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Susceptibility to desertification in a semiarid microregion of Brazil

Susceptibilidade à desertificação em uma microrregião semiárida do Brasil

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Abstract: The susceptibility to desertification is a real concern for environmental Conservation and human survival in semiarid areas of Brazil. The present work had as objective analyzing the susceptibility to desertification of the microregion of Ribeira do Pombal in Bahia State, Brazil. Data on agricultural, territorial, economics, vegetation cover, land use and deforestation aspects and shapes for the microregion were collected from specific literature and official government agencies and analyzed together by image overlay for confection of thematic maps using Shapes through the software Quantum GIS 1.7.4. As result, the local vegetative cover comprises 35% of its original formation with the largest remnants of Caatinga located in the municipalities of Itapicuru and Ribeira do Amparo. By the General Index of Environmental Degradation, the microregion is at a fairly high level of degradation, with the highest IGD in Adustina and Paripiranga (0.21 < IGD < 0.30), and Antas, Cipó and Nova Soure with the minors (IGD < 0,10). By the Aridity Index and Drought Incidence Index, the different types and levels of environmental degradation, the thermal instability, the low and irregular rainfall in the microregion of Ribeira do Pombal, more than 90% of the microregion is susceptible to moderate desertification, especially Ribeira do Pombal, Banzaê, Cicero Dantas, Novo Triunfo and Antas.

Keywords: Microregion; Semiarid; Desertification.

Resumo: A suscetibilidade à desertificação é uma preocupação real para a conservação ambiental e a sobrevivência humana em áreas semiáridas do Brasil. O presente trabalho teve como objetivo analisar a susceptibilidade à desertificação da microrregião de Ribeira do Pombal no estado da Bahia, Brasil. Dados sobre aspectos agrícolas, territoriais, econômicas, de cobertura vegetal, uso do solo, desmatamento e *Shapes* para a microrregião foram coletados em literatura específica e órgãos oficiais do governo e analisados em conjunto por sobreposição de imagens para confecção de mapas temáticos utilizando software Quantum GIS 1.7.4. Como resultado, a cobertura vegetal local compreende 35% de sua formação original, com os maiores remanescentes de Caatinga localizados nos municípios de Itapicuru e Ribeira do Amparo. Pelo Índice Geral de Degradação Ambiental, a microrregião encontra-se em um nível elevado de degradação, com o maior IGD em Adustina e Paripiranga (0,21 < IGD < 0,30), e Antas, Cipó e Nova Soure com menores (IGD < 0,10). Pelo Índice de Aridez e Índice de Incidência de Seca, pelos diferentes tipos e níveis de degradação ambiental, pela instabilidade térmica, pela baixa taxa e irregularidade das chuvas na microrregião de Ribeira do Pombal, mais de 90% da microrregião é susceptível a desertificação moderada, with higher occurrence in the municipalities of Ribeira do Pombal, Banzaê, Cícero Dantas, Novo Triunfo e Antas.

Palavras-chave: Microrregião; Semiárido; Desertificação.

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1. Introduction

The susceptibility to desertification is a real concern for environmental Conservation and human survival in semiarid areas of Brazil. The occurrence of degraded areas in Brazil has generated socio-environmental problems in alarming levels, with irreversible changes on the environment and negative socioeconomic implications, mainly for the populations in the affected and surrounding areas (BEZERRA, et al., 2006; CRUZ, et al., 2008).

Desertification has been defined as the degradation process of dryland ecosystems which involves all changes in the normal conditions of natural resources caused by variations in climate, that lead to changes in the soils, water, flora and fauna, compromising the balance and maintenance of ecological services, also affecting the use of environmental resources, and, consequently, reducing the quality of human life (UNCCD, 1995; DIAS, 1998; CUNHA & GUERRA, 2012). Although interpretations of desertification terminology may vary, the consensus of concern has been the human-caused land degradation in areas with low or variable rainfall (arid, semi-arid, and sub-humid lands) that can initiate or intensify the desertification process.

In general, environmental degradation undeniably compromises not only the conservation of local biodiversity but the whole of humanity, mainly in food production, where small holders farmers and traditional communities are the most vulnerable to suffer the effects of this process, such as the water scarcity that restricts agricultural production.

In some localities the impacts caused by anthropogenic pressures on natural resources culminate or intensify desertification processes in long-term or short-term depending on what impacts and how often they act (CUNHA & GUERRA, 2012).

In arid, semiarid and dry sub-humid areas, desertification is recognized as a global problem, and in Latin America an area superior than 516 million hectares has been affected, causing a loss of 24 billion tons of surface soil per year, harming socioeconomic development and environmental conservation (COSTA, et al., 2016).

In the scales context, the susceptibility determination of an area to desertification can be classified as very high, high or moderate, based, mainly, its Aridity Index (AI) according to the National Plan to Combat Desertification (BRASIL, 2005) and with the drought incidence index (PAULA & BRITO, 2008; ANGELOTTI, et al., 2009; ISMAEL-FILHO, et al., 2015; RIBEIRO, et al., 2016; GOMES, 2017).

In the Northeast region of Brazil, the most affected areas by degradation processes and susceptible to desertification are being recognized in semiarid regions, due in large part by the intense exploitation of natural resources (COSTA, et al., 2016).

