THE INFLUENCE OF GEOMORPHOLOGICAL ASPECTS IN DEGRADED AREAS SUSCEPTIBLE TO DESERTIFICATION IN THE CEARÁ STATE, BRAZIL

A INFLUÊNCIA DOS ASPECTOS GEOMORFOLÓGICOS NAS ÁREAS DEGRADADAS SUSCETÍVEIS À DESERTIFICAÇÃO NO ESTADO DO CEARÁ, BRASIL

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ABSTRACT

This study tries to empirically correlate the genesis of the three cores of desertification in the state of Ceará with the areas located in the leeward position of the crystalline massifs, in most cases accented by direct or indirect human actions. The three cores/spots of desertification were identified and mapped by the Meteorology and Water-FUCEME Resources Foundation of Ceará, in 1990, and later by the State Action Program to Combat Desertification and Mitigate the Effects of Drought (PAE-CE) in the year 2010. It is clear that we cannot attribute the position of these geomorphological features as the only determinants of the occurrence of the degraded areas susceptible to desertification, it should also be noted that the environmental degradation is an ancient process that has been aggravated over time due to man's inappropriate use of techniques for the management of soil and vegetation in the Ceará semiarid region.
Keywords: Desertification. Orographic effect. Semiarid cearense.

RESUMO

O presente trabalho procura correlacionar empiricamente a gênese dos três núcleos de desertificação do estado do Ceará, na maior parte das vezes acentuados por ações antrópicas diretas ou indiretas, com as áreas situadas em posição de sota-vento dos maciços cristalinos. Os três núcleos/manchas de desertificação do Ceará foram identificados e mapeados pela Fundação Cearense de Meteorologia e Recursos Hídricos em 1990 e, posteriormente, pelo Programa de Ação Estadual de Combate à Desertificação e Mitigação dos Efeitos da Seca em 2010. É evidente que não se pode destacar apenas o fato da posição dessas feições geomorfológicas como determinante para a ocorrência das áreas degradadas suscetíveis à desertificação. Isso também se deve ao fato de a degradação ambiental ser um processo antigo, que tem se agravado com o tempo devido à utilização de técnicas inadequadas para o manejo do solo e da vegetação pelo homem no semiárido cearense.
Palavras-chave: Desertificação. Efeito orográfico. Semiárido cearense.

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1 INTRODUCTION

The advancement of studies conducted by the national and international scientific community in order to minimize the social impact of environmental degradation and desertification processes in drylands (arid, semi-arid and dry sub-humid) is clear. However, it is well noticeable that governmental institutions and other civil society organizations have been, until recently, far from understanding the relationship between social and natural systems that contribute to the above degradation processes.

The land degradation and the desertification growth is a real and significant risk for the populations of the countries located in arid, semi-arid and dry sub-humid areas of the planet. These processes already affect 33% of the earth's surface, where about 2.6 billion people live (42% of the total population). In Brazil, the desertification susceptible areas represent 15.7% of the national territory and shelter a population of over 31.6 million people. (BRAZIL, 2005).

Among the attempts made to recognize desertification as an environmental issue, we highlight the United Nations Conference on the Human Environment held in Stockholm in 1972, representing the first worldwide discussion on this process. However, only since 1977, with the completion of the United Nations Conference to Combat Desertification (UNCOD) in Nairobi, Kenya, desertification has taken on a global and interdisciplinary character, recognized by the United Nations Environment Program (UNEP) as an environmental problem that threatens the biosphere and represents severe costs to society. (NASCIMENTO, 2013).

In 1992, during the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, several environmental issues were discussed, such as global warming, the ozone layer depletion and the biodiversity protection, relegating the deep degradation processes of natural resources that lead to desertification to a secondary plane. The official desertification definition was recorded in Agenda 21, the main document produced during Eco-92, which reads as follows:

> Land degradation in arid, semi-arid and dry sub-humid areas resulting from different factors, including climatic variations and human activities in which land degradation means soil, water resources, vegetation degradation and the reduction of life quality of the affected population. (BRAZIL, 1995, p. 149).

In the same year, the International Conference on Climate Changes and Sustainable Development in the Semi-arid (ICID) held in Fortaleza, Ceará (Brazil), the desertification was considered holistically, associated or not to climate change. This conference inspired the Guidelines for the National Policy on Desertification Control.

The Convention to Combat Desertification – CCD, held in Paris in 1994 and ratified by 196 countries, including Brazil, served as the framework for the estab-

lishment of the World Day to Combat Desertification, whose main aim was to implement anti-discrimination policies and prevention of land degradation in areas susceptible to desertification, in addition to consolidating the idea that desertification is a problem of degradation in drylands.

