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IDENTIFICATION OF LEVELS OF ANTHROPIZATION AND ITS IMPLICATIONS IN THE PROCESS OF DESERTIFICATION IN THE CAATINGA BIOME (JEREMOABO, BAHIA-BRAZIL)

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ABSTRACT. Desertification is one of the most serious current environmental problems and corresponds to the impoverishment and decrease of moisture in sandy soils located in regions with a sub-humid, arid and semiarid climate, with its main causes related to climatic variations and the resulting negative impacts of human activities. Studies show that the soils located in the Brazilian semiarid and especially in the Caatinga biome have been suffering an intense process of desertification due to the replacement of natural vegetation as a result of economic activities. Most municipalities that have an economy based on agropastoral activities are at the centre of desertification in several centres in Brazil. Based on this context and considering that the original vegetation cover is a preponderant factor for soil conservation, and subsequently for the maintenance of the ecological stability of the Caatinga biome, this work aimed to map the vegetation cover of the Vaza-Barris watershed corresponding to the municipality of Jeremoabo (Bahia-Brazil), with the purpose of identifying and quantifying, in terms of surface, the main types of interaction between human activities and the remnants of the vegetation cover, listing the potential impacts that have a direct consequence on the desertification processes. The delimitation of the vegetation cover was the result processing Sentinel 2A satellite images and the use of the Soil Adjusted Vegetation Index - SAVI. Five thematic classes representative of the study area were identified, classified according to the increasing level of anthropization that allowed us to conclude that desertification causes damage to agriculture, making the areas unproductive, as well as excessive agriculture with inappropriate practices causes the loss of fertility of the soils, aggravating the desertification process. With this, the environmental and social quality is threatened, considering that the main source of income in the municipality of Jeremoabo comes from agricultural activities and these are dependent on climatic conditions, soil conservation and water resources.

Identificación de niveles de antropización y sus implicaciones en el proceso de desertificación en la Caatinga (Jeremoabo, Bahía-Brasil)

RESUMEN. Actualmente la desertificación es uno de los problemas ambientales más graves y coincide con el empobrecimiento y disminución de la humedad de los suelos arenosos localizados en regiones de clima subhúmedo, árido y semiárido. Sus principales causas están relacionadas con las variaciones climáticas y los consiguientes impactos negativos de las actividades humanas. Los estudios muestran que los suelos ubicados en el semiárido brasileño y especialmente en el bioma Caatinga vienen sufriendo un intenso proceso de desertificación debido a la sustitución de la vegetación natural como resultado de las actividades económicas. La mayoría de los municipios, que tienen una economía basada en actividades agro-pastorales, están en el centro de la desertificación en varias áreas de Brasil. En este contexto, y considerando que la cubierta vegetal original es un factor importante para la conservación del suelo y para el mantenimiento de la estabilidad ecológica del bioma Caatinga, este trabajo tiene como objetivo cartografiar la cubierta vegetal de la cuenca del río Vaza-Barris correspondiente al municipio de Jeremoabo (Bahía-Brasil). Se trata de identificar y cuantificar, en términos de superficie, los principales tipos de interacción entre las actividades humanas y los remanentes de la cubierta vegetal, enumerando los impactos potenciales que tienen una consecuencia directa sobre los procesos de desertificación. La delimitación de la cubierta vegetal fue resultado del procesamiento de imágenes del satélite Sentinel 2A y el uso del Índice de Vegetación Ajustado al Suelo - SAVI. Se identificaron cinco clases representativas de la zona de estudio, clasificadas según el nivel creciente de antropización que permitieron concluir que la desertificación provoca daños a la agricultura haciendo improductivas las áreas. También la agricultura excesiva con prácticas inadecuadas provoca la pérdida de fertilidad de los suelos, agravando el proceso de desertificación. De esta forma, la calidad ambiental y social se ve amenazada, considerando que la principal fuente de ingresos del municipio de Jeremoabo proviene de las actividades agropecuarias y éstas dependen de las condiciones climáticas, la conservación del suelo y los recursos hídricos.

Key words: Desertification, Caatinga, Anthropogenic Activities, SAVI, Sentinel 2A satellite.

Palabras clave: Desertificación, Caatinga, Actividades Antropogénicas, SAVI, Satélite Sentinel 2A.

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1. Introduction

Controlling occupation and soil use, a legal attribute in historically neglected Brazilian towns, has contributed over recent decades to the reduction in the conservation of environmental resources, including superficial and subterranean water resources, making it more difficult for human and animal populations to survive in areas which are characterised by their low annual precipitation rates, having a direct impact on the increase of the processes linked to desertification (Vieira *et al.,* 2013; Wijitkosum, 2016).

