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Evaluation of Desertification Processes in Seridó Region (NE Brazil)

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ABSTRACT

This paper outlines procedures to analyze the desertification processes in the semi-arid Seridó Region (NE Brazil). Using the Geosystem theory, the detection of desertification areas was based on environmental indices, digital image processing in multispectral analysis and Geographic Information System (GIS). The first step was to treat the rainfall data and NDVI satellite Modis, aiming at identifying areas which do not present vegetation cover, even during the rainy seasons. The second step was to work on a regional scale using Landsat ETM + images (2000-2005) and data collected in the field, as the evaluations of exposed surfaces, that together with MDT/SRTM-NASA and thematic maps, allowed to classify the altitude and slope of the relief, soils type, different morphologies and geology, and correlate them with the areas susceptible to desertification process. The integration of the georeferenced data, related to these indicators, allowed the identification of five different levels of susceptibility to desertification (very high, high, moderate, low and very low), and the geographic domain of each class. Based on the analysis of the dynamics of the vegetation cover, we can establish that the main results refer that there is a decrease of the biomass at the region, associated with the dense caatinga vegetation areas, but more important, with the scrub and degraded areas.

Keywords: Desertification; Caatinga; MODIS; Landsat; NDVI; Seridó; Brazil

1. Introduction

The United Nations Conference on Environment and Development, (Rio-92), officially defined as "Desertification", [chapter 12 of Agenda 21], as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The susceptibility to desertification process according the Agenda 21 [1], affects about one third of the Earth surface (about 36 million km^2), or 70% of the dry lands of the world (arid, semi-arid and dry sub-humid), excluding hyper-arid areas and deserts.

Many developing countries suffer from problems such as soil degradation and destruction of natural resources, including Brazil, where the most vulnerable area is located in the NE semi-arid region. This area exceeds 900,000 km^2, and a 20 million population, corresponding 44% of the Northeast and nearly 10% of the population of Brazil [2]. This region is characterized by high evapotranspiration, the occurrence of periods of drought, narrow soils and reduced water retention capacity, thus limiting their productive potential. All these combined elements lead to very fragile ecosystem, which is worsening mainly due to degradation of vegetation cover and mismanagement of land, due to the predatory exploitation of the particular biomass known as Caatinga, deforestation and burning.

The state of Rio Grande do Norte (RN) is the 4th northeastern state (on eleven) with number of municipalities included in the semi-arid desertification susceptibility area. About 50% of these municipalities belong to the Seridó Region, located in the most vulnerable area to desertification, with an area of 6,836 km^2 and concentrating the largest number of inhabitants (216.500) of this region. The objective of this study is to identify and map areas of Seridó Region showing advanced process of desertification, using Remote Sensing and Geographic Information Systems (GIS) to quantify and evaluate its impacts and influences on the regional environment.

2. Characterization of the Area

The region is located over a Precambrian crystalline basement and shows nucleus of desertification due to geoecological fragility, accentuated by the forms of land use, using a model of development whose economic base is not tied to environmental restrictions. Processes of environmental degradation and desertification in various stages of development are recurring, especially in spots discontinuous and fragmented spaces that permeate most part of the Caatinga **(Figure 1)**. The area has a semiarid vegetation which more typical feature are represented by a shallow ground cover composed mainly of grasses, above which emerge the shrubs and trees with low or medium-sized, with lots of thorny plants, from lop down, interspersed with various cactuses and bromeliads. These environmental conditions in the Seridó Region are naturally susceptible to erosion, desertification and degradation of its natural resources, and are accentuated by the inadequate management of human activities.

Under the system of climatic classification of Thornthwaite [11], the climate of this region is semiarid, megathermal, with little or no hydric surplus and concentration of evapotranspiration in the summer months equal to 26%, reaching an annual average of 1.464 mm. The high temperatures are shown throughout the year, reaching an average maximum of 28˚C (with picks of 37˚C) and a minimum of 22˚C. These climatic aspects cover a high rate of evaporation, contributing to a large hydric deficit, which marks the intermittent seasonal surface water [13].