In Brazil, the process of desertification is evident in the semiarid region of the Northeast, an area of approximately 788,064 square kilometers (48% of the region), which holds 11.85% of the country's population or 42.57% of the Northeastern population. And this population group, which is around 22,598,318 inhabitants, makes this region stand out as the most highly populated semiarid area of the planet. (BRAZIL, 2010). Out of this total, the Brazilian states of Paraíba, Bahia and Ceará are the most affected ones, the latter being the one which has the largest susceptible area to desertification, with 92.1% of its territory distributed on the perimeter of the semiarid area, where the resident population reached the mark of 4,724,705 inhabitants in 2010. (NASCIMENTO, 2013).

The semi-arid region of Ceará extends over 136,142 square kilometers (CEARÁ, 2005) and is characterized by having marked lithological heterogeneity, where soils are presented with a variety of associations; the occurrence of Luvisols (*Luvissolos*), Acrisols (*Argissolos*), Planosols (*Planossolos*), Leptosols (*Neossolos Litólicos*) and rocky outcrops associated with stony floors is very common; they are covered by caatingas of varying physiognomic and floristic standards with different levels of degradation. Furthermore, according to the data collected by the National Institute for the Semi-Arid – INSA (2011), this space is characterized by a high average annual temperature (27 to 29°C) and a strong evaporation index (2.000 mm), with rainfall of up to 800 mm/year, which is concentrated between three to five months and also irregularly distributed in time and space. When associated with human activities and possible drought, these contribute to heighten the geosystems fragility of the dry poor hinterlands, which promotes low environmental sustainability and high vulnerability to degradation/desertification.

Historically, this portion of the Ceará state territory has been used, since the early eighteenth century, for subsistence agriculture, cotton monoculture and especially for extensive cattle farming. The relations of production, according to Conti (2005), with some exceptions, have always been characterized by the primitivism of the procedures and the absence of a preservationist concern.

In 1990 the Meteorology and Water Resources Foundation of the Ceará state (Brazil) – Funceme produced a paper that aimed to indicate and map the areas of the State's towns that were susceptible to desertification processes, based on the criteria of semi-arid areas adopted by the United Nations-UN (1991) and the occurrence, in these areas of degradation, of the physical and biological components, identified by analyzing the satellite images based on remote sensing techniques.

Afterwards, in 2010, the State Action Program to Combat Desertification and Mitigating the Effects of Drought (PAE-CE) was launched, whose main objective is to contribute to the balanced coexistence with the Ceará semiarid region through environmental and socioeconomic public policies, focused on poverty reduction.