Desertification is one of the most serious current environmental problems (Mirzabaev *at al.,* 2019) and corresponds to the impoverishment and decrease of moisture in sandy soils located in regions with a sub-humid, arid and semiarid climate, with its main causes related to climatic variations and the resulting negative impacts of human activities, like the inadequate management of animal husbandry, the suppression of vegetation cover and the illegal practice of mining activities (Mouat *et al.,* 2019), as well as the salinization of the soil from irrigation, overgrazing, the unsustainable use of superficial and subterranean water resources (Salama *et al.,* 1999).

Studies show that the soils located in the Brazilian semiarid have been suffering an intense process of desertification due to the replacement of natural vegetation as a result of economic activities. Most municipalities that have an economy based on agropastoral activities are at the centre of desertification in several cities in the country (Brazil, 2005; Oliveira Junior, 2014; Souza, 2020).

A collaboration between the Ministry for the Environment, the State University of Feira de Santana, EmbrapaSemiárido and Embrapa Solos showed that only 40.5% of the original area of the Caatinga biome has remnants of its native vegetation (Sá *et al.,* 2010). The Caatinga is different in that it is an exclusively Brazilian biome, located mainly in the north-east region where a semiarid climate is most predominant, characterised by precipitation levels below 800 millimetres/year, covering an area of approximately 735,000 km^2 (Silva *et al.* 2004). The Caatinga receives the official classification of a Stepiccal-Savannah (Veloso *et al.*, 1991).

This is where the area of study of this paper is located, the municipality of Jeremoabo, in the north of the State of Bahia (Fig. 1), where the main vegetation coverage is arboreal/shrub-like, branched and thorny, with different species of bromelia and cactus (Almeida *et al.,* 2011).

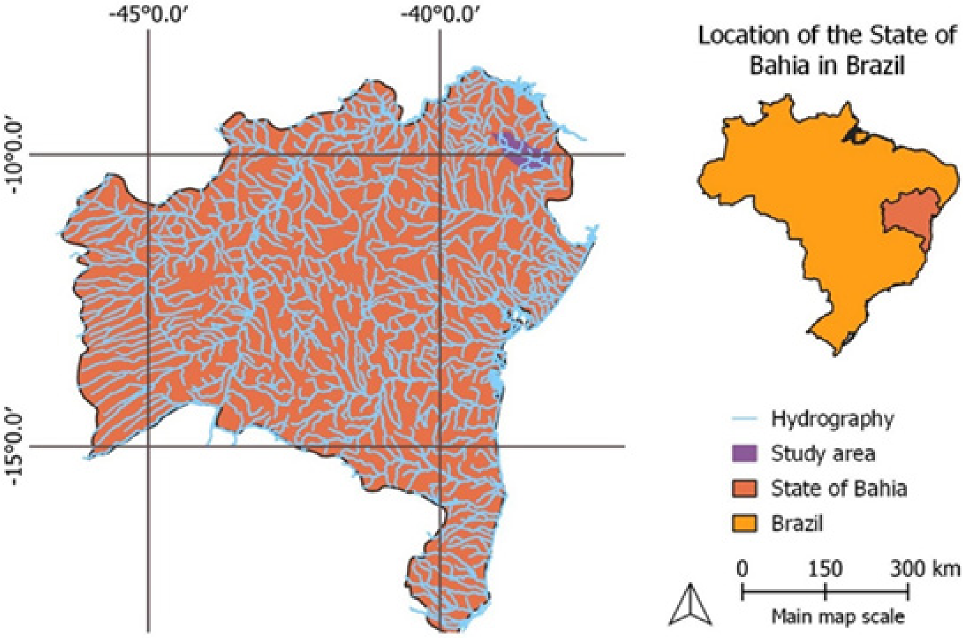

Figure 1. Location of the municipality of Jeremoabo in the State of Bahia, Brazil.

This individual type of tropical xerophile vegetation can only be found in the north-east of Brazil, as a result of the physiological defence mechanism of plants against the high level of transpiration (Brazil, 2005). In this region, the factors regarding the climate are more striking than other ecological factors when it comes to defining the type of vegetation coverage.

Jeremoabo has high temperatures throughout the year, with an average of 24º and a low rainfall index (a historical average of 654 mm/year), rainfall which is consolidated into the months from May to July and a high risk of drought, with it being more susceptible to erosion caused by the torrential rains (Grilo *et al.,* 2009). Such aspects are reflected in high evaporation rates or soil with a low liquid retention capacity, causing intermittence throughout rivers (Carvalho, 2010). In this type of environment, vegetation coverage is one of the main control factors of desertification, because as it is deciduous, it plays the role of protecting the soil from bad weather, thus lessening its deterioration (Sá *et al.,* 2010).