The water deficit results from the infrequent rainfall and high potential evapotranspiration. The rain is concentrated in three to four months and with great variation between sequences of years with periods of extreme dry. Associated with variation of water deficit, there are soil always very shallow that has low water stock capacity and low permeability, lithological discontinuities in the profiles, and salinity of the surface layers. The most important systems that generate precipitation are: Intertropical Convergence Zone (ITCZ), formed mainly by the convergence of the northeast trade winds and southeast trade winds which are considered primarily responsible for the period of heaviest rains in the RN state.

The variability, intensity and positioning in the equatorial Atlantic are closely related to thermal conditions that occur in the tropical oceans (Atlantic and Pacific). The region is under the influence of the South Atlantic anticyclone, which provides the stability of the time most of the year [3].

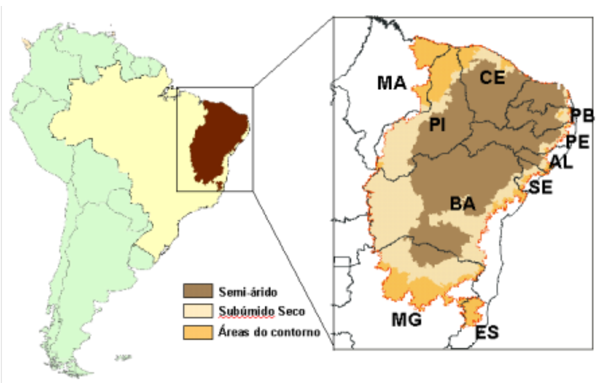

Figure 1. Seridó region (NE Brazil).

Table 1 shows the aspects of the distribution of rainfall throughout the year. In **Table 1** we can observe the rainfall data for the period 1961-2010, collected in Station of Patos (PB) (Lat-70.02”, Long-37. 27”).

We can observe the data of rainfall distribution showing the rain concentration on March-May. Is very evident characteristic of seasonal rainfall distribution of this region, varying in time and space, setting up a rainy season, irregular, varying from 3 to 4 months in the beginning of the year, and a prolonged dry season in the final months. These observations are important because they will orient the selection of MODIS images that will mark the distribution of rainfall periods.

3. Date and Methods

The Modis NDVI were used to identify areas that do not show vegetation cover, even during the rainy seasons. In a second step, the Landsat ETM+ images (2000-2005) were worked on a regional scale and checked with data collected in the field, as the evaluations of exposed surfaces. A model of MDT/SRTM-NASA (2003) (Shuttle Radar Topographic Mission) refined at a resolution of 30 meters using the Bicubic Spline interpolation and prepared with the software SPRING, has allowed classify the altitude and slope of the relief, different morpholgies and correlate them with the areas susceptible to environmental degradation (**Figure 2**).

A 16-day composite Terra/MODIS obtained image during Feb. 1982 to May 2007 (121 full scenes of MOD13Q1 data) was downloaded from NASA’s DAAC web site (http://daac.gsfc.nasa.gov/data/). The MODIS image was firstly geo-rectified and resized into 30 m

Table 1. Average rainfall (mm) (1961-2010) on the studied area (INMET-Brazil).

Trimester	Lower Limit	Average	Upper Limit
Jan-Feb-Marc	361	437	500
Feb-Marc-Apr	381	505	590
Marc-Apr-May	291	425	513
Apr-May-Jun	141	254	309
May-Jun-Jul	58	109	136
Jun-Jul-Aug	25	49	65
Jul-Aug-Spt	8	20	26
Aug-Spt-Oct	3	11	11
Spt-Oct-Nov	3	11	15
Oct-Nov-Dec	18	48	51
Nov-Dec-Jan	78	135	152
Dec-Jan-Feb	178	270	313