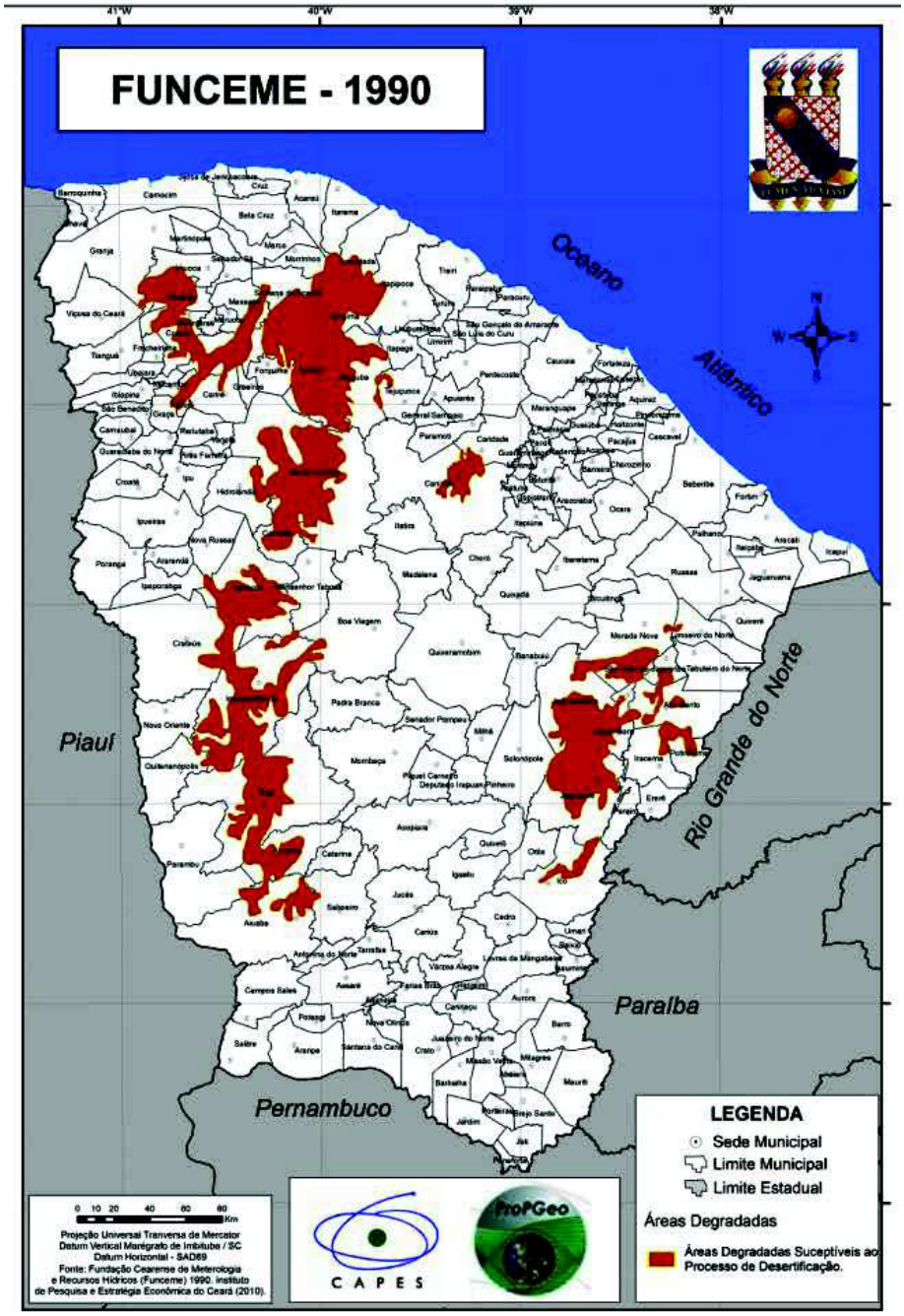


Figure 1a Comparative study of Funceme (1990) and PAE (2010).
Source: Prepared by Jáder Ribeiro de Lima, 2014.

This program delimited Areas Susceptible to Desertification – ASD throughout the state from satellite images, natural and socio-economic indicators. The researchers pointed out as the main causes of desertification, in the Ceará semiarid region, the disorderly use of the land, the deforestation and the practice of burning the