It is important to emphasize that the semiarid region possess a territorial extension of 983,613,427 km², and 45.6% of it is anthropized, being classified as the most populated among all dry lands of the tropics or between the tropics, with a population estimated at 23,846,982 inhabitants, which corresponds to 42.44% of the entire population in the Northeast region and 11.76% of Brazil, also where 38% of this population living in rural areas without infrastructure or basic sanitation, the majority of these municipalities (93%) considered as small size (MEDEIROS, et al., 2012; INSA, 2014b).

The main type of vegetation that cover the semiarid regions of the Northeast of Brazil is the Caatinga, which already suffered loss of 45.6%, with the largest deforestation occurred in the states of Bahia, Ceará and Piauí, at a rate of 2,7% per year, where 80% of all existing vegetation cover is considered secondary forest (PIMENTEL & GUERRA, 2009; BRASIL, 2009; 2016a).

A good example of this is that the most affected areas by deforestation through inadequate agricultural practices, which contributes to desertification, are the marginal ranges of natural water courses, the surroundings of the rivers springs and the recharges areas, besides the tops of hills that constitute Permanent Preservation Areas. This loss of habitat already accounts for 1/3 of the Caatinga, where Ceará, Pernambuco and Paraíba are recoginized as the most affected states, where only in Paraíba have 71% of its territory suffers with desertification effects (BRASIL, 2009; PIMENTEL & GUERRA, 2009; RIBEIRO, 2015).

Moreover, the problem of water scarcity in the semiarid states have been understood by public policies as possible to be solved through the construction of water reservoirs such as dams, wells and cisterns for rainwater harvesting and storage (CURADO, et al., 2014). Thus, although the proposal for measures to coexist with dryness, based on the sustainability paradigm, encompassing notions of access to land, water and labor, opposing the reductionist notion of combating drought according to Silva (2006), it itself does not guarantee decent living conditions for local populations if the processes of degradation continue without public policies committed to circumvent them, since the semiarid is a region critical, fragile economy, concentrating low Gross Domestic Product (GDP) per capita, being 67% lower than the average of Brazil, and 32% than the Northeast region, besides the low investment and low Human Development Index (HDI) (INSA, 2014b; LIMA & LIMA, 2016).

Considering the Bahia State, more than half of its territory is located in the semiarid region (69.31%), presenting also the largest population contingent of that territory, which represents 29.83% of the entire population of the Brazilian semiarid (MEDEIROS, et al., 2012) and with more than 54% its area composed by Caatinga vegetation (GARÍGLIO, et al., 2010). Among the mesoregions of Bahia State, the Northeast of Bahia is formed by six microregions, including among them the microregion of Ribeira do Pombal (BRASIL, 2016b).

Accordingly, considering that desertification is a phenomenon that needs to be understood as a result of integrated environmental, socioeconomic and climatic processes (SANTOS, et al., 2016), the present work was performed with the objective of analyzing aspects of susceptibility to desertification of the microregion of Ribeira do Pombal, located in the semiarid region of Bahia State, Brazil.

2. Material and methods

2.1 Study site characterization

Located in the northeastern mesoregion of the Bahia State, the microregion of Ribeira do Pombal occupies a territorial extension of8,299.7 km² (GAMA & JESUS, 2018), and an estimated population of 312,602 inhabitants (BRASIL, 2017), with Gross Domestic Product (GDP) calculated around R$ 592,254,751.00 (BRASIL, 2013).

The anthropization of the microregion is 68%, considering the different forms of occupation such as road networks, urban agglomerations and productive rural establishments (GAMA & JESUS, 2018).

Situated in the ecoregion of the Raso of Catarina, in the Caatinga Morphoclimatic Domain, predominate in this semiarid microregion mainly an open-shrub vegetation and Latosols, Argisols and dystrophic quartz sands correspond to 78% of the soils in the microregion(VELLOSO, et al., 2002; BRASIL, 2014; GAMA & JESUS, 2018). The topography is relatively flat, predominating the Hydrogeological Domains of the sedimentary basins with the presence of the Barreiras (granular aquifer) and Cristalinos (fissure aquifer) groups (GAMA & JESUS, 2018).

The tropical climate is of type Bsh, characterized as dry and warm, according to the climatological classification of Köppen (ALVARES et al., 2013). The annual averages of precipitation and temperature are around 769.3 mm and 23.7 ºC, respectively. Average thermal amplitude of 4.4 ºC e average altitude of 271 (±114.45) (CLIMATE-DATA.ORG, 2012; GAMA & JESUS, 2018). The rainfall in the microregion of Ribeira do Pombal is unstable and poorly distributed, with rainfall concentrations from May to August (winter rains) and mainly from November to March (summer rains) (CLIMATE-DATA.ORG, 2012).

The trade and agricultural activity, especially in cattle breeding, beekeeping and family production of corn and beans, has been the economic base of the microregion of Ribeira do Pombal, which comprises fourteen municipalities: Adustina,Antas, Banzaê, CíceroDantas, Cipó, Fátima, Heliópolis, Itapicuru, Nova Soure, Novo Triunfo, Olindina, Paripiranga, Ribeira do Amparo andRibeira do Pombal (BRASIL, 2006; 2016b) according the Figure 1.

2.2. Data obtaining and processing

For the present study the data referring to the microregion of Ribeira do Pombal (Bahia State, Brazil) were collected based on information available in the specific literature, with addition of official data from the government agencies available on the websites of the same agencies as:

- ✔ Brazilian Institute of Geography and Statistics (IBGE) - data about agricultural, territorial, economic and environmental aspect of the microregion;
- ✔ Ministry of the Environment (MMA) - data on vegetation cover, land use and deforestation of the Caatinga biome;
- ✔ National Institute of the Semiarid (INSA) - Shapes and table of environmental attributes and census data for the microregion of Ribeira do Pombal.