The reduction or disappearance of this vegetation coverage in recent decades has caused an imbalance in the thermal balance, leading to an increase in the reflectivity of solar radiation, thus intensifying the atmospheric subsistence and driving the dry air from the high troposphere to the surface, which ends up reducing the amount of cloud formation and the likelihood of rainfall. Besides this, soil that is directly exposed to solar radiation has less retention capacity for subterranean water (Castelletti *et al.,* 2003).

The main reason for this loss of vegetation coverage is linked to an economy which is based on farming and livestock, vegetation extraction and forestry which do not make use of the suitable technical resources to make these activities compatible with the characteristics of the Caatinga biome, making the soil more susceptible to external variables, mainly regarding leaching and slipping processes and the evolution of gullies (Almeida *et al.,* 2011). It often causes the deterioration which contributes to desertification due to porous dryness and the loss of the soil's productive capacity (Oliveira Junior, 2014).

Based on this context and considering that the original vegetation cover is a preponderant factor for soil conservation, and subsequently for the maintenance of the ecological stability of the Caatinga biome, this work aimed to map the vegetation cover of the Vaza-Barris watershed corresponding to the municipality of Jeremoabo (Bahia-Brazil), with the purpose of identifying and quantifying, in terms of surface, the main types of interaction between human activities and the remnants of the vegetation cover, listing the potential impacts that have a direct consequence on the desertification processes.

The hydrographic basin in the Vaza-Barris river spans a total area of 16,787.47 km^2, with its sources in Serra da Canabrava in the Bahia municipality of Uauá. Its mouth is in the State of Sergipe, between the municipalities of Aracaju and Itaporanga d'Ajuda. The area covered by this study encompasses a population of 37,680 inhabitants which are unevenly distributed across 4,267.5 km^2, located in the Bahia Sertanejo lowland depression, a region which is known its low soil development (Marques *et al.,* 2009).

2. Method and Materials

In order to make a breakdown of the vegetation coverage, Sentinel 2A satellite images with bands 4 (red) and 8 (near infra-red) were used which were obtained from the site https://lv.eosda.com/, provided by the Earth Observation System, showing a spatial resolution of 10 metres.

Sentinel 2 is a multi-spectral sensor with a typical spatial resolution, which, according to the United States Geological Survey (USGS), is from an imaging mission carried out by the GMES Programme (Global Monitoring of the Environment and Security) together with the European Community and the ESA (European Space Agency), with the aim of gathering high-resolution soil, vegetation, humidity, river and coastal area data and data for atmospheric correction (up to 10m), with a short revisiting period (5 days), and is free and open for public access.

The images were pre-processed using the Semi-Automatic Classification of the ArcGIS (ESRI) software in order to carry out the atmospheric correction, considering the parameters present in the metadata on each band. After this stage, the composition of the bands used in the classification and the cutting process of the images was carried out in accordance with the limit of the hydrographic basin. After these procedures, the transformation of the Mapping Reference System (SRC) was made with the aim of matching the themed maps that would be produced with the SIRGAS 2000 geodetic reference system, used for the Brazilian Mapping Agency's activity.

Then, the differentiation of the types of soil use was made using the SAVI (Soil Adjusted Vegetation) calculation, a vegetation index adjusted to the soil developed by Huete (1988) with the aim of minimising the reflectance of the soil on the NDVI (Normalised Difference Vegetation Index), with the incorporation of an "L" constant which is adjusted according to the soil coverage, thus reducing the effects of the soil's colour in the classification results (Qi *et al.,* 1994; Lima *et al.,* 2017).

Using the near infra-red and red bands, Huete (1988) developed the SAVI by visiting areas of grasslands and agricultural crops, mainly canopies with around 50% of vegetation coverage, bearing in mind that the brightness of the soil, especially that of the darker shades, increases the value of the vegetation indexes and thus, the SAVI's aim is to produce vegetation isograms more separate from the soil (Huete, 1988 in Washington-Allen *et al.,* 2003; Gameiro *et al.,* 2016).

In accordance with Braz *et al*., 2015), the SAVI is calculated using the following equation:

$$SAVI = \left(\frac{NIR - R}{NIR + R + L} \right) . (1 + L)$$

In it, according to the aforementioned authors, “NIR” is the Near Infra-Red band, “RED” is the Red band, and “L” represents the constant that reduces the effects of the soil and that can vary depending on the degree of density of the canopy in the studied area. The value of the L constant varies between 0 (identical to the NDVI) and 1, with the following being considered optimum values: value 1 for low vegetation densities; 0.5 for average densities; and 0.25 for low vegetation densities (Huete, 1988; Qi *et al.,* 1994; Rodondeaux *et al.,* 1996; Silva *et al.,* 2015).

In the majority of studies, the L value equal to 0.5 is the most common, regardless of the type of soil, since it covers a larger variation of vegetation (Washington-Allen *et al.,* 2003) and this is why it was the parameter used in this paper. Despite the results from the SAVI being similar to those from the NDVI, they are different in that the SAVI has wider values that highlight the characteristics of vegetated regions, non-vegetated rations and bodies of water, offering a more authentic view of the study area (Gameiro *et al.,* 2016).

