



Importance of land use and rainfall in the dynamics of the Caatinga vegetation cover in Northeastern Brazil

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ABSTRACT. Many factors, such as climate, land use, and cultural and social aspects, influence the vegetation cover dynamics. We aimed to analyze the vegetation cover dynamics in three municipalities of the Brazilian semi-arid region (Aroeiras, Boqueirão, and Congo, state of Paraíba, Brazil) and to check for the influence of land use and inter-annual variations in rainfall. We selected 18 Landsat satellite images between 1995 and 2017. We performed supervised classification based on pre-established regions of interest: Closed or conserved vegetation, Sparse or disturbed vegetation, Exposed soil, Water bodies, clouds, and shadows, according to color, shape, and texture criteria. In addition, we collected data from the IBGE's Agricultural Census and annual rainfall. Variations in land use and rainfall variations worked synergistically on vegetation cover dynamics. In the municipality of Congo, very wet years were associated with higher percentages of closed vegetation and decreased soil exposure. High percentages of land use were related to a higher cover of sparse vegetation and exposed soil. In Boqueirão, we observed the opposite phenomenon, with drier years associated with higher percentages of closed vegetation and exposed soil. In Aroeiras, we identified no clear relationship between rainfall and variations in vegetation cover. Similar to that observed in the other municipalities, the abandonment of agricultural and cattle ranching activities increased dense vegetation. Our results show that the analysis of land use and vegetation cover dynamics in the semi-arid region represents a complex task ranging from regional factors, such as climate, characterized by inter-annual rainfall variations, to local factors, such as land use intensity and demographic/social aspects.

Keywords: temporal analysis; remote sensing; semi-arid; Landsat.

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Introduction

Seasonally dry tropical forests (SDTFs) are Biomes with varied phytophysognomies, including tall forests in wetter locations and vegetation rich in succulent plants in drier areas (Linares-Palomino, Oliveira-Filho, & Pennington, 2011). Regarding global coverage, SDTFs comprise about 42% of the planet's tropical and subtropical forest area and are considered the world's second most important forest type (Linares-Palomino et al., 2011). Studies show that SDTFs present a loss of native vegetation cover at a more alarming rate than tropical rainforests in Latin America (Aide et al., 2012). Between 2001 and 2010, there was a loss of dry forest cover by 3.8% of the area in square kilometers, while wet forests lost 1.9% (Aide et al., 2012). These changes in land cover have multiple causes, such as climate variations, the advance of agriculture and cattle ranching, logging, urban expansion, land structure, and cultural factors, among others.

Agricultural and cattle ranching activities and climate variations have a determining influence on forest cover dynamics and represent the most studied factors (Aquino, Rocha Neto, Moreira, Teixeira, & Andrade, 2018; Aquino, Andrade, Filho, & Campos, 2021; Grau, Gasparri, & Aide, 2005; 2008; Schulz, Cayuela, Echeverria, Salas, & Benayas, 2010). In the municipality of Tauá, in the state of Ceará, Brazil, in years with rainfall above the historical average, there was a significant increase in degraded areas, resulting from the advance of land incorporated into subsistence agriculture. On the other hand, the opposite behavior was found in drought periods. There was a natural regeneration of the shrub-tree stratum due to the abandonment of agricultural areas (Aquino et al., 2018).

When analyzing the dynamics of land cover and land use in the municipality of Quixadá, Ceará State, Brazil, Aquino et al. (2021) found that in years of severe drought, there was a decrease in conserved Caatinga and growth of disturbed areas, with modification of the herbaceous and shrub strata. For these authors, rainfall does not have as much influence on vegetation dynamics. It is more closely correlated with disturbed areas than with the natural regeneration of the forest cover since plants native to the Caatinga are adapted to cope with water stress. Aquino et al. (2021) indicated that vegetation regeneration was associated with increasingly frequent fallowing practices and rural exodus in the Northeast region and not necessarily with above-average rainfall. Thus, these results diverged from those found by Aquino et al. (2018).

Agriculture and cattle ranching act in synergy with climate variations and influence the vegetation cover dynamics, and can even lead to desertification (Primavesi, 2016). However, it is immature to think that using these two means of production is unnecessary. In Chile's dry forests, urban and agricultural expansion, cattle ranching, logging, and the introduction of exotic species persist throughout the region and have led to soil degradation (Schulz et al., 2010). In the Chaco region, Grau et al. (2005; 2008) estimated a loss of 588,900 hectares (20%) of dry forest between 1970 and 2000. They state that the high degree of deforestation is strongly associated with the increased human population and agricultural expansion. In Brazilian dry forests, research conducted in the upper Paraíba River sub-basin has shown a relationship between desertified or desertification areas with cattle ranching (cattle and goats) and the extraction of wood for firewood manufacturing (Travassos & Souza, 2014; Leal, Vicente, & Tabarelli, 2003). Chronic disturbances linked to these types of exploitations have also caused a reduction in biodiversity and compromised land cover (Tabarelli, Leal, Sacarano, & Silva, 2018).