The data were organized in excel sheets for analysis and thematic maps were made using Quantum GIS software version 1.7.4, adding Shapes obtained from the database available from SIGSAB (INSA, 2014a) analyzed together with other data from the aforementioned agencies by image overlay.

The Aridity Index which is considered as corresponding to the ratio between precipitation (mm) and potential evapotranspiration (mm) (THORNTHWAITE, 1948; UNCCD and UNEP, 1997), and the Drought Incidence Index which relates rainfall precipitation to temperature based on the annual Lang Rain Index method (FERNANDES, et al., 2009), both were obtained directly from the Shapes attributes table available at SIGSAB (INSA, 2014a).

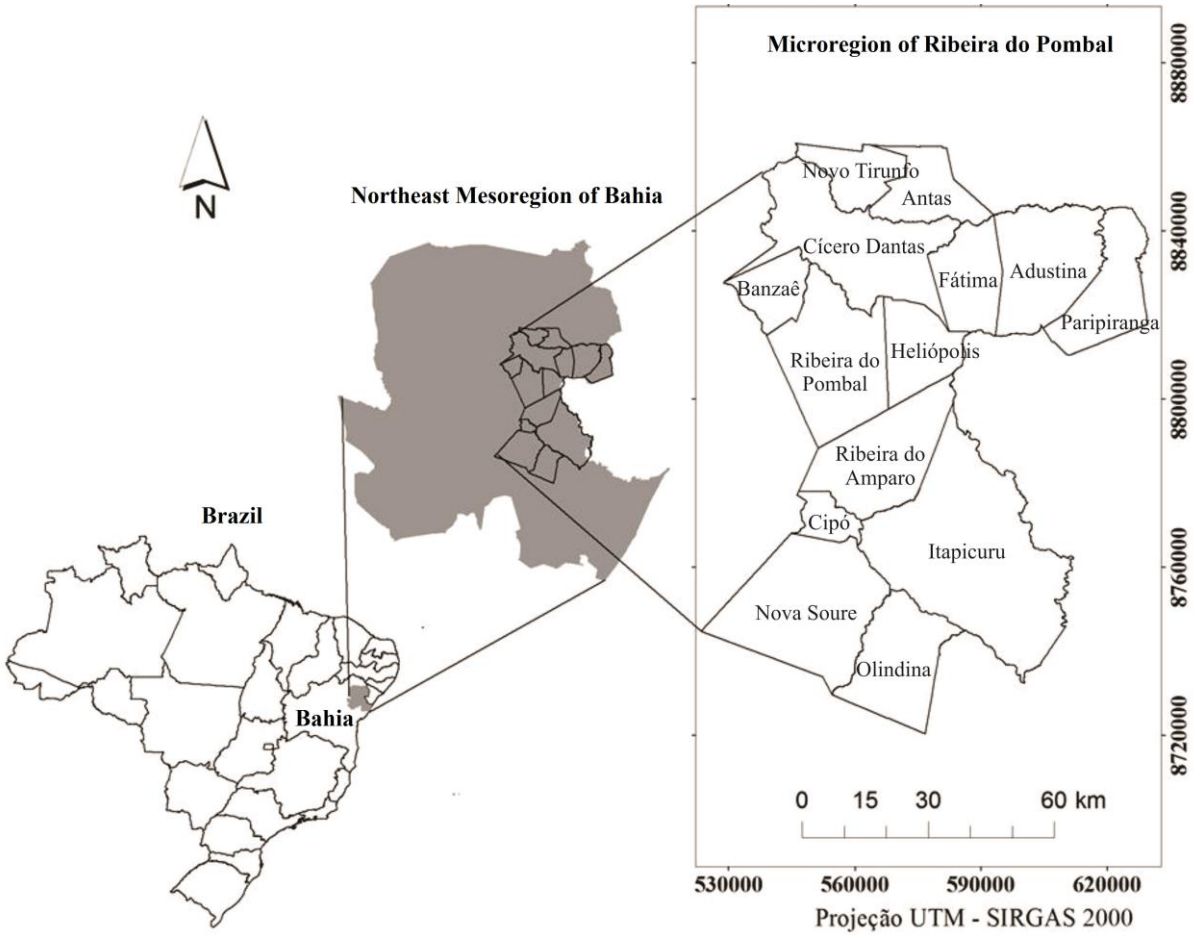

Figure 1 – Geographic location of the municipalities belonging to the microregion of Ribeira do Pombal in Northeast of Bahia State, Brazil.
Source: Of the authors, 2020.

The General Environmental Degradation Index (IGD) used for the Ribeira do Pombal microregion was obtained from the study published by Pais et al. (2012) performed for the entire State of Bahia, where the IGD considered the actions that cause impacts, such as the existence or not of burned areas or pastures, areas with use of fertilizers and agrochemicals, natural sources of water not protected by forests, type and number of equipment used (harvesters, tractors, etc.), intensive use of soil, animal overload in relation to pastures, among others (PAIS, et al., 2012).