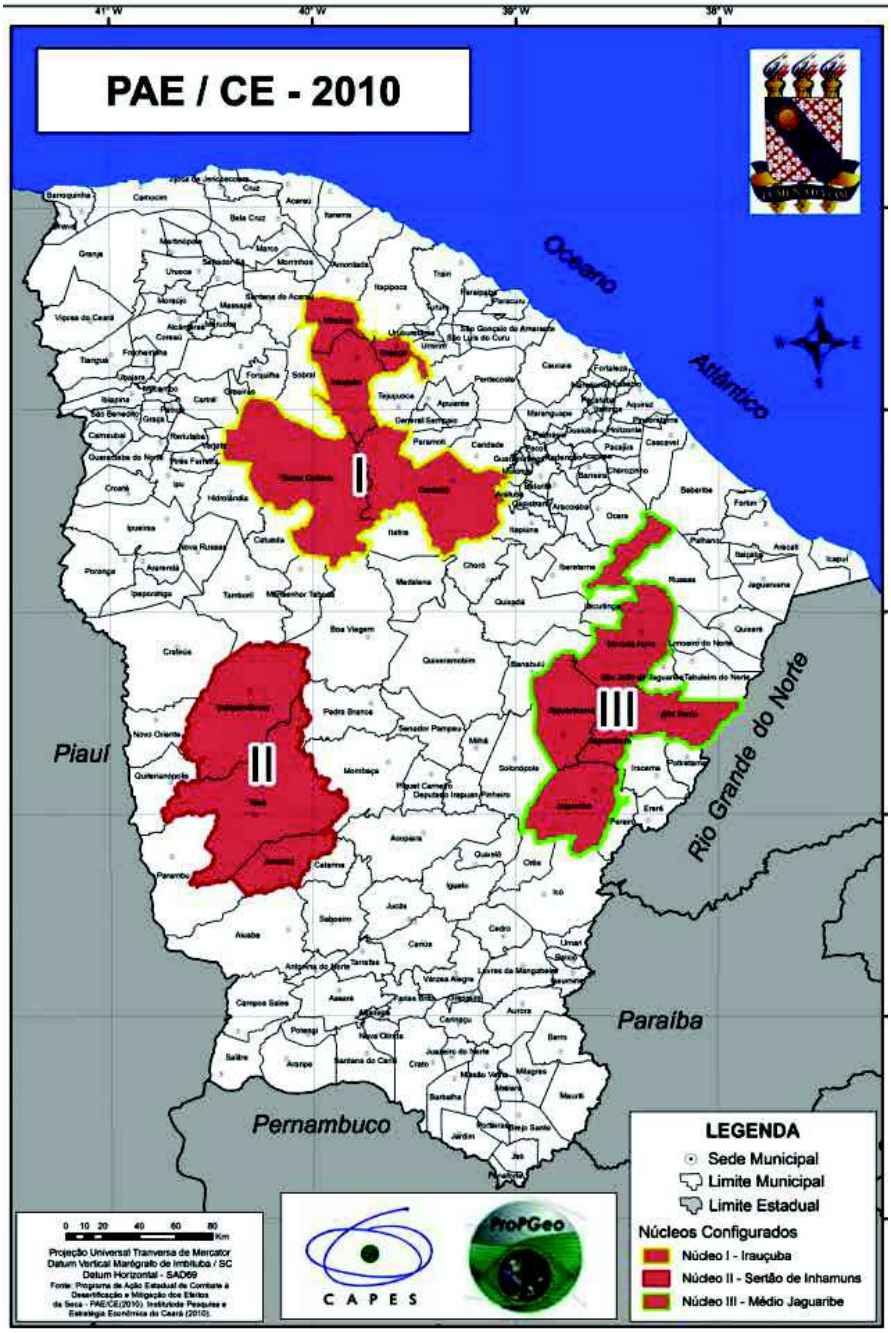


Figure 1b Comparative study of Funceme (1990) and PAE (2010).
Source: Prepared by Jáder Ribeiro de Lima, 2014.

land. It is observed that despite a time difference of 20 years, the areas susceptible to desertification in the research papers of Funceme (1990) and PAE-CE (2010) showed spatial similarity, with different delimitations, though (figures 1a and 1b).

The natural characteristics of the Ceará state dry environments are increased, among other aspects, by orographic influences. This statement can be easily found in the leeward areas of crystalline massifs scattered throughout the state territory.

Given the above, the present study attempted to correlate the genesis of the three desertification nuclei, in the State of Ceará, in most cases brought about by direct or indirect human actions, with the areas located in the leeward position of the crystalline massifs of that State.

The geographic position of these geomorphological features is a determinant for the occurrence of the degraded areas susceptible to desertification; also, it should be noted that the environmental degradation is an old process that has worsened over time due to man's inappropriate use of techniques for the management of soil and vegetation.

2 TECHNICAL AND METHODOLOGICAL PROCEDURES

The methodological procedures in this study were divided into 5 stages. The first consisted of the survey of the existing literature and the cartographic material for the study area. The second phase consisted of mounting a database in a Geographic Information System (GIS), in which ArcGIS software was used. The third stage corresponded to digital image processing, which served as a product for the generation of thematic maps, including the vegetation cover classification through the process of *Normalized Difference Vegetation Index* (NDVI). In the fourth stage, fieldwork was developed to better quantify the accuracy of the information gathered in the office and the fifth and final step was the generation of thematic maps relating the influence of the Ceará crystalline massifs in the areas of degradation susceptible to desertification existing in the state of Ceará.

The research began with a survey of publications that would strengthen the theory of the massifs influence over the localities beyond the leeward area of the crystalline massifs present in the Ceará territory. Geomapping data were collected from all over Ceará that addressed the same theme, from different institutes with activities focused on the environment.

In the bibliographic and cartographic data collection step, a survey of the satellite images from Landsat 8 in the bands 4, 5 and 6 was made; these were provided via free download from the site of the United States Geological Survey (USGS). The images were selected taking into account the cloud cover in the region and the temporality of dry and rainy season. They are images dated from July to September of the years 2013 and 2015. Other images from this site were used, such as

the Shuttle Radar Topography Mission (SRTM) to identify altimeter patterns of the study area and identify the presence and spatial distribution of crystalline massifs.

In order to identify the state's rainfall patterns, rainfall data were accessed from Funceme, especially to make it possible to compare the leeward areas to the windward areas of the crystalline massif regions. These data were acquired through the Funceme website by selecting the pluviometric stations of the desired areas.

Then, in the second stage, all the map data was organized into geographic information system environment. A system which allows the crossing of various types of information and the application of digital image processing, which is the third stage of the research.