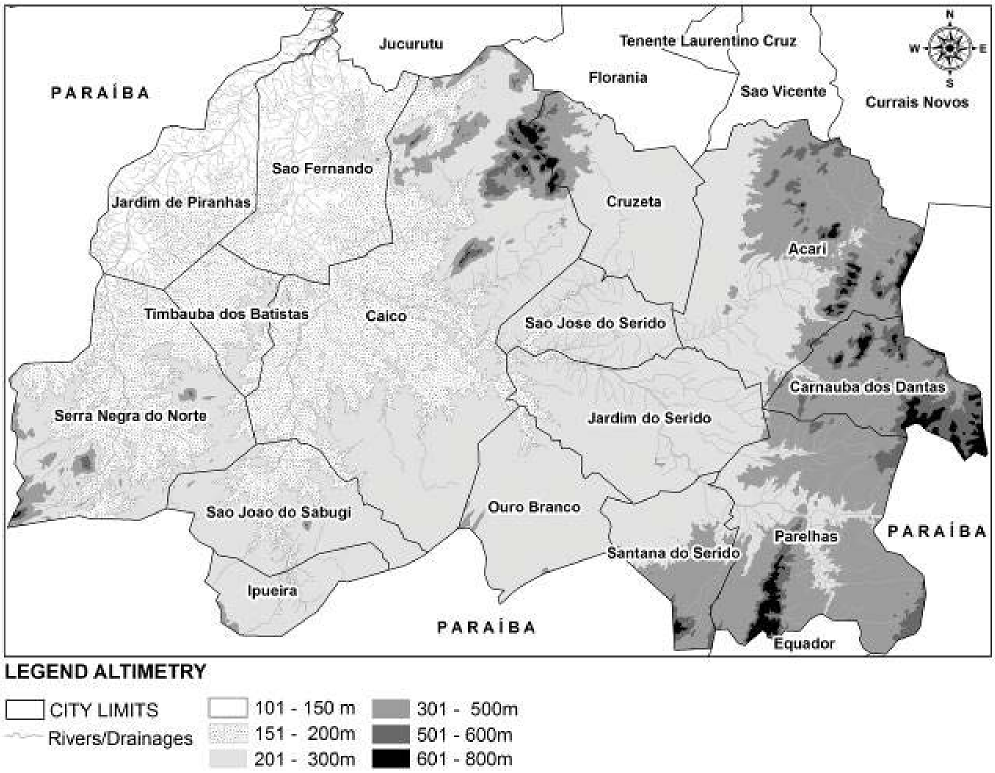

Figure 2. Relief, morphologies and correlate areas susceptible to environmental degradation.

resolution to match the TM image, and then, a relatively atmospheric correction was applied to minimize the effect of atmospheric conditions difference between these images. All procedures were performed using the GIS and image processing, ArcGis and ENVI. To compose the database, three sets of data were used: (1) the available data in systematic mapping (1:100.000): altimetry-landforms, settlements, roads, hydrography, (2) the thematic mappings on regional scale (between 1:100.000 and 1:500.000), such as hydrogeological potential, geology, lithological resistance, soil types, class of land use, underground water wells, mineral occurrence, (3) data obtained from digital processing of remote sensing data, such as levels of vegetation cover classes and fragmentation of vegetation cover.

3.1. NDVI MODIS Images

Vegetation change has been successfully observed at scales ranging from local to global using the Normalized Difference Vegetation Index (NDVI), derived from satellite data [5-7,15]. The NDVI minimizes the effects of topography and atmosphere, requires no prior knowledge of ground conditions, and is sensitive to the amount of photosynthetically active vegetation present [4]. The change in the value of the NDVI between 1982 and 2007 obtained from imagery acquired by the MODIS satellite was used for this indicator. Due to the fact of the satellite MODIS present a constant imaging we could process a complete series of images month to month. First they are processed and analyzed the MODIS images with the purpose of evaluate areas with vegetation deficit in the dry and on rainy periods, selecting which areas would be analyzed in a second moment with the Landsat images.