It is worth noting that the vegetation cover and land use dynamics in SDTFs and their causes still lack a better understanding because of the multiple causes involved. Multi-temporal studies on land use and land cover changes are still incipient (Lambin, Geist, & Lepers, 2003; Oliveira et al., 2022). A better understanding of this issue is essential for seeking better conservation strategies and less harmful alternatives to the environment without implying a delay in the economic development of the people inhabiting these regions. Therefore, the importance of research in this area goes beyond environmental aspects to the social sphere since land use/land cover changes also determine, in part, the vulnerability of places and people to climatic, economic, and socio-political disturbances (Lambin et al., 2003; Margono et al., 2012).

Remote sensing represents an essential tool in monitoring forest use and forest cover dynamics across the globe (Grinand et al., 2013; Margono et al., 2012). Using satellite images is based on the fact that each element of the landscape (water, vegetation, soil, etc.) interacts in a certain way with the electromagnetic radiation (EMR) that is subsequently captured by remote sensors (Ponzoni, 2002). These differences stem from the physicochemical and biological properties of the different landscape elements (Moreira, 2011). In the case of vegetation, characteristics such as density and distribution of individuals, biomass, and phenology interfere with the spectral response, which allows differentiating vegetation physiognomies (Ferreira, Ferreira, & Ferreira, 2008).

The Caatinga domain (Andrade-Lima, 1981) represents one of the large SDTF clusters in South America (Moro, Lughadha, Araújo, & Martins, 2016). It is characterized by a semi-arid climate, predominant in the Northeast region of Brazil (Nimer, 1989). In this domain, there is a predominance of average annual rainfall, generally less than 1,000 mm (Moro et al., 2016), high evapotranspiration rates, and high average annual temperatures, predominantly between 24 and 26°C (Alvares, Stape, Sentelha, Gonçalves, & Sparovek, 2014). In the Northeast region of Brazil, rainfall has high intra- and inter-annual variability, which imposes on vegetation a dynamic strongly related to water availability (Barbosa, Huete, & Baethgen, 2006; Marengo, Alves, Beserra, & Lacerda, 2011).

The Caatinga has a history of chronic use over the centuries. Changes in vegetation began with the Brazilian colonization process due to cattle ranching, associated with rudimentary agricultural practices (Andrade, Pereira, Leite, & Barbosa, 2005). A mapping done by Map Biomas (<https://mapbiomas.org/>) revealed that 63% of the biome is still covered with native vegetation, while 35.2% of the territory is used for agriculture and cattle ranching activities. Within this percentage of native vegetation, there has been a 23% increase of disturbed areas and a 10% loss of caatinga cover in the last 35 years. This study aimed to analyze the vegetation cover dynamics in three municipalities of the Brazilian semi-arid region, specifically in Cariri, in the state of Paraíba, Brazil, and to investigate whether the native vegetation dynamics are related to land use and rainfall variations over time. Thus, we used data from the Brazilian agricultural census, annual rainfall data, and satellite image analyses between 1995 and 2017.

Material and methods

Study site

The study was conducted in the municipalities of Aroeiras and Boqueirão, in the Eastern Cariri Microregion, and in the municipality of Congo, in Western Cariri, state of Paraíba, Brazil (Figure 1). These municipalities are inserted in the most degraded Caatinga area in Paraíba in recent years (Alves, Nascimento, & Souza, 2009; Vendruscolo et al., 2020) and represent areas of Northeast Brazil susceptible to desertification (Araújo & Barbosa, 2019; Souza, Suertegaray, Antunes, & Lima, 2011). The municipalities analyzed here are located in the upper and middle course of the Paraíba River (Figure 1). They are included in the Long Term Ecological Project (PELD) Integrated Paraíba River (RIPA) Research Program. This program proposes studies related to the Paraíba River Basin, aiming at receiving the waters of the São Francisco River, climate change, and the integration of research with a focus on socio-environmental and economic sustainability.

The three municipalities are located in a region with a semi-arid climate of low latitude and low altitude (BSH) (Alvares et al., 2014), with average annual rainfall of 526, 426, and 411 mm (historical series between 1994 and 2017) concentrated from February to April (<http://www.aesa.pb.gov.br/>), and average annual temperatures around 26°C (Alvares et al., 2014). The region is inserted in the Caatinga Domain (Andrade-Lima, 1981), whose vegetation presents adaptations to water stress, such as loss of leaves during drought, spinescence, stunted growth of woody species, and water accumulation in the tissues, as occurs in Cactaceae and Bromeliaceae (Alves, 2007). The vegetation of Cariri is characterized by a shrub-tree physiognomy, with a predominance of leguminous species, and seasonal herbaceous vegetation little known but cited as highly diverse (Alves, 2007; Alves et al., 2009; Barbosa et al., 2007).

