DESERTIFICATION STUDIES IN THE BRAZILIAN NORTHEASTERN AREAS WITH GIS DATABASE

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ABSTRACT

This paper provides spatial and georeferenced information related to the susceptibility to desertification of several areas of the Northeast of Brazil. We aim to test the usefulness of spatial analysis methodologies to capture spatial-temporal heterogeneity from environmental gradients, for the assessment of desertification process at Remote Sensing data. In this sense, the analysis and integration of geo-environmental variables and the creation of environmental indicators associated with the development of the desertification process was performed, based on the use of spatial modeling procedures applied to data from the semi-arid portion of the Northeastern Brazil region.

A set of sixteen-year period of Landsat 5-TM and Landsat 7 ETM+ images were explored for vegetation and soil study and local analysis of association and variability of spectral data were performed. 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 and on the evaluation of field data, we can establish that the main results refer that there is a decrease of the biomass at the region, associated either with the dense *caatinga* vegetation areas, but more important, with the scrub and degraded areas. From an environmental perspective, the decreasing biomass level associated with scrub and degraded areas are according to the negative feedbacks of the desertification process. Considering the last ten-year periods of comparisons, the spatial variances leave almost different, which means that heterogeneity pattern, is increasing very considerably. This fact means an explicit expansion of spatial heterogeneity of the desertification landscapes, during the last years.

KeyWords: Desertification, Environmental Indicators, Environmental Analysis, Susceptibility, Geoprocessing, Geographic Information Systems (GIS), Spatial Modeling, Semi-arid, Northeastern region, Seridó, Rio Grande do Norte, Brazil

1. INTRODUCTION

About 3,6 billion of the world's 5.2 billion hectares of useful dryland for agriculture has suffered erosion and soil degradation. In more than 100 countries, 1 billion of the 6 billion world population is affected by desertification, forcing people to leave their farms for leave in the cities. The economic impact is horrendous, with a loss of more than $40 billion per year in agricultural goods and an increase in agricultural prices. According to the World Wide Fund for Nature, the world lost about 30% of its natural wealth between 1970 and 1995.

Desertification takes place in dryland areas where the earth is especially fragile, where rainfall is nil and the climate harsh. The result is the destruction of topsoil followed by loss of the land's ability to sustain crops, livestock or human activity. But the deserts are not necessarily only the product of external forces like dryness and decreasing rainfall, rather, it is the internal ecology of the desert region itself - its habitat of plants, animals, and soil, - that drives its development. Climatic changes can trigger the desertification process, but human activities frequently are the proximate cause. Attending to the historical evolution of some deserts, it has been found that internal arrangements drive the ecosystems from smooth to patchy, and to find the driving forces of that movement means the explanation of desertification.

In the last 25 years, satellites have begun to provide the global monitoring necessary for improving our understanding of desertification. Landsat images of the same area, taken several years apart but during the same point in the growing season, may indicate changes in the susceptibility of land to desertification. Studies using Landsat data help demonstrate the impact of people and animals on the Earth.

