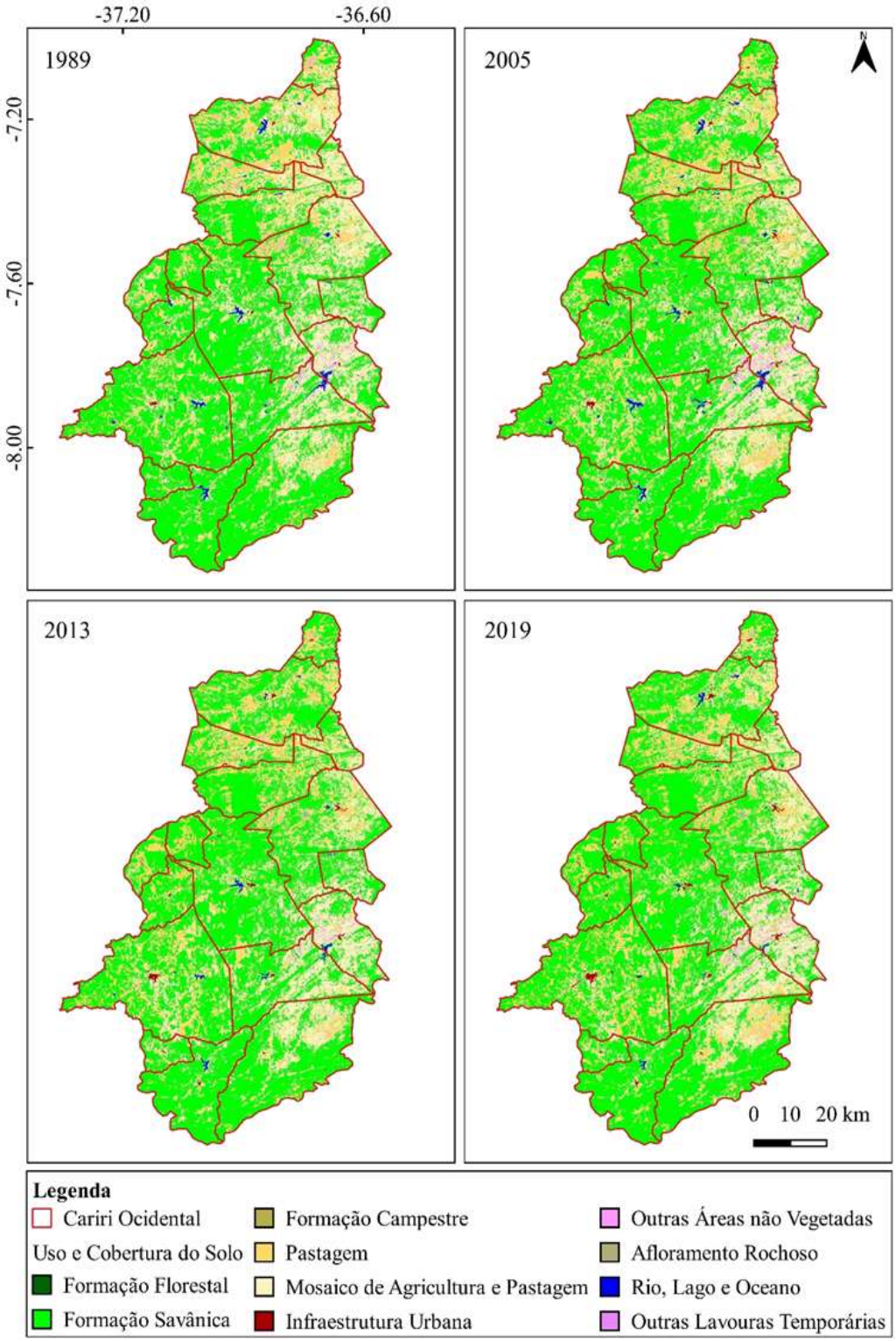

Figure 2 – Land use and land cover in Western Cariri, Paraíba (1989-2019)
Source: Own authorship, based on the MapBiomas 7.0 Database (2023).

For 2019, the predominant class of land use and cover in this region was also the Savannah Formation. This showed a small reduction in its coverage area of 1.97%, which corresponds to a decrease of 82.3 km^2, followed by the Mosaic of Uses, which showed a reduction in the area of 2.75%, corresponding to 44.0 km^2 when compared to 2013, as shown in Table 3.

According to MapBiomas data, around 90.0 km^2 (1.29%) of the territory of Western Cariri is made up of non-vegetated areas in the process of desertification. Souza et al. (2011), analyzing the evolution of desertification in the Cariri region of Paraíba, observed that the main areas in the process of desertification are located near the rivers, occupying the floodplains around the hydrographic basins that cross the region.

In the temporal comparison of the analysis of land use and occupation, the distribution of vegetation makes it possible to identify and characterize the behavior of the different typologies observed in the study area. The process of land use and land cover in the area that delimits Western Cariri underwent significant changes between 1989 and 2019.