In order to support the definition of the types with the different levels of anthropization, the studies developed for the São Francisco River Water Resources Plan (São Francisco River Hydrographic Basin Committee, 2016). Using the classification made by the SAVI, reference mapping was drafted to associate the vegetation coverage with the anthropic activity, the respective potential environmental impacts arising from this interaction and their relationship with the desertification processes, as well as the ascertainment of the surface area occupied by each type and its percentage in relation to the total area of the basin in the municipality of Jeremoabo.

3. Results

Five representative subject types of the study area were identified and classified in accordance with the growing level of anthropization (Fig. 2), which are: Caatinga with Possible Crops, Caatinga Interspersed with Grasslands, Grasslands and Crops Interspersed by Caatinga, Agriculture and the Urban Area, which were dealt with as follows.

Figure 2. Subject types with a growing level of anthropization.

3.1 Caatinga with Possible Crops

The Caatinga with Possible Crops type corresponds to around 34.9% of the study area and covers around 1,364 km^2. It tends to be located in the central-northern and central-southern part of the municipality and boasts a larger concentration of vegetation coverage. It is located in higher altitude areas at between 550 and 766m (Grilo *et al.,* 2009). It is made up of Caatinga vegetation interspersed by seasonal crops such as beans, cassava, melon and corn (IBGE, 2019).

Taking into account the climate characteristics in Jeremoabo, a typical quality which is consistent with the dry areas during the 3 wet months per year can be observed, which rejuvenate the Caatinga and provide the temporary crops (Almeida, 2011). In the other 9 dry months there is a considerable drop in farming activity. The Caatinga provides species of different sizes like the *Commiphora leptophloeoes,* the *Bromelia antiacantha,* the *Schinopsis brasiliensis,* the *Pilocereus gounellei,* the *Mimosa hostilis,* the *Cereus jamacaru,* the *Cnidoscolus quercifolius,* amongst others, with it now being dense and open (Almeida, 2011), as shown in Figure 3.

Figure 3. Arboreal/shrub Caatinga. Source: Almeida (2011).

A large part of the areas of crops are monocultures that cause significant changes to the environment's fauna and flora and a reduction in the biodiversity, mainly due to the replacement of the original vegetation cover by non-autochthonous species (Rohila *et al.,* 2017; Killebrew and Wolff, 2010), as well as creating problems for the crop itself, as is the case with corn that has increased grain and cob rot which was burnt due to the practice (Trento *et al.,* 2002).

In accordance with the IBGE (2019), between 2004 and 2018 there was a dramatic fall in the production of seasonal crops, such as beans, which in 2004 equated to around 13,680 tonnes, and that by 2018 had fallen to just 51 tonnes. This substantial drop in production could be related to the process of desertification, bearing in mind that desertification and farming find themselves in a cycle: desertification causes damage to farming, making areas barren, and excess farming with unsuitable practices, such as the intensive use of irrigation, which results in soil compaction, increased erosion, decreased productivity and salinization, makes the soil less fertile, which in turn exacerbates the process of desertification (Dourado, 2017; Mirzabaec *et al.,* 2019).

3.2 Caatinga Interspersed by Grasslands

The Caatinga Interspersed by Grasslands occupies around 19.2% of the study area, spanning some 750 km^2 and mainly being found in the north-east of the municipality. This type is predominant at altitudes of between 195 and 550m (Grilo *et al.,* 2009), is only slightly entropized, and characterised by prickly, deciduous species with microfolia and floral diversity, encompassing plants with varied vertical structures (arboreal, grassy, herbal and shrubby) and varied densities of coverage, including primary and secondary vegetation where grazing takes place with loose cattle, often without any fencing, as shown in Figure 4 (Oliveira Junior, 2014).

Figure 4. The Caatinga and the area allocated for cattle grazing. Source: Oliveira Junior (2014) y Almeida (2011).

3.3 Grasslands and Crops Interspersed by Caatinga

The Grasslands and Crops Interspersed by Caatinga cover 31.5% of the area, occupying 1,230 km^2. This type can be found at altitudes of between 195 and 550m (Grilo, 2009), boasting land which is harvested using subsistence methods (where there is no mechanization and farming depends mainly on the occurrence of rain) and modern methods (exportation), and is occupied by the traditionally-handled livestock (Oliveira Junior, 2014), interspersed with farming mainly to the east of the municipality and the outskirts of the Vaza-Barris river, bearing in mind the need for the availability of water resources that support the farming and livestock activity and irrigation (Fig. 5).

Figure 5. Grasslands and crops along the Vaza-Barris river. Source: Almeida (2011).