First results of the MODIS cloud flagging attempts with 5 masks (3 cloud + 2 shadow) produce large masked areas. Further Investigations have to be carried out using only 3 cloud + 1 shadow mask (shadow2) or using only the cloud masks. Despite of the large coverage of masked areas, these 5 masks cover the cloudy and shadowed areas fits good results. After repeat this same procedure with all the set of five years images and filtering of time series data, we have the overview of this period and the different season of dryness and rain. In this series of 121 Modis images from 1982 to 2007, it is possible to identify very clearly the positive peaks that mark the rainy seasons and negative peaks that identify the dry seasons (**Figure 3**).

The integration of data generated from the processing of MODIS images allowed to identify which areas of the Seridó Region showed lack of vegetation even during the rainy seasons and thus these areas were selected for the next step which was centered on the processing of Landsat images to map and quantify the areas in the process of desertification.

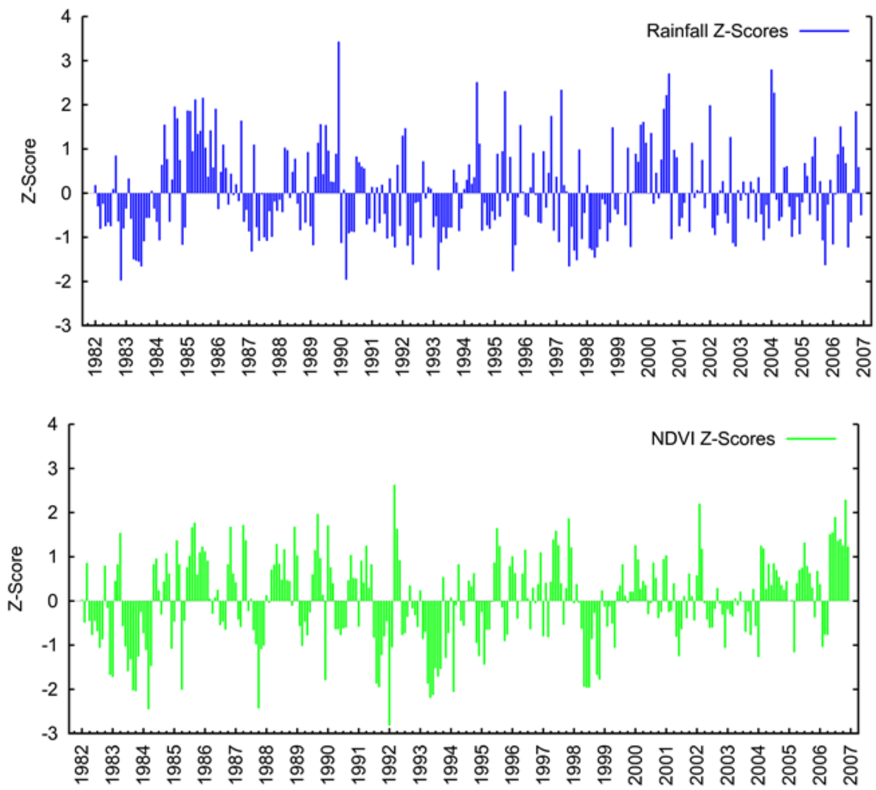

Figure 3. Standardized anomalies (Z-scores) of Normalized Difference Vegetation Index (NDVI) and rainfall data for Northeast Brazil between 1982 and 2007. The diagrams show the anomaly of a single month to normalized long term monthly mean values (1982-2007).

3.2. Landsat 5-TM and Landsat 7 ETM+ Digital Analysis

For mapping the desertification level of the Seridó Region, on the selected areas establish in the anterior images processing, were used images of the sensor LANDSAT-7 ETM+, cut according to the coordinates of the study area. These images were taken between September of 1999 and in the consecutive years, more precisely in March and Setember/2001, April and October/2002, September/2003 May and September/2004 and April 2005. This aspect of multiple temporalities of the images is important, because it allows the comparison of the spectral response of the land features in conditions of different humidity, as well as the monitoring of the evolution of the patterns of anthropogenic activity in the area.