In the third stage, the pre-processing work of satellite images was carried out, such as the composition of bands, projection transformation and adjustment of images to work with a better spatial resolution (15 meters). Still at this stage, the NDVI process with the satellite images for identifying the degradation stains was performed.

According to Liu (2006), the multiple vegetation indices used to monitor and quantify the conditions and spatial distribution of vegetation, using the digital data of spectral reflectance of electromagnetic radiation, has aimed to condense spectral information and discriminate what is or is not vegetation, evaluating the growth conditions of crops, occurrence of diseases, pests, drought or frost, and various meteorological events.

With the identification of different patterns of vegetation stains, fieldwork was done in the study area, in order to validate such stains according to the conservation status of the vegetation. This way, it was found that the most degraded areas are mostly in the rear of the leeward region of residual massifs. Hence, confirming the hypothesis of relative influence of these massifs over the surrounding areas.

In the last step, the thematic maps of topographic profile were generated, from the municipality of Guaramiranga, in the Baturité Mountain up to Itatira, in the Machado Mountain, passing by Canindé. A map that shows the areas of influence of the residual massifs in their surrounding regions was generated (figure 2).

3 INFLUENCE OF GEOMORPHOLOGY IN AREAS SUSCEPTIBLE TO DESERTIFICATION IN CEARÁ

The Ceará State presents most of its territory under the semi-arid climatic conditions, without the presence of homogeneous natural features with varied patterns – both in the morphostructural or edaphoclimatic point of view. In general, it is possible to highlight the hinterland depressions covered by caatingas as the predominant landscape units of the Ceará semiarid region. These hinterlands are vast erosion surfaces located between highland topography such as crystalline massifs and sedimentary plateaus.