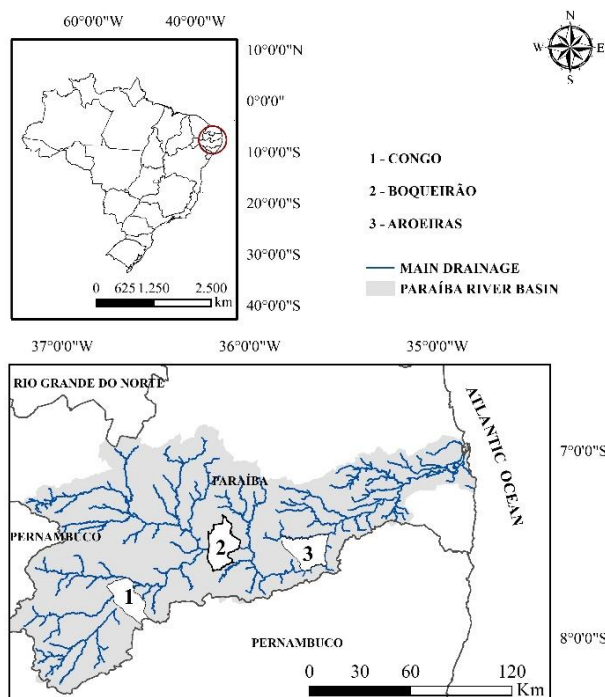


Figure 1. Municipalities of Aroeiras, Boqueirão, and Congo, state of Paraíba, Brazil. Sources: AESA (Retrieved from <http://geoserver.aesa.pb.gov.br/geoprocessamento/geoportal/shapes.html>), IBGE (Retrieved from <https://www.ibge.gov.br/geociencias/downloads-geociencias.html>).

Data collection

The vegetation cover dynamics was evaluated using Landsat 5 and 8 (Land Remote Sensing Satellite) satellite images obtained from the OLI sensor, with a spatial and temporal resolution of 30 m and 16 days, respectively. We conducted searches on the U.S. Geological Survey website (<https://earthexplorer.usgs.gov/>). As a result, we obtained 18 images at the surface reflectance level and with low cloud cover referring to the municipalities of Aroeiras, Boqueirão, and Congo between 1995 and 2017 (Table 1). Since rainfall can interfere with land use and vegetation regeneration, we looked for images of years with annual rainfall around the

historical average and years with rainfall well above/below the historical average. Images were preferably taken during the drought period because there are many clouds during the rainy season, which makes it impossible to see the landscape elements.

Table 1. Information from the images collected at the study site.

Municipalities	Image acquisition date			Path/row	Satellite
Aroeiras	06/14/1997	06/04/1999	02/10/2004	214/65	Landsat 5 and 8
	08/26/2006	01/04/2014	12/14/2017		
Boqueirão	04/29/1995	10/14/1998	12/17/2004	214/65	Landsat 5 and 8
	04/07/2007	08/04/2013	11/19/2017	215/65	
Congo	04/29/1995	10/14/1998	11/02/2005	215/65	Landsat 5 and 8
	04/19/2009	04/14/2013	11/19/2017		

In order to identify factors related to vegetation cover dynamics, we collected land use and annual rainfall data. We used data from the Agricultural Census of the Brazilian Institute of Geography and Statistics (IBGE) for 1995/96, 2006, and 2017 (<https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/20700-1995-1996-censoagro1995.html?edicao=18356&t=downloads>) and annual rainfall data between 1994 and 2017 on the website of the Executive Agency for Water Management of the state of Paraíba – AESA (<https://www.aesa.pb.gov.br/aesa-website/meteorologia-chuvas/>).

Image Processing and Mapping

After acquiring the scenes, we reprojected them for the Southern Hemisphere, Datum WGS 1984 UTM Zone 24/25S, because they are available with projections for the Northern Hemisphere. Then, for each municipality and year, we combined the visible region bands (blue, green, and red) into a single color image called "true color". Based on the *extract by mask* tool, we delimited the colored compositions according to the *shapefile* of each municipality.

The classification of the color compositions was obtained using the Supervised Classification Maximum Likelihood method based on pre-established regions of interest: closed or conserved vegetation, sparse or disturbed vegetation, exposed soil, water bodies, clouds, and shadows, according to color, shape, and texture criteria. From the selected regions of interest, we obtained error matrices and calculated the Kappa coefficient of agreement (k) to evaluate the performance of the classification method. We considered the intervals suggested by Congalton and Green (2008), where $k < 0.4$ is considered poor, k between 0.4 and 0.8 is reasonable, and $k > 0.8$ is excellent. All ratings were satisfactory, with k between 0.8 and 0.9. All these processes were performed in ArcMap 10.6 (21-day trial license). Based on the mapping, we calculated the percentage coverage of each class regarding the total area of each municipality. In order to better understand the results, we present the land cover percentages associated with the rainfall data (historical and annual averages).

Results

Land use and land cover in the municipality of Congo

Closed vegetation showed the highest percentages of cover, above 40%, in 1995, 1998, and 2009, and the lowest values, between 30 and 40%, in 2005, 2013, and 2017 (Figure 2). For disturbed or sparse vegetation, percentages were between 25% and 30% in 1995, 1998, 2005, and 2017. The lowest percentages of coverage for this class were observed in 2009 and 2013, between 15 and 20%. Regarding soil exposure, the highest percentage was 28% in 2017 (Figure 2). In previous years, the exposure of exposed soil ranged between 12 and 16% (Figure 2).

Years with annual rainfall well below the historical average tended to show less closed vegetation cover and more exposed soil (Figure 2, Table 2). On the other hand, in the wettest years, we observed more closed vegetation cover and less exposed soil. Furthermore, the percentages of vegetation cover did not respond only to the rainfall of the corresponding year but were influenced by the rainfall of previous years (Figure 2). The year 2009 was characterized by the highest rates of closed vegetation and was preceded by four years with above-average rainfall (2004, 2005, 2006, and 2009). In 2017, we observed the highest levels of soil exposure (approximately 30% of the area), and in the previous five years, rainfall was below the historical average. For the disturbed vegetation, the wettest years tended to show higher percentages (Table 2).