The digital analysis was processed directly in the software ENVI and the mapped classes were transformed of the format raster for the vectorial format, being after exported for the software ArcGIS where it was made the last adjustments (in the mapped classes) in the intention of obtaining the physiographic maps of Geology, Geomorphology, Soils and Vegetation (**Figure 4(a)**, **(b)**, **(c)** and **(d)**) for this region, base of the identification of areas with desertification process.

The normalized vegetation index (NDVI) was used to identify unvegetated regions and generate the Desertification Map (**Figure 5**). The field evaluation and the physiographic aspects combine with the low values of this index were used to represent in this map the areas with stronger process of desertification. Comparisons were made with composite images to derive the threshold, and then unvegetated areas were identified.

4. Results

The map of the degraded areas susceptive to the desertification processes (**Figure 5**) it evidences in this condition of analyze, that has a great numbers of area located on the center, northwest and north of the studied area, that present serious levels of the desertification process. The total of the areas where the phenomenon is verified reaches 638 km^2, that represent 27.26% of the total area of Seridó Region. It is in these municipal districts of the focused region where it is the largest extension of areas in process of environmental degradation and susceptive desertification process.

In Caicó District the spots that represent the degraded areas are concentrated on the south, southeast and northeast of the municipal area. The total of the areas committed by the degradation reaches 29.588 hectares, in