Spatial heterogeneity is assumed as an environmental system property, essential to understand both the environmental gradients and the systems functioning. Heterogeneity refers to some pattern of variation, both in space and time, but within some range. Usually the pattern and the range are physically adequate for the ecosystem it occurs, defining the system resiliency. A change of spatial heterogeneity can be viewed as an indicator of environmental changes, and a clue of some process. We aim to test the usefulness of spatial analysis methodologies to capture spatial-temporal heterogeneity from environmental gradients, for the assessment of desertification process at Remote sensing data on the Seridó Region (Northeast Brazil).
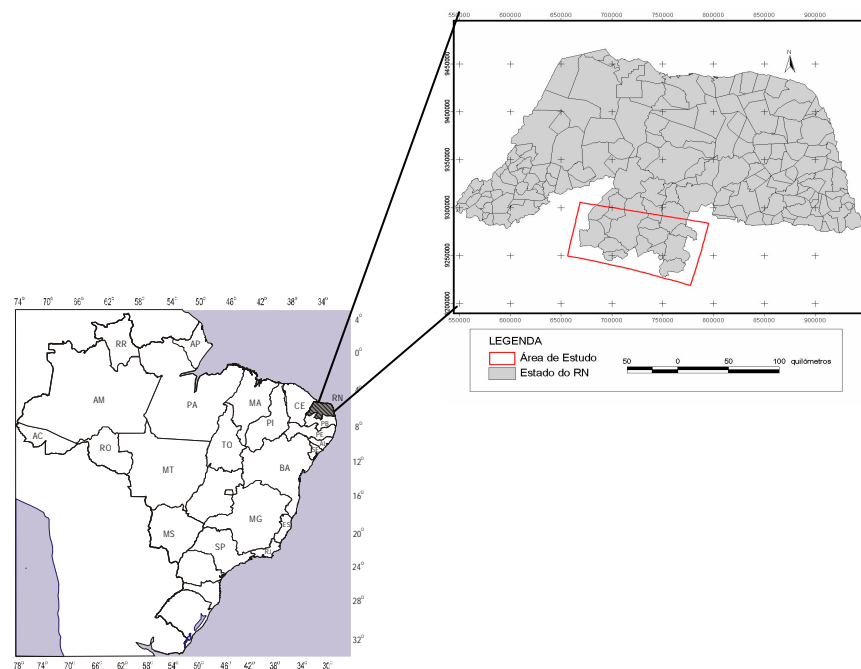

Fig. 01-Study Area - Seridó Region (Northeast Brazil)

2. CHARACTERIZATION OF THE AREA

Generalities: The Seridó Oriental (easter) Micro region is located in Meso region of Borborema Province (NE Brazil). Although it is one of the oldest areas of northeast of Brazil, in settlement terms, Seridó presents the more bass index of demographic density of the State and, associate to that, they are the low precipitation indexes, what makes that the agricultural activity suffers the consequences of those climatic limitations. It is therefore an area strongly individualized, for the natural limitations, for the economic activity or for the low demographic density. This area is characterized by presenting a low vegetation index, very spaced and a soil shallow, sandy and dry, still presented biggest granites outcrops. Those characteristics become decisive to increase the fragility of the ecosystem, favoring the installation of processes of environmental degradation.

In its natural feature, it can stand out the vegetation, which is constituted of savanna arboreal arbustive (*caatinga*). The physiognomy of that sub-formation is marked by a vegetation caducipholic, could be open or close according to the density and distribution of the species, being basically constituted by stratum arbustive and arboreal significant and different.

The *Caatinga* is a typical biome of the interior of the Brazilian northeast, was usually distributed in a semi-arid climate area, that it presents heatstroke and high temperatures, low cloudiness, irregular distribution of the rains during the year, and only two defined seasons, a drought with prolonged periods and one with rains, reduced, being like this the whole area subjects to long drought periods, that echo directly in the conditions of permanence certain populations there rooted. Due to all those conditions, that area was delimited by National Brazilian Council of Geography in 1949 and denominated of "Polygon of the Droughts".

In agreement with statistic accomplished by the DESERT Nucleus, presented in the National Conference of organized Desertification by FGEB in March of 1994 in the Fortaleza-CE (Brazil), the desertification reaches, in their several degrees, about 55,25% of the lands of the semi-arid Northeasterner, affecting direct or indirectly 42,17% of his population. The same study shows that the annual economical loss, in the affected areas for the desertification process, it is esteemed in approximately US$ 470 millions and that the minimum cost for the recovery of these areas is of US$ 4 millions, to be applied in twenty years.

Situation and extension: The studied area is located between parallel $6^{o}15'$ and $6^{o}50'$ S and the meridians $37^{o}00'$ and $37^{o}30'$ to west of Greenwich, in the micro region of Seridó (Rio Grande do Norte-Brazil), with an approximate area of 3.320 Km^2, constituted by the municipal districts of Serra Negra, São João Sabugi, Jardim de Piranhas and Caicó. (Fig. 01)

Hydroclimatic Conditions: The river Piranha-Assu, constitutes the main resource of water of every area, in which several dams and little dikes (*açudes*) were built, that allow the capacity to accumulate 1 to 2 billion of m^3 of water. The climatic aspect is, largely, under the effects of the semi-arid climate with having accentuated irregularity of the rain regime and with hydro balance negative along the year. It is justified with that the occurrence of a drainage net whose fluvial regimes are intermittent seasonal.