The livestock is characterised by its extensive nature (Oliveira Junior, 2014), grazing and the use of vast areas for production, which usually takes places without heavy investment or the use of the latest technology that would enrich the grassland. Production has fallen as a result of this, and it has been affecting the livestock in the municipality throughout recent years. Goat farming, which in 2012 had a total count of 40,414, fell to 19,263 in 2018, which is a 52.3% drop in production (IBGE, 2019). More data from the IBGE (2019) shows that sheep farming also fell, with a total count of 41,476 in 2012 in comparison with 21,015 in 2018, representing a 49.3% drop.

Within this type, two areas with different features are noticeable (Fig. 6): one to the west, with an area where agricultural output is lower, superficial soil (New soils) and low annual rainfall rates (up to 600 mm), and another to the east, with higher annual rainfall rates (up to 700 mm), more developed soil (Latosols and Acrisols) and, as a result, an increased use of the soil for farming and livestock activity (Marques, 2009).

Figure 6. Contrast between the landscapes on the western side (on the left) and the eastern side (on the right). Source: Marques et al. *(2009).*

3.4 Agriculture

Agriculture corresponds to 13.7% of the total area, spanning 535 km^2. It is found at the lower altitudes in the municipality, varying between 195 and 403m (Grilo, 2009), and mainly found to the east and along the Vaza-Barris river, bearing in mind that these farming areas are located in places with more water availability and depend highly on irrigation (Almeida *et al.,* 2011). As a result, an increase in the demand for water (one of the most limiting factors of the region) could cause social, economic and environmental conflict in the event that there is less of it available, considering that it is an area susceptible to desertification (Brasil, 2005).

As per the IBGE (2019), the main permanent crops in the municipality are: bananas, coconuts, guavas and papaya. Like with seasonal crops, they also experienced a decline in production; for instance, the number of bananas produced in 2004 (2,100 tonnes) and 2018 (960 tonnes), with approximately a 54.2% fall.

3.5 Urban Area

The Urban Area type occupies just 0.1% of the total study area, covering around 4 km^2. There is an urban density of 4,359 people/km^2 with a population of 17,437 inhabitants (IBGE, 2018). It is located in the east where the town centre is found (Fig. 7). Figure 8 shows the spatial distribution of the different types of anthropization in the municipality.

Figure 7. Urban centre of the municipality of Jeremoabo. Source: Google Earth (2021).

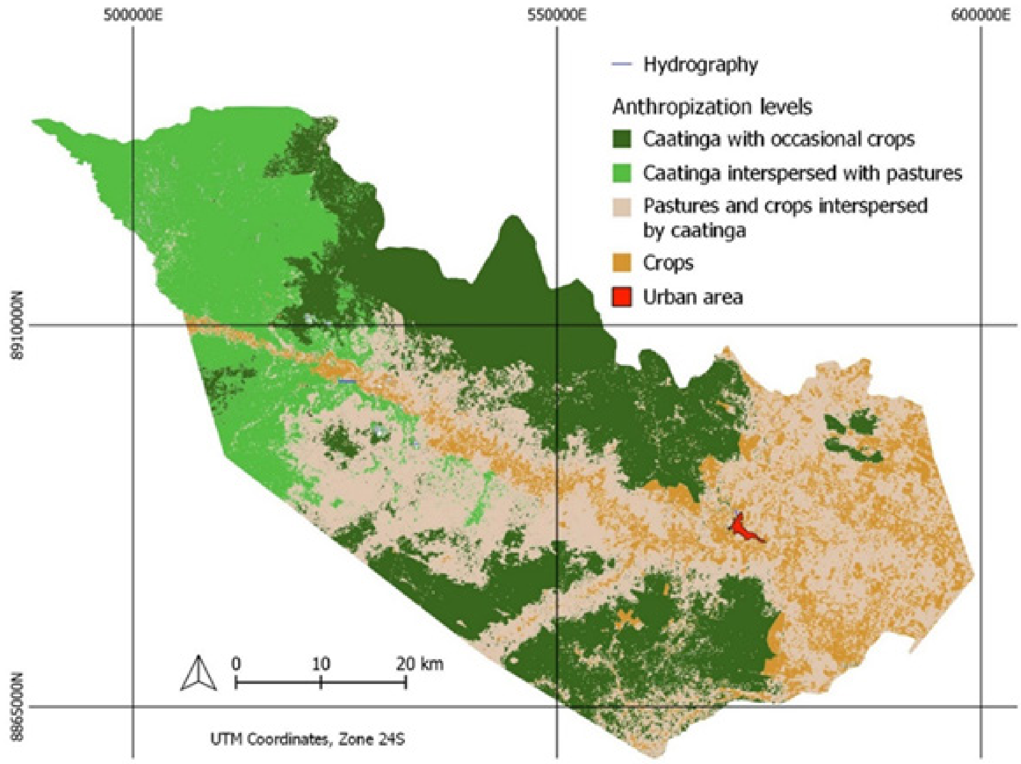

Figure 8. Spatialisation of the types of anthropization.