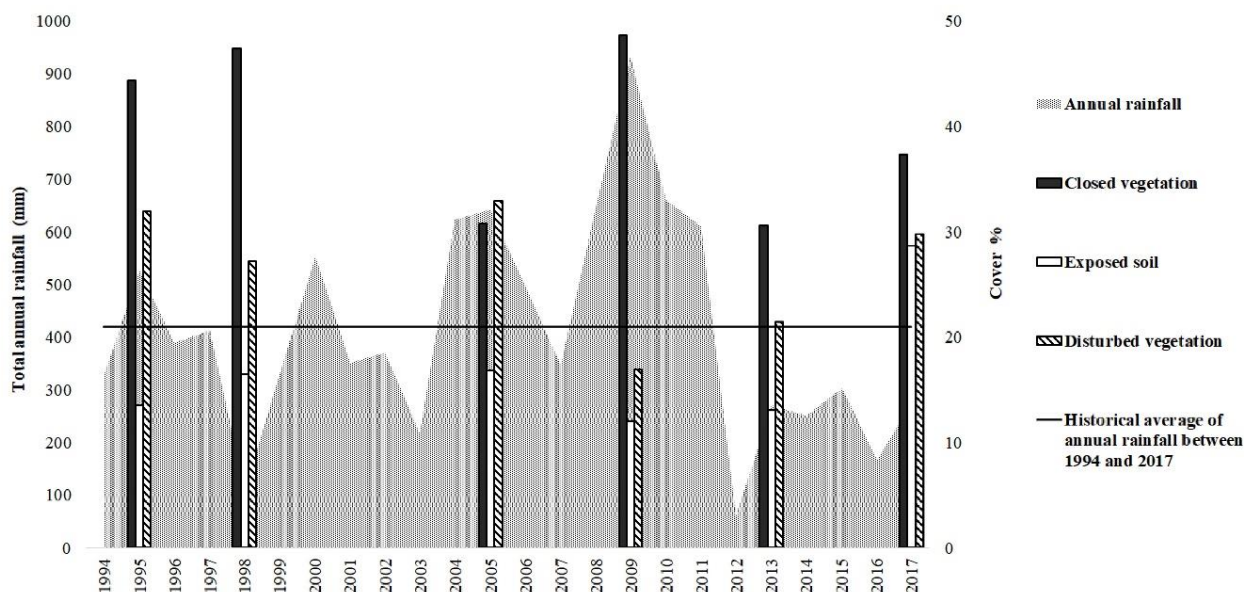


Figure 2. Dynamics of vegetation cover and exposed soil associated with annual rainfall for the municipality of Congo, state of Paraíba, Brazil. The columns represent the cover percentages of closed vegetation, disturbed vegetation, and exposed soil. The black colored line represents the historical average annual rainfall between 1994 and 2017. The dotted area indicates the total annual rainfall between 1994 and 2017.

Table 2. Average and standard deviation of the percentages of vegetation cover of the mapped classes according to rainfall, municipality of Congo, state of Paraíba.

Classes	Very dry years (1998, 2013, and 2017)	Very rainy years (1995, 2005, and 2009)
Closed vegetation	38.44 ± 5.97	41.26 ± 6.99
Exposed soil	19.39 ± 6.17	14.14 ± 1.82
Disturbed vegetation	26.13 ± 3.14	27.25 ± 6.90

As for the data obtained from the Agricultural Census for the municipality of Congo, Paraíba State, Brazil (Figure 3), crops comprised about 47% of the territory in 1995, decreasing considerably in 2006 and 2017, with percentages of 8 and 1%, respectively. Pasture areas presented a different dynamic, with high values in 1995, around 34%, decreasing greatly in 2006, and returning to high percentages in 2017. Considering farming and pasture activities together, they corresponded to 81% of the municipality's territory in 1995, which suggests that these activities were developed not only in the sparse Caatinga areas or without vegetation (typical use in the semi-arid region) but also in dense vegetation.

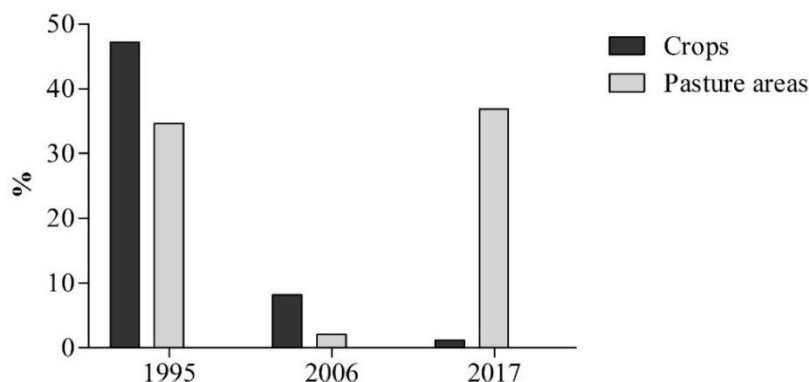


Figure 3. Percentage of land use in the municipality of Congo, state of Paraíba, Brazil, in 1995, 2006, and 2017. Source: Agricultural Census – IBGE (Retrieved from <https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/20700-1995-1996-censoagro1995.html?edicao=18356&t=downloads>).