It was performed also incursion in some municipalities (Ribeira do Pombal, Ribeira do Amparo, Cícero Dantas, Banzaê, Heliópolis, Fátima and Novo Triunfo) microregion between the periods of August 2012 and July 2016, for validation of the data presented in the specialized literature and observed in the images (shapes). Local images (photographs) were obtained to record new information.

3. Results and discussion

Based on available processed data, the Caatinga vegetation of the Ribeira do Pombal microregion corresponds to little less than 35% of its original formation. The municipalities of Itapicuru and Ribeira do Amparo present the largest remaining areas of Caatinga, around 18,723 ha and 14,987 ha respectively, contrary to what has been observed for the municipalities of Olindina (1,232 ha), Fatima (1,247 ha), Antas (1,936 ha) and Heliopolis (2,876 ha), that are practically denuded from their natural Caatinga vegetation, according to data from BRASIL (2006b) and the images obtained from INSA (2014a) (Figure 2).

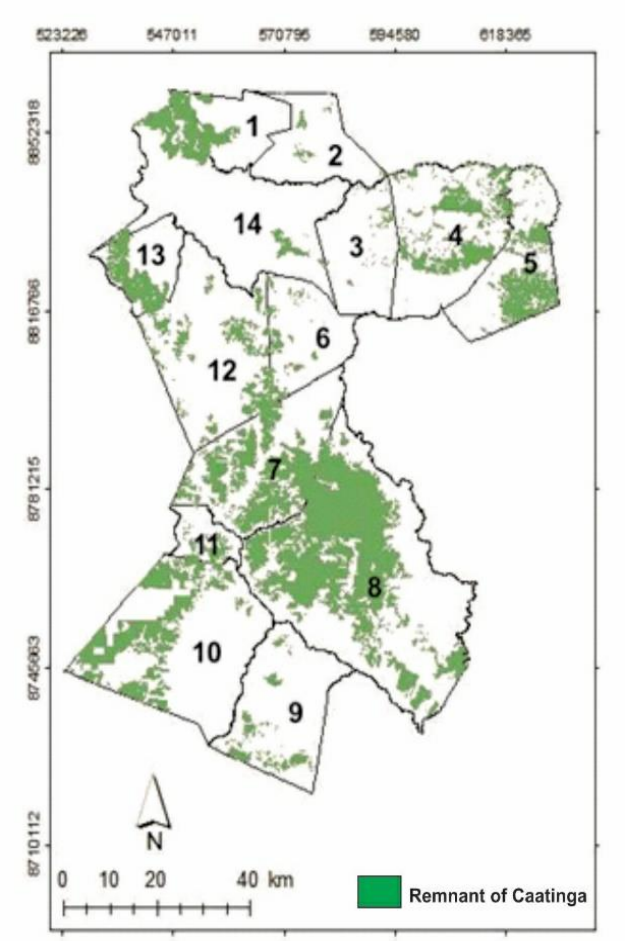

Figure 2 – Remaining Caatinga areas registered in the municipalities in the microregion of Ribeira do Pombal in Northeast of Bahia, Brazil, according to data obtained by the National Semiarid Institute (INSA, 2014a): 1 – Novo Triunfo; 2 – Antas; 3 – Fátima; 4 – Adustina; 5 – Paripiranga; 6 – Heliópolis; 7 – Ribeira do Amparo; 8 – Itapicuru; 9 – Olindina; 10 – Nova Soure; 11 – Cipó; 12 – Ribeira do Pombal; 13 – Banzaêand 14 – Cícero Dantas.
Source: Of the authors, 2020.

The indiscriminate deforestation of the Caatinga vegetation observed in the Ribeira do Pombal microregion is mainly due to the anthropic impact for pasture and agriculture formation, with an annual firewood extraction of about 157,460 m³ for an annual production of 66 ton of charcoal, with the municipalities of Itapicuru (51,000 m³ per year) and Olindina (31,000 m³ per year) being the largest producers of firewood, and Nova Soure (14 ton per year) and Itapicuru (11 ton per year) the largest in charcoal production, according to IBGE data (BRASIL, 2015).

In the microregion of Ribeira do Pombal, the main alternative land use, resulting in a reduction of forest cover, is the pastures formation (56%), followed by agriculture (18.6%), forming an extension of 614,535 ha of agricultural establishment, which corresponds to 74.6% of the territorial extension of the microregion, highlighting the municipality

of Itapicuru, with an area of more than 90,000 ha of its land converted into agricultural establishments, followed by Nova Soure with an area of 79,089 ha (Table 1).

Table 1 – Vegetal material volumes removed from the Caatinga and areas extension of Caatinga converted into agricultural establishments in the microregion of Ribeira do Pombal in Northeast of Bahia, Brazil.

Municipalities	*Extraction of Vegetation		**Agricultural Establishments	
	Firewood m³/year	Charcoal Ton/year	Amount (No)	Extension (ha)
Adustina	440	03	3,698	49,324
Antas	2,170	02	2,531	34,511
Banzaê	1,430	03	1,599	17,551
CíceroDantas	2,500	04	4,707	63,708
Cipó	21,000	07	1,173	12,286
Fátima	2,500	03	3,487	32,324
Heliópolis	600	01	2,857	29,832
Itapicuru	51,000	11	3,792	90,617
Nova Soure	20,000	14	4,370	79,089
Novo Triunfo	2,500	01	1,848	19,066
Olindina	31,000	05	2,595	33,690
Paripiranga	830	03	7,220	36,027
R. do Amparo	21,000	06	2,602	47,395
R. do Pombal	490	03	4,983	69,115
Total	157,460	66	47,462	614,535

*BRASIL (2015); **BRASIL (2006a).