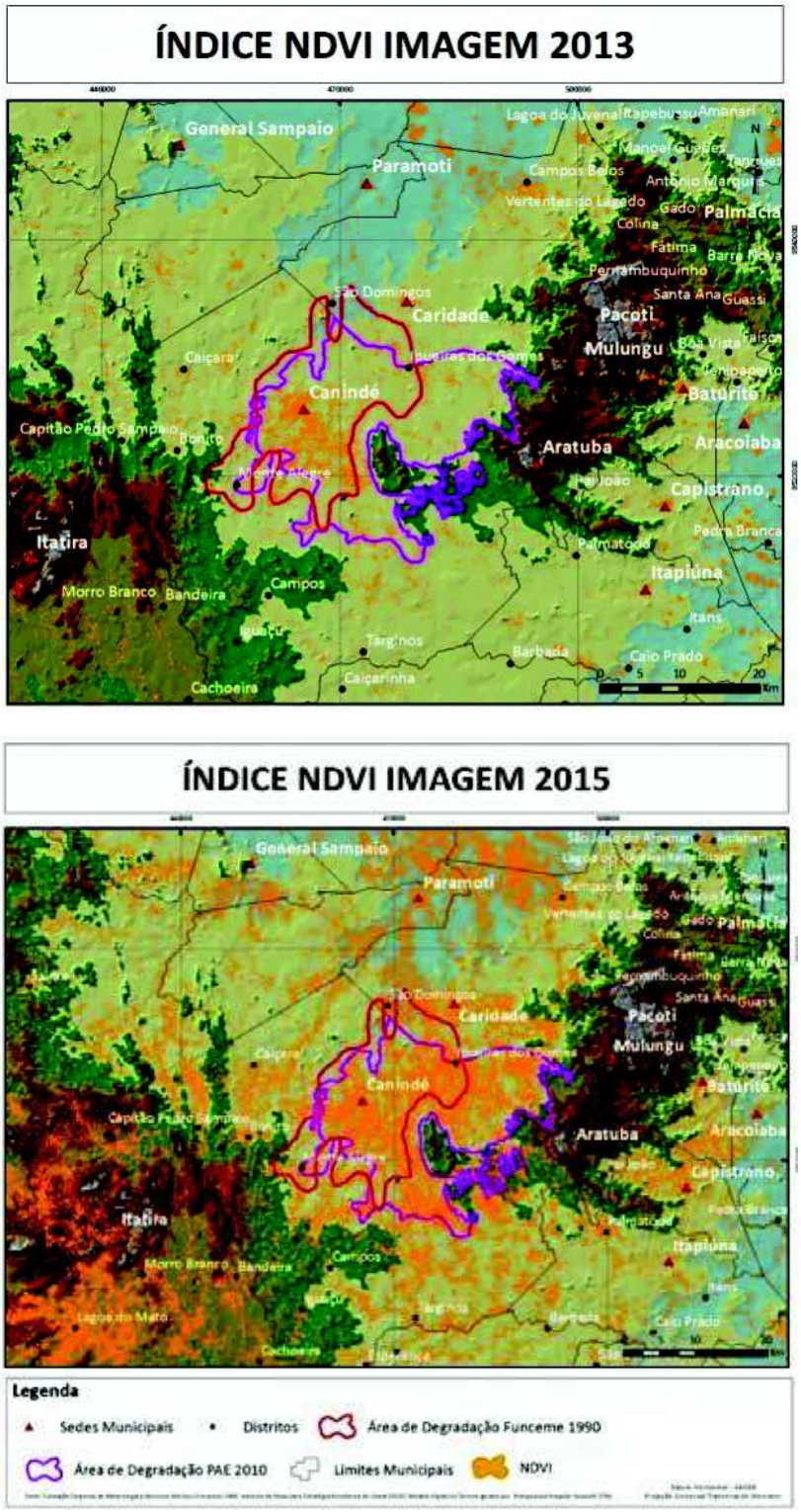


Figure 2 Degraded areas for the years 2013 and 2015.
Source: Prepared by Jáder Ribeiro de Lima, 2015.

These higher surfaces of highland topography with different dimensions and subject to the influences of altitude semi-arid climates (SOUZA, 2011) represent in the geo-ecologic context of the semiarid region, true environments of exception. Areas that have a completely different dynamic nature, with deep soils, semi perennial rivers, evergreen vegetation/sub evergreen vegetation of arboreal size and the predominance of chemical weathering. (BASTOS; CORDEIRO, 2012).

According to Conti (2005), the topography of the Brazilian Northeast presents altitudes a little over 1000 meters and introduces significant natural changes resulting from windward and leeward situations. In higher areas, unlike the drier hinterlands of Ceará, such as the Baturité Massif, the Meruoca, Uruburetama, Maranguape, Pacatuba and das Matas Mountains, the semi arid effect is mitigated by the orographic influence. In these "green islands" or "altitude marshes" (AB'SÁBER, 2003) the annual rainfall totals reach values greater than 1.000 mm. (SOUZA; OLIVEIRA, 2006).

In general, the air masses shift patterns in the state of Ceará are predominantly in the east-west direction, windward in the eastern sectors of the highlands and leeward in western areas. Such positions regarding the climatic effects also leave marks in the surrounding areas of the highlands, where caatingas are evident, with much more significant physiognomic patterns in the eastern hinterland depressions than in the western hinterlands.

The lack of annual rainfall is increased in the surrounding hinterlands, especially the ones located in the leeward position (CONTI, 2005), as in the western slope of the Baturité Massif, in Ceará, where the towns of Caridade and Canindé, located in the central hinterland, expressed in 2013, average rainfall totals that reached, respectively, 788 mm and 756 mm. (CEARÁ, 2014). There are also examples of other towns, such as Irauçuba (539 mm), Tamboril (685 mm) and Jaguaribe (676 mm), towns in Ceará located opposite the dry side of the Uruburetama, Matas and Pereiro mountains, respectively, where the semiarid effect is revealed more intensely (figure 3).

In this perspective, it can be observed that the crystalline massifs alignment patterns in Ceará – preferably oriented according to NE-SW directions – and its relation to the direction of the trade winds from the east and southeast, have a direct influence on the low rainfall indices in the surrounding hinterlands, located in the leeward position, besides contributing to the emergence of areas susceptible to desertification, as can be seen in the red patches in figure 3.

The direct influence of this highland topography in the low precipitation rates and, consequently, in the hinterland landscapes situated downwind, can be seen when comparing the rainfall rates in the towns of Guaramiranga and Canindé, where the rainfall differentiation between nearby areas is discrepant (figure 1). It is important to point out that these two towns are only 43km away from each other;