In 2006, agriculture and cattle ranching corresponded to 10% of the territory and showed a very significant decrease between 1995 and 2006. In 2017, crops and pastures comprised about 38% of the land cover. This

increase in agropastoral activities between 2006 and 2017 was followed by an increase in disturbed vegetation and exposed soil between 2009 and 2017 (Figure 2), suggesting that the land use in this period is related to the dynamics of the areas of exposed soil and disturbed vegetation. Based on the data obtained, the relationship between the dynamics of land use and closed vegetation areas is not very clear or shows no significant direct relationship.

Land use and land cover in the municipality of Boqueirão

Considering land cover dynamics (Figure 4), closed vegetation showed the highest percentages of cover in 1995 and 2017, between 55 and 60%. In the other years, the percentage ranged between 47 and 49%. Overall, the closed vegetation showed approximate percentages throughout the analyzed years. For the exposed soil class, we observed a percentage of 9% in 1995, decreasing in 1998 and 2004 (3%), and with an increasing trend in the following years, reaching 10% in 2017. The disturbed or sparse vegetation showed percentages of 9, 13, and 10% in 1995, 1998, and 2004, respectively. In the following years, there was an increase in these areas, reaching a percentage of 17% in 2017 (Figure 4).

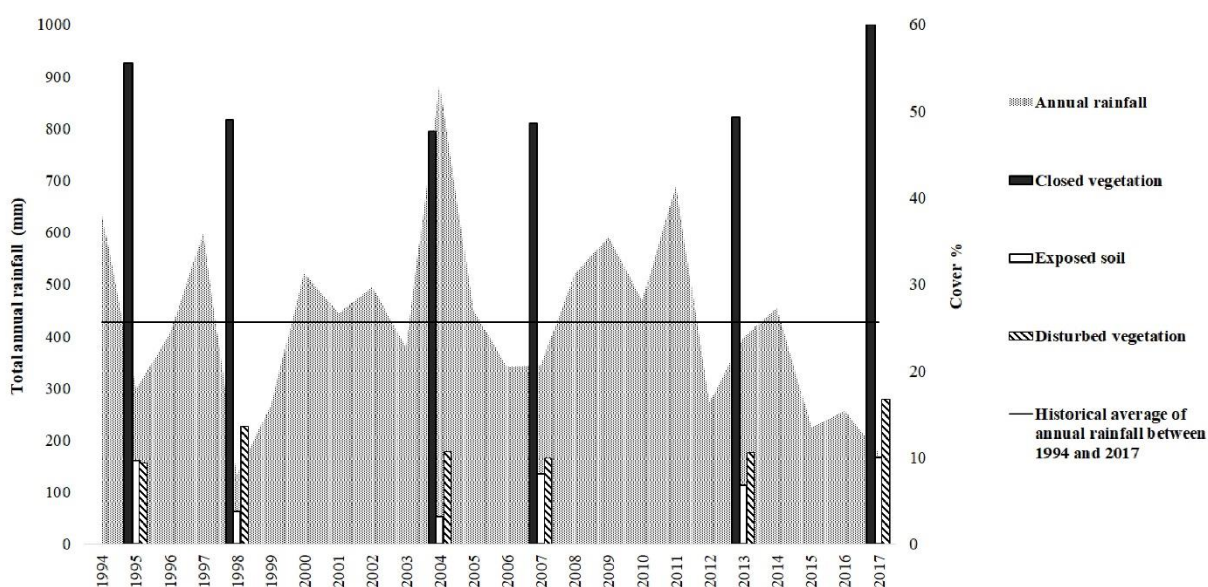


Figure 4. Dynamics of vegetation cover and exposed soil associated with annual rainfall for the municipality of Boqueirão, state of Paraíba, Brazil. The columns represent the percentages of closed vegetation, disturbed vegetation, and exposed soil. The black colored line represents the historical average annual rainfall between 1994 and 2017. The dotted area indicates the total annual rainfall between 1994 and 2017.

The analysis of cover percentages along with the annual rainfall variation (Figure 4, Table 3) indicated that years with near-average annual rainfall and drier years tended to have higher percentages of closed vegetation and exposed soil. Regarding the disturbed or sparse vegetation cover, the percentages between the years overlapped, considering the range of percentages in the driest years, between 9.6 and 15.2%.

Table 3. Percentages of the cover of mapped classes according to rainfall, municipality of Boqueirão, state of Paraíba, Brazil. Very dry years comprise the mean and standard deviation.

Classes	Very dry years (1995, 1998, 2007, and 2017)	Very rainy year (2004)	Year with near-average rainfall (2013)
Closed vegetation	53.29 ± 4.47	47.59	49.31
Exposed soil	7.90 ± 2.04	3.2	6.8
Disturbed vegetation	12.43 ± 2.77	10.65	10.59

Agricultural and cattle ranching activities showed higher percentages in 1995, decreasing considerably in 2006 and 2017 (Figure 5). Crops comprised about 12% of the territory in 1995, decreasing in the following years, with percentages of 3 and 1.7%. Pastures showed a similar dynamics but with a steeper decrease, with 48% coverage in 1995 and about 1% in the following years (Figure 5).