4. Discussion

The inappropriate treatment of the semiarid agricultural ecosystems is one of the main causes of deterioration in the studied area, where anthropic interference associated to the particular climate conditions causes negative impacts on the entire ecosystem, as well as significant rates of desertification (Rossi, 2020).

The majority of the species present in the Caatinga tend to regrow after being cut down. Meanwhile, burning the soil, which is one of the most aggressive preparation techniques, progressively decreases vegetation regrowth, where the rate of colonization by woody species is much slower, and with a much smaller population in areas cultivated over a long period than in newly opened areas within a mature forest, causing effects on the biomass that last for over 6 years (Sampaio *et al.,* 2005; Dourado, 2017). Furthermore, the use of fire destroys the humus layer and the microbial life, forming a crust under the soil through the deposit of particles and materials that are susceptible to pollution, which prevents water filtration (Sá *et al.,* 2010; Martín *et al.,* 2016). Continuous burning in one area also reduces the soil's humidity, limiting infiltration and the level of organic material, increasing the evapotranspiration and flooding (Oliveira and Montebello, 2014; Almeida *et al.,* 2011).

Around 80% of Caatinga's natural ecosystems have already been modified, which is mainly due to deforestation and burning. Recent research shows a 25.9% fall in wood, coal and firewood production in areas that are susceptible to desertification, displaying a serious lack of vegetation (Dourado, 2017; CGEE, 2016).

Of the types identified in this article, the area made up of grasslands and crops interspersed by the Caatinga appear to be the most susceptible to desertification, considering that there is more human intervention within this type, characterised by crops and inappropriate animal farming techniques, thus reducing the amount of native vegetation particularly in areas closest to the Vaza-Barris river (Grilo *et al.,* 2009). This activity involves alternate output between agriculture and livestock, something that has been common since the 17th century, with land being used for ploughing and grazing with a seasonal dynamic due to the cyclicity of the rainfall and droughts, which are common for the municipality's type of climate (Oliveira Junior, 2014).

In most cases, the native vegetation was replaced with grassy pastures or short-cycle crops that have different sizes compared with the Caatinga's original vegetation, which makes the soil more exposed, causing a loss of fertility and leading to processes of erosion, resulting from surface rainfall, where recurrence reason the opening of gullies, which are mainly caused by torrential rain. Subsequently, there is the evolution of land and sand bank slides in river and streams (Sampaio *et al.,* 2005; Grilo *et al.,* 2009).

In a large part of the municipality, particularly in the areas closest to water courses, the *Prosopis Juliflora* can be observed; it is a perennial, drought-resistant plant that has a high wood and coal supply potential (Fig. 9), besides serving as food for cows and goats, but it is not native to the region (Almeida, 2011).

Figure 9. The expansion of the Prosopis juliflora through the municipality. Source: Almeida (2011).

However, competing for space, the *Prosopis Juliflora* prevent the native vegetation from evolving, as it consumes a large amount of water. The heavy presence of the *Prosopis Juliflora* reduces the soil's protection to erosive processes and increases the risk of fires due to an accumulation of biomass, which impacts the ecosystem and alters the local water regime, whilst also lowering the area's biodiversity, as it overshadows other species (Pegado *et al*., 2006). The chemical composition of its pods may cause dental and digestive problems for goats, sheep and cows, and may even be fatal when it is consumed in excess for extended periods of time (Aboud *et al.,* 2005).

In grassland areas, the main factor for desertification is the removal of the native vegetation (Nascimiento, 2013), leading to a reduction in organism diversity, which affects the self-regulation mechanisms present in natural ecosystems (Matches, 1992 in Bilotta *et al.,* 2007). The expansion of goat rearing makes it difficult for the vegetation which is typical of the Caatinga to evolve, consuming up to 70% of the existing species and having a negative impact on their growth (Dourado, 2017).

The large livestock infrastructure generates different environmental impacts that cause deterioration and is difficult to reverse (Oliveira Junior, 2014). Overgrazing causes excessive treading which significantly alters the structure of the superficial later of the soil, intensifying its aggregation and diminishing the vegetation coverage, which in turn bolsters the process of erosion and affects the replenishment of fresh water, reducing its infiltration into the water tables (Souza, 2010; Bilotta *et al.,* 2007; Mirzabaev *et al.,* 2019). Livestock production is responsible for a part of the greenhouse gas emissions into the atmosphere and is generally something which consumes a lot of water (Vera and Muñoz, 2017).