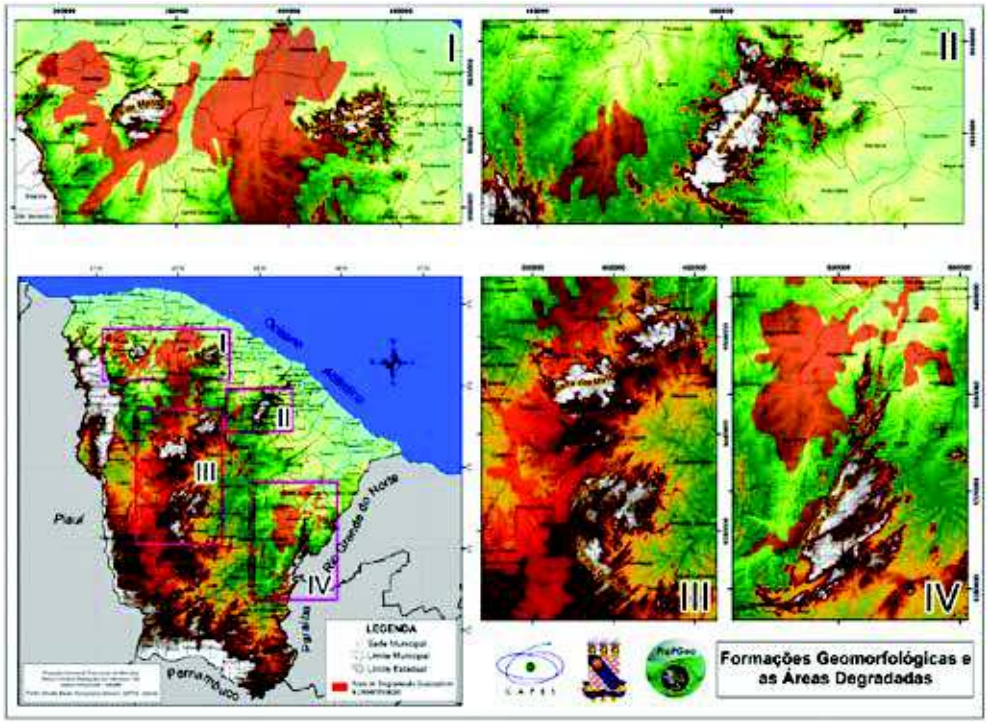
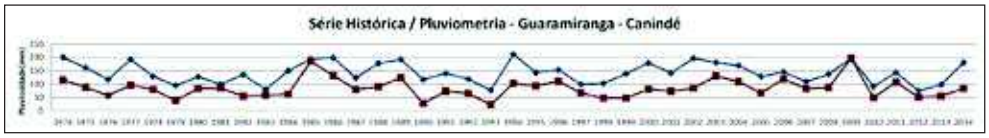


Figure 3 Occurrence of areas susceptible to desertification associated with the presence of Residual Massifs, in the state of Ceará: I) Uruburetama and Meruoca Mountains; II) Baturité Massif; III) Machado and Pedra Branca Mountains; IV) Pereiro Mountain.
Source: Prepared by Jáder Ribeiro de Lima, 2014.



Graph 1 Historical rainfall series of Guaramiranga (Blue) and Canindé (Red), Ceará, Brazil.
Source: Funceme, 2015.

the reason for the significant rainfall difference is, mainly, their geographical location, considering that Guaramiranga is situated on the Baturité massif plateau at an altitude of 865, 24m, with an average rainfall of 1.737,5 mm/year, while the town of Canindé, which is located in hinterland depression, at an altitude of 148m above sea level, and in the leeward of this massif, presents an average rainfall of 756 mm/year. (CEARÁ, 2013).

The Baturité massif presents maximum altitudes of 1.114 m (High Peak), becoming a natural orographic barrier and making the region west of the massif a differentiated landscape area, a reflection of the low rainfall rates (figures 4 and 5).

However, it is clear that one cannot stress only the altitude and exposure of these geomorphological features as determinants of the occurrence of areas susceptible to the phenomenon of desertification, it should also be noted that the