Where: m³ = cubic meter; ton = tonne; No = number of establishments; ha = extension in hectare.

Source: Of the authors, 2020.

The landscape of the studied microregion, had significant reduction of the forest cover, which can cause serious environmental implications to the affected municipalities, such as: impairment of the areas of aquifer recharge; reduction of rainwater infiltration capacity; increased surface runoff with high risk of soil erosion; low production and water quality of the springs, among others (TUCCI & CLARKE, 1997; GIGLIO & KOBIYAMA, 2013; TORRES, 2016; SANTOS-JÚNIOR, et al., 2016). Comparatively, in the state of Paraíba, Brazil, in the Taperoá River Basin, also inserted in the semiarid region, Xavier et al. (2016) found a significant reduction in water production, silting of rivers and soil erosion caused by deforestation.

It has been observed in the municipalities of Nova Soure and Olindina, eucalyptus silvicultural establishments that in the medium term can become, probably, an energy alternative to replace the current suppression of native phytomass in this region of the Caatinga.

Otherwise, the inadequate use of ecosystems has promoted environmental changes and changes in the local climate in several regions of the Bahia State, such as the historical devastation that occurred between the years of 1950 and 1960 in the south of Bahia that caused the extinction of the Jacarandá trees [*Dalbergia nigra* (Vell.) Allemão ex Benth], with emphasis also on burnings in the Chapada Diamantina region in the 1980s, as well as changes in the microclimate in western Bahia caused by the deforestation of the Cerrado for expansion of agriculture, being the municipality of Barreiras considered the most degraded in the entire state of Bahia (CARVALHO-JÚNIOR, 1999; PAIS, et al., 2012).

In this respect, the semiarid microregion of Ribeira do Pombal is highly degraded with the effect of various environmental impacts, such as deforestation, forest fires, overloaded and largely abandoned pastures (Figure 3).

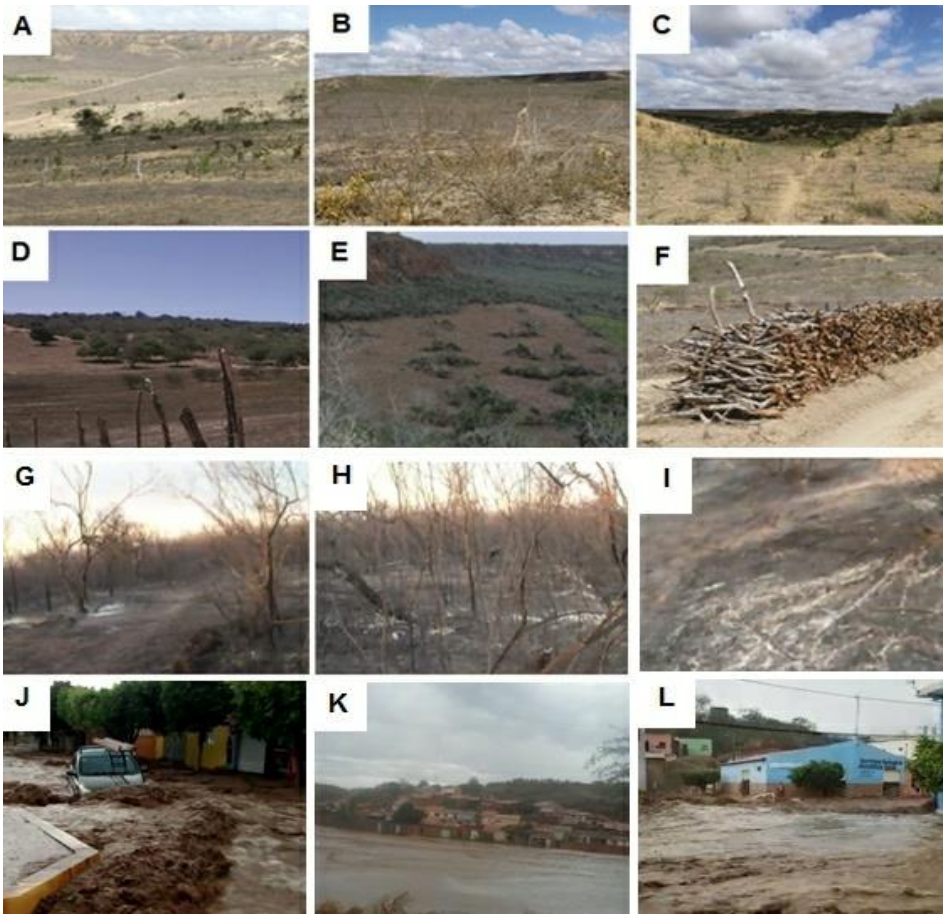

Figure 3 – Caatinga degraded after conversion of original vegetation into dry and abandoned pastures (A, B, C and D) and deforestation practices of Caatingas remnants (E), with production of firewood (F), fires (G, H and I) and floods (J, K and L), recorded between 2012 and 2016 in the microregion of Ribeira do Pombal, Northeastern region of Bahia State, Brazil: A, B, C and D - occurrence in the municipality of Ribeira do Pombal; E, F, G, H and I - occurrence in the municipality of Banzaê; J, K and L- occurrence in the municipality of Novo Triunfo.
Source: Of the authors, 2020.