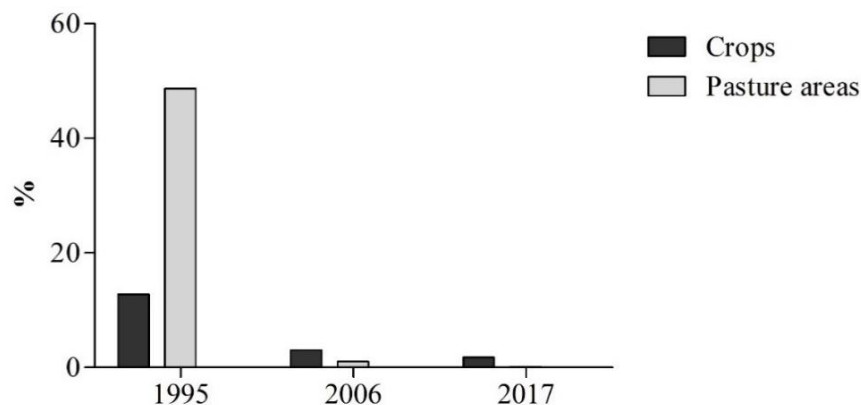


Figure 5. Percentage of land use in the municipality of Boqueirão, state of Paraíba, Brazil, in 1995, 2006, and 2017. Source: Agricultural Census – IBGE (Retrieved from <https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/20700-1995-1996-censoagro1995.html?edicao=18356&t=downloads>)

The joint analysis of the mapping data with the usage data showed a sharp reduction in agricultural and cattle ranching activities, which preceded the increase in closed vegetation in recent years. Thus, it seems that the increase in vegetation cover is due to the abandonment of the land and, consequently, vegetation regeneration. When analyzing the evolution of the percentages of disturbed vegetation, there was an increasing trend in recent years, even after the decrease in use activities. However, it is worth noting that between 2012 and 2017 a considerable sequence of drier years caused a sharp reduction in water bodies (Figure 4) and, consequently, an increase in areas of exposed soil and secondary vegetation.

Land use and land cover in the municipality of Aroeiras

Very low percentages of soil exposure were observed, less than 1% in all analyzed years (Figure 6). Between 1997 and 2006, the percentages of closed vegetation decreased, ranging from 41.8% to 33.5%. In the following years, 2014 and 2017, there was an upward trend, with percentages of 50% and 60%, respectively. For the disturbed or sparse vegetation, we observed an opposite trend, with an increase in 1997 and 1999, and a decrease in 2014 and 2017, reaching a percentage of 7% (Figure 6).

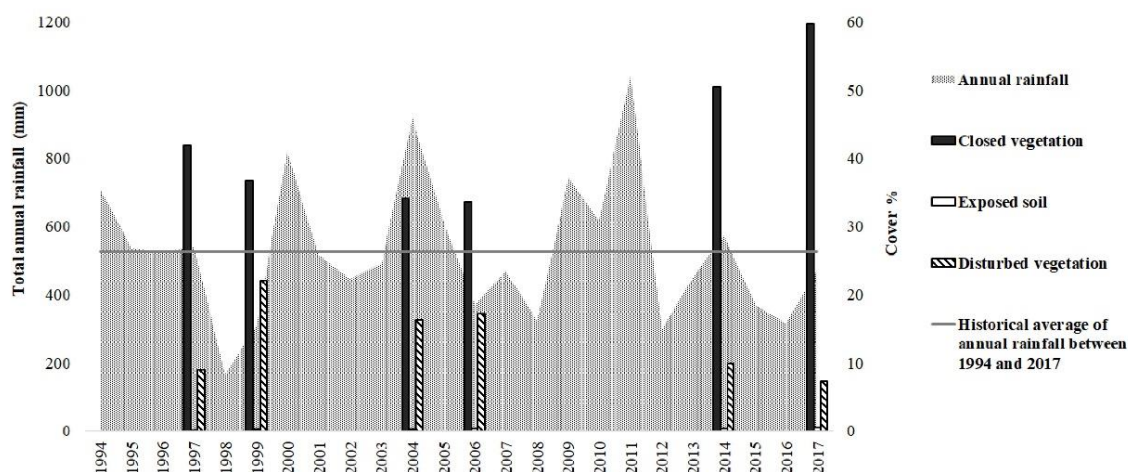


Figure 6. Dynamics of vegetation cover and exposed soil associated with annual rainfall for the municipality of Aroeiras, state of Paraíba, Brazil. The columns represent the percentages of closed vegetation, disturbed vegetation, and exposed soil. The black colored line represents the historical average annual rainfall between 1994 and 2017. The dotted area indicates the total annual rainfall between 1994 and 2017.

Regarding the cover percentages along with the annual rainfall variation (Figure 6, Table 4), we found overlapping percentages of closed vegetation, exposed soil, and disturbed/sparse vegetation under the different rainfall conditions, suggesting no differences between the mapped years. There was a similar result to that in the municipality of Congo: a series of rainy years can result in an increase in the percentage of closed vegetation in the following years. For example, 1997 (Figure 6) was preceded by a period of rainfall

above or close to the historical average, and in that same year, the closed vegetation presented a percentage of approximately 42%. In 1998 and 1999, annual rainfall dropped considerably, followed by a decline to 36% of closed vegetation in 1999.