Soils: It prevail in the micro-region of Medium Seridó the following classes of soils: Soils Eutrophic Litholic, Bruno's No Calcic, Plano soils Sodics / Solonetz Solodizated and Podzolic Eutrophic Red-yellow. For the mentioned relationship, the predominance of soils a little deep is verified and with morphologic characteristics, physics and chemistries that favor the location of erosive processes. Such fact contributed to increase the hydric deficit in the area, tends in view that, when reducing the thickness of the soil as a result of the erosion it also reduces the capacity of storage of water of the same ones.

Vegetable covering: In the area the primitive vegetation is quite altered as product of an action disordered anthrop and predatory, remaining, just, small stains presenting aspects that denote certain level of preservation of the vegetable species. Field observations and analyze of images Landsat allowed to classify the vegetable covering of the area, as constituted by the savanna hiperxerophic, which is treated of formations arboreal-arbustive that possess, as main characteristic, the foliar caducity. They are woody formations, with high xerophitism degree,

predominantly arbustive, little dense, with load species low, spotty and totally losing the leaves in elapsing of the station dries. For their characteristics, this little vegetable formation protects the soil that is nearly underlying.

2. METHODOLOGY:

The research goal concerns the assessment of heterogeneity in remote sensing images, both in the spatial and temporal domain. In this analysis were used images obtained by the TM sensor of the LANDSAT-5 and ETM+ sensor of the LANDSAT-7, cut according to the coordinates of the study area. The images of TM-5 were taken in May/1984 and the one of ETM-7+ in three consecutive years, more precisely in Setember/2001, October/2002 and September/2003. That aspect of multiple temporalities of the images is important, because it allows the comparison of the spectral answer of the land features in conditions of different humidity, as well as the monitoring of the evolution of the patterns of anthrop activity in the area.

The treatment of the orbital images was executed through the software ENVI (Environment for Visualing Images), version 4.0. Initially, the images of TM-5 were corrected geometrically, through extracted control points from the plane-altimetry map of DSG (Management of Geographical Service of the Army) in the 1:100.000 scale. The reached result was just considered satisfactory, once the residual error of the georefering was around 3 pixels (± 100 meters). When we acquire the products of ETM-7+, it was verified, through over position of vectorial files, that the correction level presented by the distributing company of the images warranty a precision of about 1 pixel, or be 30 meters, perfectly acceptable for the elaboration of this work. In this sense, we opted for make the georefering of the oldest images tends as base the most recent image (September/2003). For this, was used the module Image Analysis of the software ArcView GIS 3.2 from ERSI (Environmental Systems Research Institute), reaching a value of the residual error of the georefering inferior to 1 pixel.

Through techniques of emphases analysis and transformations were obtained improvements in the visual quality of the images, which it served as base for several themes, as extraction of drainages, structural lineaments, updating of the road net and other several interpretations. Those procedures were implemented systematically in several stages of the project, involving: applications of contrasts, colored compositions in RGB, method of indexes, analysis for principal components, among others. We were also used techniques of supervised classification of images, seeking to the composition of the map of vegetable covering, where the six spectral bands of 30 meters of the images were used for the sixteen years in study.

The techniques of supervised classification base on the readiness of a representative sample of each class identified (pond-dams, urban area, and dense vegetation, among other). These samples are information regarding the medium spectral behavior of the classes and they can be denominated as "pixels of training" of the system. Such training pixels are, therefore, examples that the classification system takes as reference to decide the one which class each pixel of the image should be designated. The used method was the statistician of maxim verisimilitude with acceptance probability equal to 0,5, although it has tested other acceptance probabilities. The maximum likelihood method presupposes that the levels of reflectance of each class follow a distribution normal multivariate.