Most of the semiarid extension is formed by fragile ecosystems, which are particularly sensitive to rainfall variability (SANTOS, et al., 2012; LIMA & GIRÃO, 2020). In the microregion of Ribeira do Pombal the soils are problematic, largely sandy, quite dystrophic, with some waterproof rocky mosaics (GAMA & JESUS, 2018), which, added to the increase temperature and changes in precipitation, makes the region susceptible to aridity (SOUZA, et al., 2015; NÓBREGA, et al., 2016).

Large extensions of all municipalities in the microregion form typical dry pastures landscapes during times of drought, many of them corresponding to abandoned pastures with fully exposed soil. Besides that, even pastures that resist droughts, when subjected to high temperatures and low rainfall, presenting low productivity due the poor maintenance and conservation conditions, being foraged only during the few months of winter rainfall between May and September (ARAÚJO, et al., 2012). The fragmentation of existing vegetation cover in the municipality of Ribeira do Pombal, presented by Jesus et al. (2019), demonstrates the fragility of the region's ecosystem to degradation.

During periods of drought, many ranchers and small farmers guarantee the survival of their herd using pasture areas called “pasture funds”, which constitute remaining areas of Caatinga in common use by farmers (FERRARO-JÚNIOR, 2010). The use of these areas strengthening further the importance of the conservation the Caatinga remnants, also showing its socioeconomic value for local population, allied to its value as refuge areas for protection of biodiversity and existing water resources.

In addition to indiscriminate deforestation, forest fires have also been a great cause of environmental degradation, especially with the immediate loss of biodiversity (SOARES & BATISTA, 2007). As an example of this can be considered the fire occurred in November 2012 in a remnant of Caatinga located between the municipalities of Cícero Dantas and Banzaê, where an area around 2,300 ha was totally devastated by the fire, probably caused by uncontrolled fires, where, according to reports from the local residents, the fire lasted for three days and three nights, uninterruptedly, as recorded in Figures 3G, 3H and 3I.

In addition, these problems include surface runoff caused by heavy rains in a few weeks during the summer rainy season, which is common in some municipalities in the microregion, such as what occurred in the municipality of Novo Triunfo in 2016, where the city was completely flooded (Figures 3J, 3K and 3L). This type of flood situation was recognized by Nóbrega et al. (2016) as caused by the effects of spatio-temporal changes in rainfall patterns with a tendency to increase rainfall (with the exception of the east coast) and a more concentrated seasonal distribution. Added to this is the effect of deforestation, which tends to facilitate and enhance the surface runoff of rainwater as a function of precipitation (mainly intensity) and the slope and elevation of the terrain (TUCCI & CLARKE, 1997).

According to the IGD presented by Pais et al. (2012), most municipalities in the microregion of Ribeira do Pombal are at a very high level of environmental degradation, with the municipalities of Adustina and Paripiranga being the most impacted (0.21 < IGD < 0.30). Unlike these two municipalities, the municipalities of Antas, Cipó and Nova Soure are low (IGD < 0.10), as shown in Figure 4.

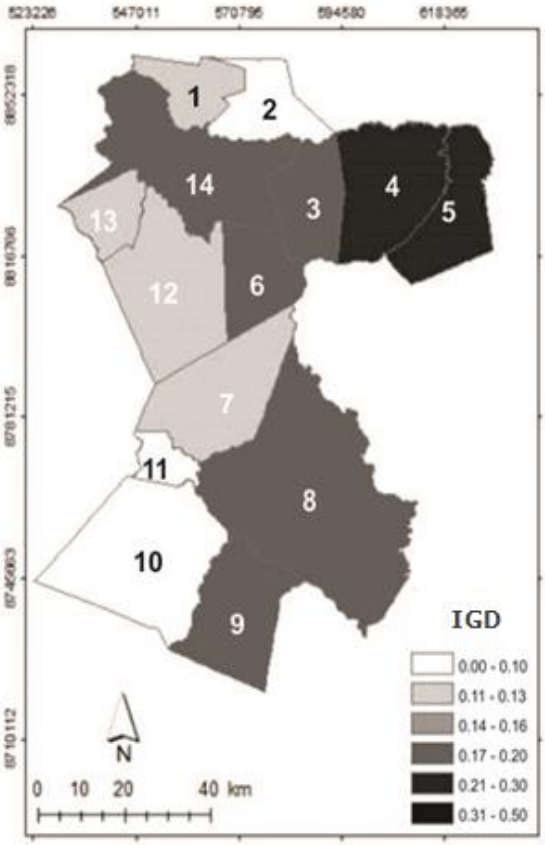

Figure 4 - Level of environmental degradation for the municipalities of the Ribeira do Pombal microregion in Northeast of Bahia, Brazil, according to the classification of the general environmental degradation index (IGD) microregion: 1 - Novo Triunfo; 2 - Antas; 3 - Fátima; 4 - Adustina; 5 - Paripiranga; 6 - Heliópolis; 7 - Ribeira do Amparo; 8 - Itapicuru; 9- Olindina; 10 - Nova Soure; 11 - Cipó; 12 - Ribeira do Pombal; 13 - Banzaê and 14 - Cícero Dantas.
Source: Of the authors, 2020.