Other important issues are linked to the commercial planting of fruits and vegetables, which is responsible for the lack of availability and deterioration in water quality, considering that the consumption made by irrigated crops exceeds that of the native species. Removing water for irrigation leads to a decrease in river flow, thus modifying the rates of evotranspiration (Sá *et al.,* 2010; Bilotta *et al.,* 2005). In these irrigated areas, the use of the water with high salt levels (above 5g/l of chlorides), the inappropriate handling of the wetting cycles and the lack of drainage leads the soil to salinization (Castelletti *et al.,* 2003), as in Figure 10.

Figure 10. Development of saline crust as a result of irrigation. Source: Almeida (2011).

Added to this are the agrochemicals and heavy metals in the pesticides used during ploughing that reach the Vaza-Barris river by being intentionally dumped or due to superficial draining, causing risks to human and animal health, polluting the soil through the infiltration of the water which transports particles present in the pesticides (Almeida, 2011; Killebrew and Wolff, 2010; Rohila *et al.,* 2017).

Generally speaking, crops are lower in height that the typical shrubs in the Caatinga and have lower stomatic resistance, leading to an increase in the susceptibility to biotic and abiotic stress, and to modifications in the water, energy and coal balances on the surface (Cunha, *et al.,* 2013). Given the permanence of these crops without their nutrients being duly replenished, there is a loss of fertility in the soil as a result (Sampaio *et al.,* 2003).

Continuously harvesting the soil for extended periods of time, the removal of the vegetation and burning the soil cause changes to its physical properties, particularly to its porosity, causing temporary or permanent changes, such as the reduction in the organic material that lowers its fertility, with losses greater than 50% of themicrobial biomass (Pereira, 2013), accelerating the process of erosion, the evolution of gullies and ravines, which are common in areas that are susceptible to desertification (Narain and Kar, 2005; Almeida, 2011), as can be seen in Figure 11.

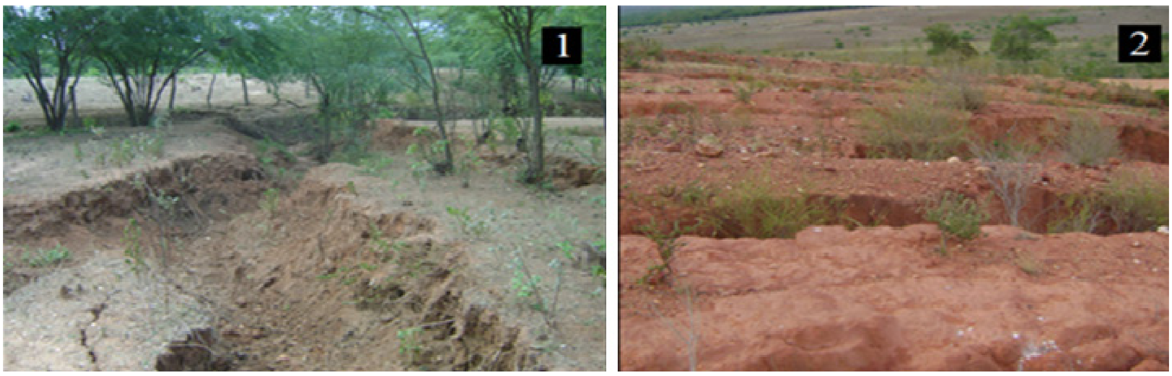

Figure 11: Processes of erosion in Jeremoabo: development of gullies (1) and exposed soil with gullies (2). Source: Almeida (2011).

Not adhering to the time required to restore the soil in farming practices gradually reduces its productivity and contributes to the onset of conditions that occur prior to desertification, which could be long-lasting or even irreversible (Brito, 2016). In some cases, they are a potential indicator of progression in the desertification process (Sampaio, 2005).

The reduction in the soil's productivity is just one consequence of desertification and causes problems for many sectors, mainly the agricultural sector, generating damage to production and crop failures, besides the high cost of recovering the soil and the plantations (Rossi, 2020; Dourado, 2017).

In Jeremoabo's case, the conversion of rural land into urban land, as well as being crude, is also characterised by pressures, interests and disputes, causing risk situations and socio-environmental vulnerabilities beyond the city limits and mainly affecting the conservation of the superficial water resources.

Of the main impact factors are the contamination caused by domestic effluents; the suppression of the vegetation coverage, which has a large effect on the conservation of the riverbanks; the paving of the streets, which reduces the potential for rainfall infiltration into the soil and all the other factors related to the increase in the speed of draining, the production of solid waste and sediment that are carried to the drains and change the natural features of the bodies of water, causing hydrological alterations (Silva *et al.,* 2016; Carpio and Fath, 2011; Ameen and Mourshed, 2017).

All these issues are linked to a lack of scientific knowledge and an inefficiency of technical means, as well as the ethical and social principles of the government and the local population, which are embodied by short-term policies with no comprehensive environmental or developmental view (Leff, 2002). In Brazil, it is the municipality's responsibility to regulate the occupation and use of the soil, as well as to establish territorial planning.