Table 4. Percentages of the cover of mapped classes according to rainfall, municipality of Aroeiras, state of Paraíba, Brazil. The driest and rainiest years are represented by the mean and standard deviation.

Classes	Driest Years (1999, 2006, and 2017)	Rainiest Years (2004 and 2014)	Year with near-average rainfall (1997)
Closed vegetation	43.3 ± 10.92	42.23 ± 8.2	41.87
Exposed soil	0.4 ± 0.09	0.36 ± 0.08	0.1
Disturbed vegetation	15.5 ± 5.44	13.10 ± 3.19	8.94

Similar to Boqueirão, agriculture and cattle ranching activities showed higher percentages in 1995, decreasing in 2006 and 2017 (Figure 7). Crops comprised about 22% of the municipality's territory in 1995, decreasing in the following years, with percentages of 9 and 7%, approximately. Pastures presented similar dynamics but with a steeper decrease, with 63% of cover in 1995, 20% in 2006, and 17% in 2017.

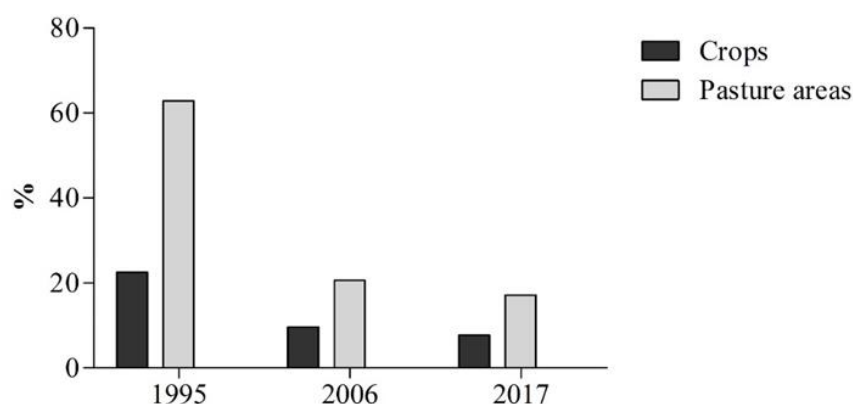


Figure 7. Percentage of land use in the municipality of Aroeiras, state of Paraíba, Brazil, in 1995, 2006, and 2017. Source: Agricultural Census – IBGE (Retrieved from <https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/20700-1995-1996-censoagro1995.html?edicao=18356&t=downloads>)

The joint analysis of the mapping data with the land use data (Figures 6 and 7) showed that the reduction in agricultural and cattle ranching activities in 2006 and 2017 coincided with a period of increasing dense vegetation cover, which denotes the abandonment of land and then the vegetation regeneration over the years. Between 2006 and 2017 (Figure 6), there was a series of very dry years and, despite this, a high percentage of closed vegetation, suggesting a more determining influence from land use than climate for this cover class. The percentages of disturbed/sparse vegetation up to 2006 were mostly the highest among the series of mapped years, suggesting that these percentages are consequences of the high percentage of land use. For example, in 1995, the percentage of agricultural and cattle ranching activities corresponded to 84% of the Aroeiras territory (Figure 7).

Figure 8 illustrates satellite images of the three municipalities (true composition) in different years, showing variations in exposed soil and closed vegetation in the analyzed period.

Discussion

Our data show that land use and vegetation dynamics differ between municipalities, corroborating the idea that local factors are of utmost importance when analyzing land use and vegetation dynamics (Aide et al., 2012). Therefore, it is important to analyze the phenomena that apply to the three municipalities and then move on to particular situations. Among these characteristics in common, 2006 presented a very expressive decrease in land use, which can be attributed to social factors, such as the rural exodus, causing farmers to abandon the caatinga areas, favoring the secondary ecological succession process. According to data collected from the State and Municipal Development Institute - IDEME (2013), the urban population of Aroeiras increased from 25.71% in 1991 to almost 49.95% in 2010, while the rural population decreased from 74.29% in 1991 to 50.05% in 2010. For the population of Boqueirão, this trend was repeated. Its urban population

increased from 39.37% in 1991 to 71% in 2010, corroborating the hypothesis. This land abandonment may also be related to the income transfer policies implemented by the federal government since 2004, increasing the financial independence of the rural population.