It is observed that for the municipalities with the highest IGD (Adustina and Paripiranga), agricultural activity was probably the variable with the greatest expressive value, since large-scale corn production in this region and its surroundings is a very common activity, where the use of technologies is frequent, such as pesticides and heavy agricultural machinery. On the other hand, the low GID for Antas was probably registered due to the possible influence of the greater presence of low impact variables, although the municipality has a very limited forest cover. The opposite of this can be observed in the municipality of Ribeira do Amparo, which, with a great impact due to high technology for the melon (*Cucumis melo* L.) agribusiness, is the second municipality in terms of preserved and conserved forest cover, surpassed only by the municipality of Itapicuru.

Worth stressing, however, that the conversions of territorial extensions in agricultural enterprises (pastures and agriculture, mainly), are conducted, for the most part, without the correct use of appropriate techniques and technologies, where in addition to implying low productivity of these properties, leaving the same lands susceptible to the processes of erosion, salinization and soil loss, as well as the high impact on the present biodiversity (CAVALCANTI, et al., 1996; CAVALCANTI, et al., 2001; SOUZA, et al., 2001; IVO, 2007; RODRIGUES, 2008; LEAL, et al., 2008).

Curado et al. (2014) emphasize that the modernization of agriculture, made without sustainable basis, based only on the technological intensification of production systems, while promoting a productive increase and income of some producers, tends to have profound negative environmental impacts on the soil, biodiversity and water springs observable in the short and medium term.

Furthermore, the expansion of agricultural frontiers in the Brazilian semiarid region has been done without previous studies such as economic-ecological zoning (EEZ), reducing the forest cover of areas that are unsuitable for agricultural activities and contributing to the increase in average air temperature, reduction of water availability and increasing the potential evapotranspiration (ISMAEL-FILHO, et al., 2015), which added to the indiscriminate use of natural resources, makes these environments ecologically unstable and extremely vulnerable to desertification (XAVIER, et al., 2016).

It is noted that just over 65% of the microregion is delimited as a dry sub-humid area (Figure 5A), with an aridity index (AI) just above 0.5. On the other hand, the municipalities of Ribeira do Pombal, Banzaê, Cícero Dantas, Novo Triunfo, Antas and part of the southern region of Paripiranga are defined as semi-arid areas (AI < 0.5). And according to the drought incidence index, the most intense indicators (41% to 60%) point to the northwest border of the microregion, with total coverage of the territories of the municipalities of Banzaê and Nova Triunfo and the central-north part of Cícero Dantas. The municipality of Antas presented just under 50% of its area affected, while the municipality of Ribeira do Pombal presented 15% (Figure 5B).

It is worth noting that, although the most intense indicators classified as the most critical of the probability of drought occurrence only occur in less than 15% of the microregion, the remaining more than 85% cannot be considered remote from desertification processes, as some climatic phenomena present in the microregion, as mentioned earlier, they are quite recurrent and prone to drought (ARAÚJO & BRITO, 2011; ARAÚJO, et al., 2012).

In addition, it is observed that droughts are cyclically prolonged, being also related to the geographical position of the municipalities, as well as under the influences of air masses and the intensity of solar radiation (LETTENMAIER, 1995), where all these factors associated with the absence of forest cover contributes to a higher incidence of droughts.

Changes in the rainfall regime in the Ribeira do Pombal microregion have been observed for decades, with short duration and different occurrences. According to Nóbrega et al. (2016), the irregular distribution of rains and prolonged droughts, observed in several studies, are conditions that imply not only climate change, but also phytogeographic changes and altering socioeconomic aspects. According to Ribeiro et al. (2016), the greater variability of rainfall and the increase in the frequency of extreme events such as droughts and floods in the semi-arid region show that climate change intensifies the processes of desertification, expanding into a greater number of susceptible areas.

Thus, the sum of these attributes to the different types and levels of environmental degradation, thermal instability and irregular rainfall, warn that more than 90% of the Ribeira do Pombal microregion is susceptible to moderate desertification (Figure 5C).

In most part of the semiarid territory of Northeast Brazil, desertification processes are present with both moderate and irreversible degrees (ANGELOTTI, et al., 2009). Some studies performed in semiarid regions of different states of the Northeast of Brazil has indicated worrying degrees of desertification, as observed by Queiroz & Santos (2016), who studied the desertification processes in the microregion of Vale do Piancó in the Paraíba State, Brazil noting that 60% of this region is in an advanced process of desertification, caused mainly by continuous deforestation, in addition to prolonged periods of drought. Among the municipalities studied by these authors, Aguiar was considered the most critical, classified as hyper arid and presenting a large extension of exposed soils.

In the case of Bahia State, as observed by Santos & Pacheco (2017), some regions of the municipality of Juazeiro already have a high risk of desertification, mainly related to the large loss of forest cover and intensification of soil erosion, what was also confirmed by the studies performed by Santos et al. (2016), which indicated that the municipalities of Juazeiro, Casa Nova, Sobradinho and Curaçá, all located in the northern of Bahia State, are regions that are highly susceptible to desertification.