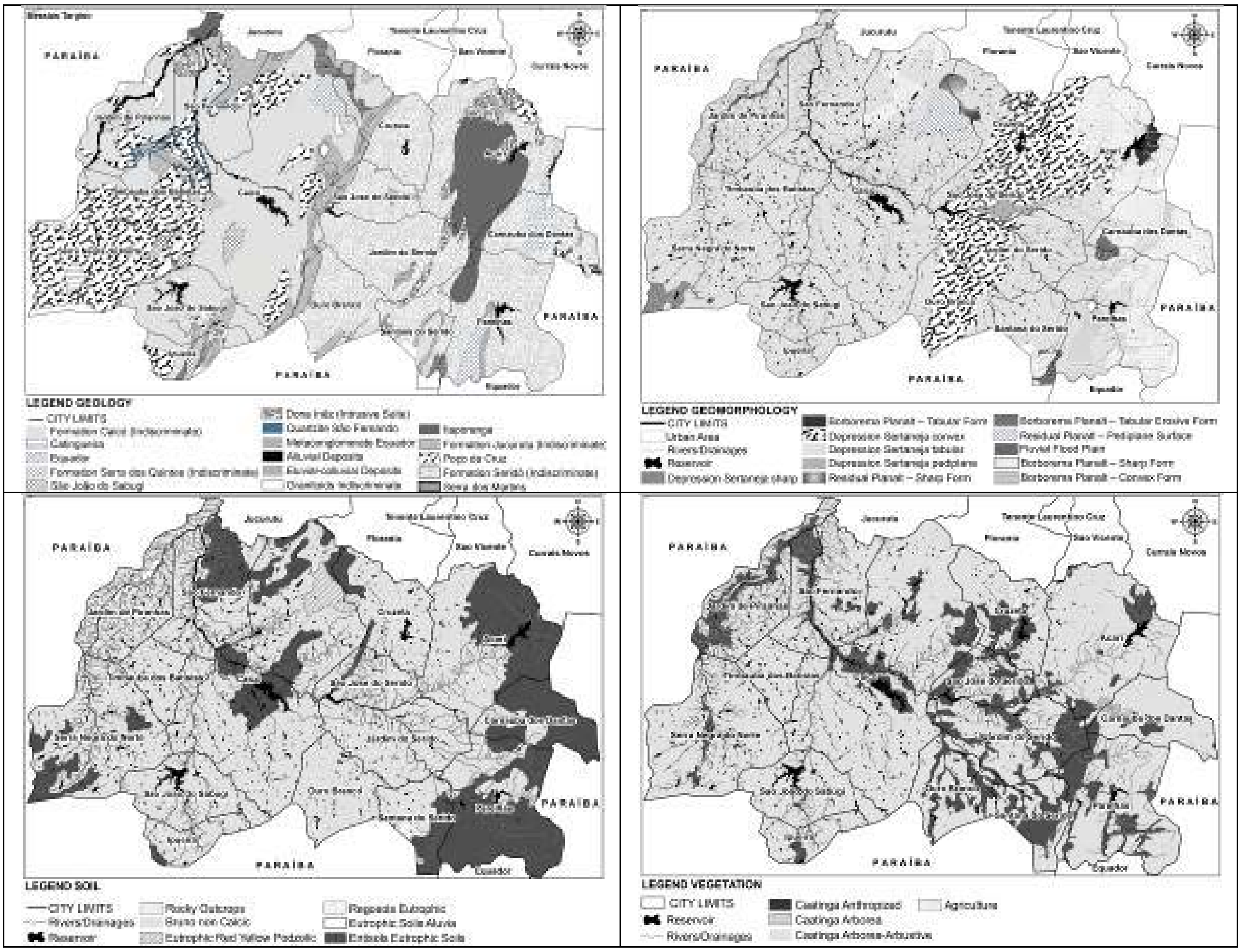

Figure 4. Maps of Geology (4A), Geomorphology (4B), Soils (4C) and Vegetation (4D).

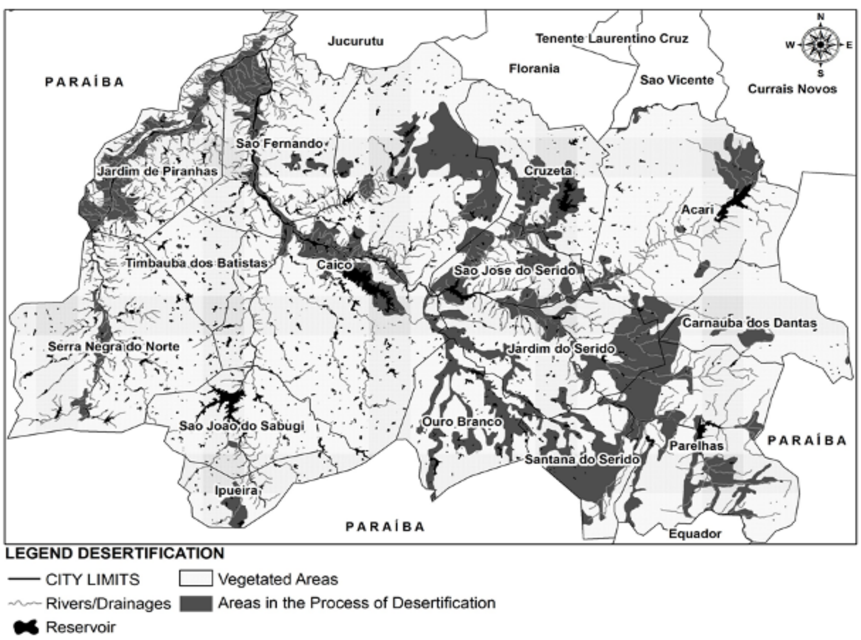

Figure 5. Areas in process of desertification (dark spots).

other words, 17.59% of the total area of the municipal district. The municipal district of Serra Negra constitutes, in Medium Seridó, the least affected for the observed environmental phenomenon, presenting dispersed scattered spots in all its extension, with a larger concentration on southwest and northeast. In quantitative terms, the degradation areas represent 7.434 hectares, corresponding to 11.34% of its total area.

The special comparison was done of NDVI indexes derived from Modis and current Vegetation NDVI on Landsat. This study has shown that to compile the maps of different images parameters of the same ecosystems, including desertification depth (through special methods), desertification yearly dynamics (through change/time series analysis), vegetation monthly and seasonal index dynamics (through NDVI change/time series analysis etc. is possible to define and analyze spatial structure of semi-arid ecosystems.

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