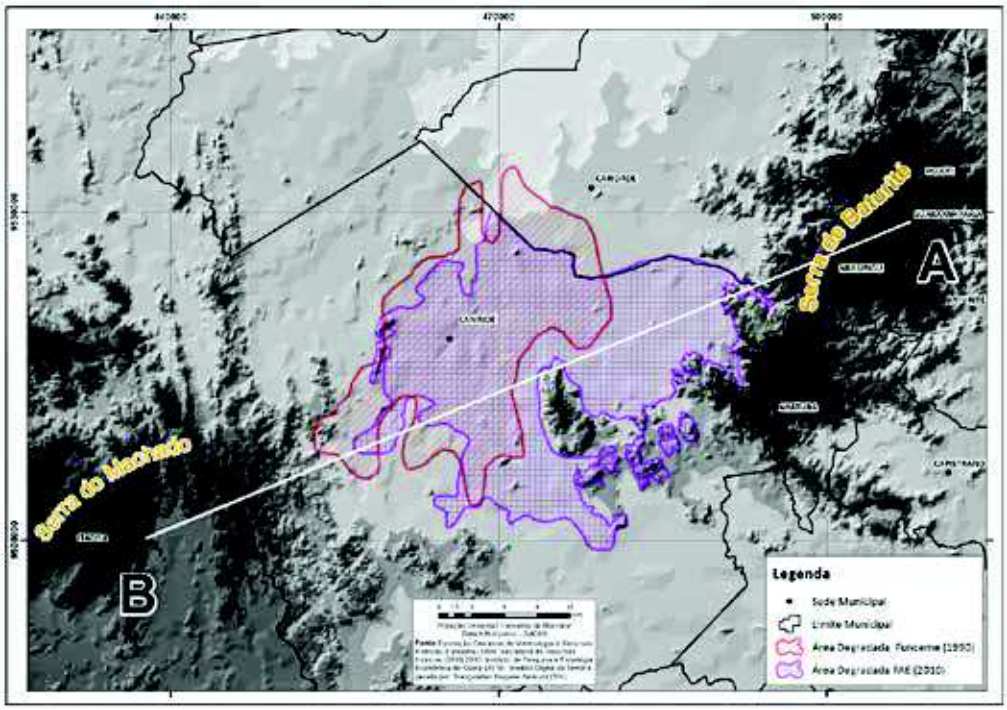


Figure 4 Elevation profile: Guaramiranga (A) - Itatira (B).
Source: Prepared by Jáder Ribeiro de Lima, 2014.

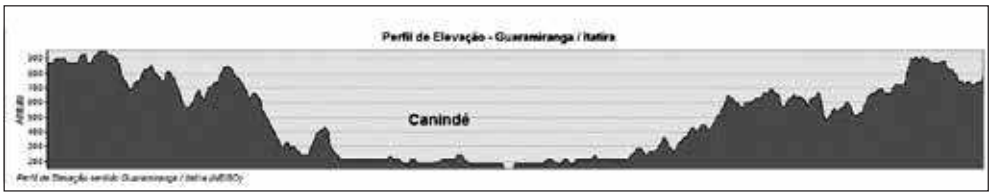


Figure 5 Elevation Profile from Guaramiranga to Itatira (NE/OS).
Source: Prepared by Jáder Ribeiro de Lima, 2014.

environmental degradation, in intermountain depressions, is an old process and that it has worsened over time due to the use of inadequate techniques of soil and vegetation management.

According Tricart (1977), the changes in vegetation cover, cause changes in the environmental balance, which accelerate erosion, increase local temperature, reduce the water recharge of rivers and aquifers, among other events, justifying the maintenance the of vegetation cover for the environmental balance.

According to Nascimento (2006), some unproven theories attempt to explain the azonality of the semiarid climate in the Northeast by generic factors. For the author, one of the theories is about the existence of the Borborema plateau, which would produce a leeward effect in the hinterlands. (CONTI, 2002). Another theory

advocates the formation of a high-pressure cell, possibly related to the southern extension of the Azores anticyclone, hindering the penetration of the continental equatorial mass, the maritime tropical and the Atlantic polar front, which would act in the weather destabilization. (NIMER, 1977). However, in an overall view, it is confirmed that the areas affected by the desertification process in the Ceará semiarid region are defined by crystalline massifs alignments presenting a certain natural homogeneity.

Leite et al. (1993) based on visual and automatic interpretation of the TM-LANDSAT satellite images, by assessing the degree of reflectance of the areas with high biomass reduction, indicated three spots susceptible to desertification processes in the State of Ceará, which are situated in the town of Irauçuba and in the regions of Inhamuns/ Sertão de Crateús and Middle Jaguaribe, both respectively located in the leeward position of Uruburetama, das Matas and Pereiro massifs.

According to Conti (2005), the signing stain of desertification evidence in the State of Ceará, forms an axis approximately NE-SW from Itapajé in the leeward position in relation to the Uruburetama moutain up to Campos Sales, at the foot of the Araripe hill, which could be considered the state's arid diagonal.

4 FINAL CONSIDERATIONS

The process of desertification in the state of Ceará presents itself differently according to the natural dynamic of the different environmental systems and the changes produced by the social actors involved. However, in inter-plateau depressions located in the leeward position of crystalline massifs, the combined effect of the lack of vegetation, the dryness of the soil and the topography, associated with the predatory forms of man's relationship with the environment, increases the susceptibility to climate contingencies, especially thermo-pluviometric.

Therefore, the desertification processes in the Ceará semiarid region result from the disposition of the structure of natural components, mainly determined by the seasonal water deficit, intensified in some regions by the presence of residual massifs which, by means of the orographic effect, determine the low pluviometric indices in the hinterland depressions localized in the leeward position, which in some sectors are associated with human activities, leading to the emergence of spots or stain groups associated with the local desertification process.

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