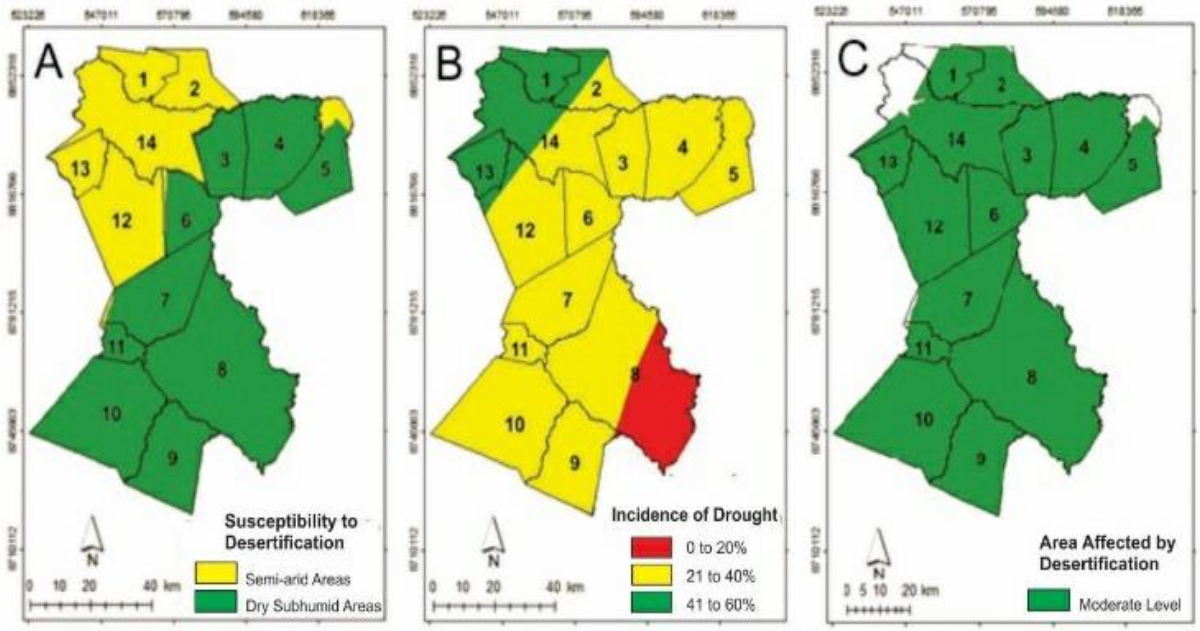

Figure 5 – Representation of territorial extensions susceptible to desertification (A) and drought incidence index - DII (B) and moderate level of areas affected by desertification (C) in the semiarid microregions of Ribeira do Pombal, Northeast of Bahia, Brazil, according to data from the National Semiarid Institute (INSA, 2012): 1 - Novo Triunfo; 2 - Antas 3 - Fatima; 4 - Adustina; 5 - Paripiranga; 6 - Heliópolis; 7 - Ribeira do Amparo; 8 - Itapicuru; 9 - Olindina; 10 - Nova Soure; 11 - Cipó; 12 - Ribeira do Pombal; 13 - Banzaê and 14 - Cícero Dantas.
Source: Of the authors, 2020.

In a study performed in the region of SeridóPotiguar, in the Rio Grande do Norte State, Rozendo (2015) found that the occurrence of desertification in the region has been provoked by the removal of clay, which causes silting of rivers and the stimulation of intense removal of firewood from Caatinga demanded by the ceramic activity, which consumes 69.7% of the total firewood extracted. Still according to this same author, the social impacts generated have been striking, culminating in the decrease of the food production, once the areas of várzea, previously used for the cultivation of foodstuffs, became unviable by the degradation caused by the activity of ceramics associated with cattle breeding.

Gomes (2017), in a study carried out in the Sertão do Moxotó and Sertão do Pajeú microregions in the Pernambuco State, found that even though there is a low susceptibility to desertification in these microregions, the local populations already suffer from reductions in quality of life, observed through socioeconomic indicators affected by the degradation of natural resources.

Desertification processes observed in some semiarid regions of the Northeast, according to studies performed by Sá & Sá (2008), indicate irreversible levels, such as the Seridó nucleus, between the States of Rio Grande do Note and Paraíba, with an extension of approximately 2,341 km² area affected by desertification caused by the extraction of firewood and clay.

Different factors are associated with the desertification process. In Irauçuba, a municipality located in the Ceará State, the intense processes of desertification extend over approximately 4,000 km² of this region, caused by burning practices and intense deforestation. In the region of Cabrobró, in Pernambuco State, deforestation and soils salinization caused desertification of more than 4,900 km². At Gilbués, in the Piauí State, are more than 6,000 km² of area under desertification caused by extensive livestock farming and mining (QUEIROZ & SANTOS, 2016).

4. Final considerations

More than 90% of the Ribeira do Pombal microregion is susceptible to moderate desertification, mainly caused by human activities and intensified by local climatic conditions.

The human actions responsible for the susceptibility to moderate desertification in the microregion of Ribeira do Pombal are mainly related to deforestation for the formation of pastures, agriculture, wood cutting and charcoal production.

The municipalities of Olindina, Fátima, Antas, Heliópolis, Cícero Dantas, Adustina, Paripiranga and Ribeira do Pombal are the most affected by environmental degradation due to deforestation and the adoption of high-impact, low-mitigation agricultural technologies.

Environmental degradation can be avoided by alternative means implemented by public policies with immediate reduction of the effects of the desertification process, guaranteeing protected territorial spaces as in the surveillance, recovery and implantation of Permanent Protection Areas, creation of ecological corridors and creation and management of Units of Conservation of Caatinga remnants still existing in the studied municipalities of the microregion.

Environmental monitoring, specialized technical assistance and continuous rural extension in the microregion are also suggested; the adoption of a plan to promote and implement planted forests to replace the suppression of native vegetation in the Caatinga. And the implementation of a Sustainable Forest Management Plan for the Caatinga remnants that show such aptitude.

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