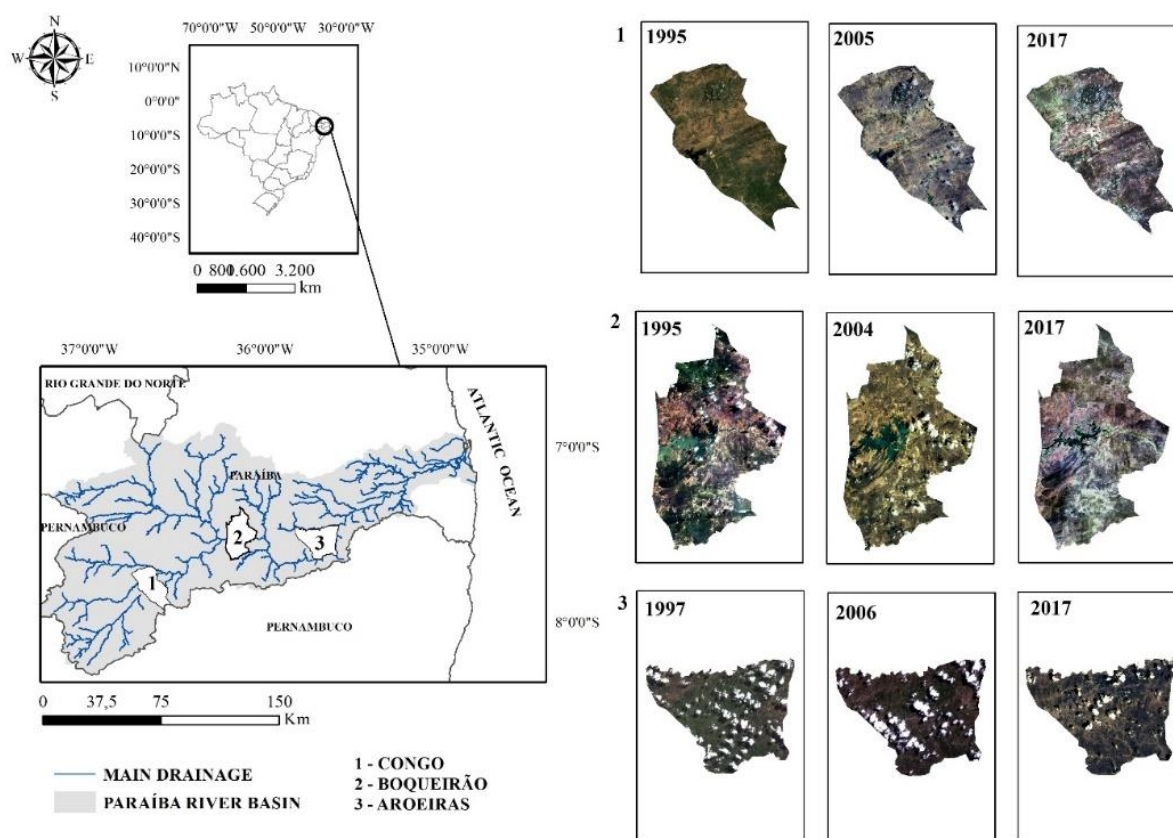


Figure 8. Satellite images of the municipalities, analyzed in different years.

This sharp decrease in agricultural and cattle ranching activities between 1995 and 2006, which may last until 2017, results in increased closed vegetation in the following years, as demonstrated by Aide et al. (2012). In a temporal analysis of land use and cover dynamics in Latin America, these authors identified an increase of more than 40% in Caatinga woody vegetation, between 2001 and 2010, related to a decrease in agriculture and cattle ranching.

Furthermore, the vegetation cover dynamics of the analyzed municipalities were not influenced by single factors, whether climate or use. The vegetation seems to respond to a set of causes and conditions. Considering the municipality of Boqueirão, the decrease in land use led to an increase in closed vegetation cover, even in periods of severe drought, indicating that use seems to have a stronger influence on the dynamics of the conserved vegetation. Importantly, this municipality has a large reservoir, the Boqueirão Dam, which supplies several other cities and increases/subsidizes the surrounding agriculture. For the municipalities of Congo and Aroeiras, the closed vegetation dynamics seem to be concomitantly influenced by climate and land use.

Another interesting issue concerns prolonged drought periods, which can reduce plant populations and ground cover. It is known that prolonged periods of drought interfere with the ability of plants to regenerate, even in an environment under a seasonal climate (Stampfli & Zeiter, 2004; Silveira, Martins, & Araújo, 2017). When analyzing the population dynamics of *Croton blanchetianus* Baill, a very common species in the Caatinga, in two years with rainfall well below the historical average, Lacerda et al. (2018) identified that the number of dead individuals was much higher than the number of recruited ones, which demonstrates that climate can interfere with the increase or loss of vegetation cover.

As expected, the relationships between exposed soil, disturbed/sparse vegetation, and land use seem well-established. The higher the use, there is a tendency for a higher percentage of disturbed Caatinga and exposed soil, corroborating Aquino et al. (2018), Aquino et al. (2021), Barbosa et al. (2006), Grau et al. (2005; 2008), Marengo et al. (2011), and Schulz et al. (2010).

Conclusion

Considering the results presented here, we conclude that the analysis of the dynamics of land use and vegetation cover in the semi-arid region represents a complex task involving regional factors, such as climate, characterized by interannual variations in rainfall, and local factors, such as the degree of land use and demographic aspects. Given the analysis of the results, implementing public policies for income transfer and the migration of the population from rural to urban areas may be related to the decrease in agricultural and cattle ranching activities. The decrease in these activities provided for vegetation regeneration and, consequently, the increase in vegetation cover. Another important aspect refers to the climate. Series of rainy years contribute to vegetation regeneration, while prolonged drought periods can inhibit agricultural practices and favor vegetation cover restoration. Our study provides interesting results on the dynamics of land use and cover in the Cariri region of Paraíba and the Brazilian semi-arid region. Multiple causes interfering with the vegetation dynamics, whether natural or anthropogenic, act in synergy and their importance may vary over time.

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