In the specific case inherent to the area of study, it is the municipal administration's responsibility to develop intervention capacity from interdisciplinary analyses and the activity of different sectors or levels of the public administration, as well as its standardisation with those representing private initiatives. Considering territorial planning are a process of organisation or an obvious condition ascribes it one or more goals that must be reached.

Of these goals, the protection and recovery of the Caatinga's environment are considered a key factor for maintaining the water resources, the soil and the economic activity concerning the processes of desertification. As a practical mechanism for enforcement, Brazilian legislation has a set of Natural Protected Area (NPA) categories (Brasil, 2000) which can be combined with local or mosaic systems in order to obtain more efficiency with regards protection and to better reconcile production activity with the principles of sustainability.

In addition, there is also the resource for Damper Areas (DA), which was introduced around the NPAs to establish different levels of restrictions regarding the occupation and use of the soil, with the aim of alleviating the environmental pressure on the protected areas and reducing the impacts on the environment (Machado *et al.,* 2020). Edmiston *et al.* (2017) suggests that the Damper Areas should work as areas peripheral to a protected area and as a way of integrating and familiarising people with the conservation and preservation goals and challenges of the different ecosystems.

The conservation of the current context of Jeremoabo's evolution, in the absence of territorial planning that would consider the environment as a space-organising agent and a basic condition for sustainability and economic development, tends to emphasise the causes that contribute to the increase in the processes related to desertification and the impoverishment of biological diversity. These issues will have a direct impact on the local human population, which could lead to an increase in social vulnerability (Vieira *et al.,* 2020).

5. Conclusion

Taking into account that the area of study is in a semiarid environment, linked to droughts and damaging human activity, the process of desertification ends up being the cause and the consequence of certain indicators, such as the reduction in ecological diversity, the growing depletion of the soil, the loss of water resources and the decline in productivity, which as a whole could lead to definitive desert-like conditions being established.

In this scenario, the use of geotechnology, particularly Remote Sensoring, is highly important for making diagnostics, facilitating data collection and analysis, especially in remote and environmentally vulnerable areas like Jeremoabo, thus offering the possibility of obtaining essential information for territorial planning.

Likewise, the classification of the use and coverage of the soil based on the different levels of anthropization made understanding the local productive system and its spatial layout possible, which was marked by the intensive and erroneous use of the soil for farming purposes that have a direct impact on the environment and are linked to the process of desertification.

Such practices, which are linked to the climate aspects that are typical of the area (high temperatures and rainfall concentrated into just 3 months of the year) break the dynamic balance of the environment, reducing the availability of water resources and favouring an increase in the process of desertification. This materialises with landscapes that show accelerated deterioration, displaying gullies, ravines, land with low levels of productivity and a high salinization of the soil. This process of erosion leads to the onset of irrecoverable areas or high recovery costs.

In relation to the classification made, the types Caatinga with Possible Crops and Caatinga Interspersed with Pastures are characterised by a lower concentration of anthropic activity, which is a result of unfavourable rainfall conditions, superficial soil and low water availability. The types Agriculture, Pastures and Crops Interspersed by Caatinga are characterised by the high level of human intervention, arising from conditions that are more suitable for the growth of animal husbandry activities, mainly to the east of the municipality and along the Vaza-Barris river, granting these types higher susceptibility to desertification as this phenomenon is directly linked to how the soil is occupied or used.

Hence, the social and environmental quality is threatened, taking into consideration that the main source of income for the municipality comes from animal husbandry activities and they depend on the weather conditions, the conservation of the soil and the water resources. In general, areas that are susceptible to desertification are characterised by low development, which shows the need for better geo-environmental conditions so as to foster improved management practices and the development of sustainable technologies.

Despite being in an area that is susceptible to desertification with an aridity rate lower than 0.20, agricultural soil potential being inadvisable and a high frequency of droughts, the area of study is not so severely affected by desertification when compared with other areas in north-west Brazil, as stated in a study carried out by the MMA in 2007, which identifies Ceará, Paraíba, Pernambuco, Rio Grande do Norte and Sergipe as being in an extreme state due to the process of desertification.

Given these circumstances, it is considered highly important that the local population is mobilised together with the public authorities in order to plan actions aimed at recovering the deteriorated areas, the creation and implementation of management programmes for water resources, environmental education and the promotion of improved agroecological exploitation techniques and the use of the municipality’s natural resources. Together, measures to monitor and control deforestation and burning practices as a form of soil protection are essential, as are crop diversification and reduction of extensive agricultural areas. Other alternatives include the use of allelochemicals extracted from plants to combat pests in the plantations and the establishment of an irrigation plan with a control on the amount of water used, as well as the adoption of a fertirrigation practice, which consists of the irrigation system applying water and fertiliser simultaneously.

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