In the first three situations presented (1989-2013), there is an increase in the area covered by Caatinga (Savannah Formation) of 228.6 km^2, with a small reduction in 2019 (82.3 km^2), accumulating an addition of 146.3 km^2 for this land cover class (Figure 2 and Table 3). However, as observed in fieldwork carried out by Souza et al. (2015b), when they assessed the degradation and risks of desertification in the upper reaches of the Paraíba River, the riparian forests present in small stretches of the region's rivers and streams are largely algaroba (*Prosopis juliflora*), an exotic species which, given the aggressiveness with which it establishes itself in floodplain environments, takes advantage of water resources. This has also contributed to the decline in the presence of native caatinga plants (Souza, 2008).

During this period, there was a 24.21% reduction in the area destined for farming (Mosaic of Uses), which represents a decrease of 497.1 km^2. However, it was observed that there was a 42.87% increase in the areas destined for pasture for animal husbandry. In addition, it was possible to distinguish, through the satellite images of Western Cariri, the classes of Other Temporary Crops (from 2005) and Rock Outcrop (from 2019), as seen in Figure 2 and Table 3.

In these 30 years, the Western Cariri region of Paraíba has accumulated an increase of 351.7 km^2 in pasture area (Table 3). According to Moreira and Targino (1997), agricultural activity in Cariri is low, mainly due to the lower availability of water. As a result, goat farming and firewood extraction predominate in the region. In addition, the lack of other economic alternatives has contributed to growing environmental degradation, making life increasingly difficult for rural people (Barbosa et al., 2007).

As noted by Souza et al. (2015b), anthropogenic activities are leading to an impoverishment of the vegetation that increases over time. In addition to this, there are also the consequences of prolonged droughts and their influence on the remnants of the caatinga. Rosa et al. (2019), through an analysis of land use and cover, observed the loss of 890,000 km^2 of native vegetation in Brazil between 1985 and 2018, leaving around 5.69 million km² of native vegetation cover. At the same time, the agricultural area increased by 250%, reaching 600,000 km², and the pasture area increased by 37%, rising to 1.74 million km².

MapBiomas data also shows that there has been a reduction of more than half (51.33%) of the area covered by water bodies (Table 3). According to data from the Executive Water Management Agency (2023), it rained an average of only 549.0 mm in Western Cariri in 2019. This figure is around 10% lower than the historical average for the region, which is 611.0 mm and exposes another worrying environmental factor: periodic droughts. Also, according to AESA (2023), below-average rainfall was recorded throughout the period from 2012 to 2019, with only 137.9 mm of rain observed in 2012 in this region. This is an alarming factor because, according to the IPPC (2014), a 22% reduction in the rainfall regime in the Northeast is projected, which is associated with a reduction of approximately 24.6% in the flow of the São Francisco River.

One worrying fact is that 90.0 km^2 is made up of non-vegetated areas, corroborating studies that point to increasing desertification in the Brazilian semi-arid region. According to the Intergovernmental Panel on Climate Change (2019), desertification is the degradation of land in arid, semi-arid, and dry sub-humid areas, commonly known as drylands, caused by a variety of factors, including human activities and climate change. Also, according to the Intergovernmental Panel on Climate Change (2014), the extent and intensity of desertification in some dry areas has increased in the last 5 years.

In contrast, Urbanized Areas grew by around 260% over the period. The area occupied by cities was 6 km^2 in 1989, rising to 21.6 km^2 in 2019. According to the IBGE (2022), the population of this region in 2022 was 124,964. According to Silva and Azevedo (2020), the metropolitan regions and small towns of the Northeast are expected to be directly affected by climatic phenomena such as extreme temperatures, droughts, floods, and landslides, among other disasters.

Estimates suggest that approximately 13% of Brazil's semi-arid region has already been affected by desertification. According to the Ministry of the Environment (Brazil, 2007), desertification is already affecting 1,488 municipalities, home to 32 million people, representing 85% of the country's poor (Souza et al., 2015a; Buriti, Barbosa, 2018).

For Silva and Azevedo (2020), the medium- and long-term outlook for the northeast is not at all promising. The increase in records of extreme hydrological events in the region validates the importance of using tools to monitor and reduce their impacts. Lins (2022) points out that changes in vegetation for the exploitation of forest products and extensive animal husbandry have put more than 97% of the remaining dry tropical forest areas at risk.

Therefore, the natural regeneration of these forests is an important process, as it is capable of maintaining their productivity and the ecosystem services related to the production of forest biomass. Tackling global challenges related to sustainability, such as the reduction of biodiversity and food insecurity, will depend on changes in land use and occupation, since it greatly affects carbon sources, causing habitat loss, as well as sustaining food production (Lins, 2022).

4 Final considerations

The data from MapBiomas 7.0 provided insight into the classes of land use and occupation. The bibliographic study enabled them to be associated with local social actors, in terms of their natural, economic, social, and cultural aspects. However, this classification fails to distinguish between native forests and forests formed by invasive species, such as the algaroba (*Prosopis juliflora*), which requires validation in the field.

Given the data, it is possible to observe the increase in population in this region, which brings even greater pressure to an already fragile ecosystem. The advance of desertification in Western Cariri could lead to irreversible damage, such as the replacement of natural vegetation with exposed soil, the extinction of native animal species, and soil degradation. It can therefore be concluded that the MapBiomas tool can be used in studies to monitor desertification in the country. However, the low resolution of the MapBiomas images opens up the possibility of future work using images with a higher resolution, such as the Sentinels or CBERS 04A.

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