The definition of the classes or training samples were accomplished starting from observations done in field and of several cartographic materials, such as vegetation and land use maps of some integral municipal districts of the study area, as well as of identifiable features in the own images. Were applied,yet, post-classification techniques in the intention of improving the result of the supervised classification, where the Clump and Sieve functions were used to agglutinate and to separate pixels badly classified in the images, being also applied the filter of median, with a 7x7 raster uniform.. All of the post-classification procedures were accomplished in the software Envi 4.0. Finally, the mapped classes were transformed of the format raster for the vectorial format (using Envi 4.0), being after exported for the software ArcView GIS 3.2, where it was made the

last adjustments (in the mapped classes) in the intention of obtaining the vegetation maps for the years of 1984, 2001, 2002 and 2003.
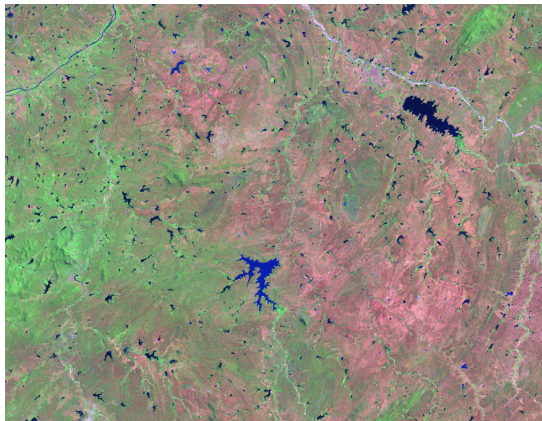

Fig. 02 - RBG 523 – Year of 1984
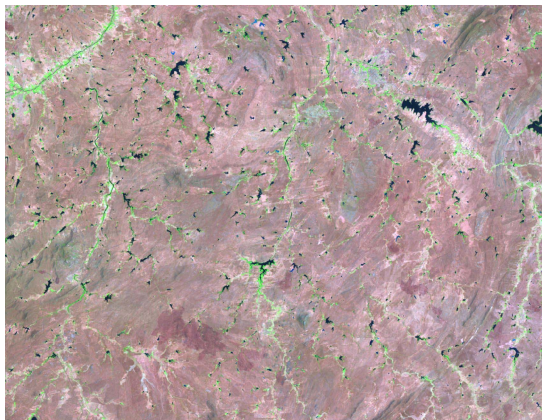

Fig. 03 -RBG 523 – Year of 2001
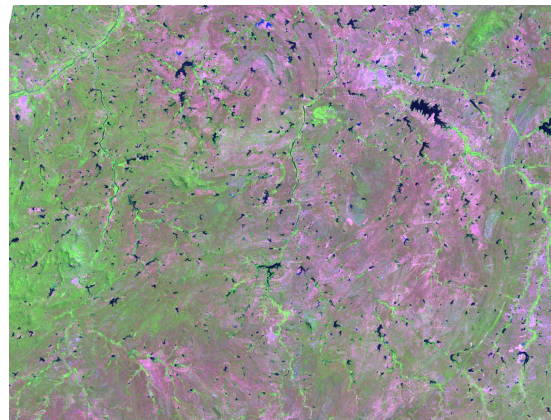

Fig. 04 - RBG 523 – Year of 2002

Fig. 05 - BG 523 – Year of 2003

A vegetation index (NDVI) was used to identify unvegetated regions. Low values of this index represented unvegetated areas. Comparisons were made with composite images to derive the threshold, then unvegetated areas were identified. In addition, to consider seasonal in vegetation, were used autumn and spring data and common areas were identified. From exploratory analysis of spectral data for the different land cover units, and from the analysis of evolution of land use, it has been concluded that: vegetation has to be assessed by the ratio TM4/TM3 (a vegetation index), considering the natural vegetation areas, namely dense and scrub vegetation; and soil can be studied based on the ratio TM3/TM7, considering scarce vegetation areas, where the soil spectral reflectance dominate. Finally, decertified areas identified based on data from different years were superimposed to obtain yearly changes. A land cover analysis was first carried, being selected the natural vegetation areas (dense, and scrub vegetation units) to study the spatial structure of vegetation issues (TM4/TM3 spectral data) and only scarce vegetation areas (TM3/TM7 spectral data) to assess the heterogeneity of soil characteristics.

3. LAND COVER, SOIL ANALYSIS AND SELECTED RESULTS

As it can be observed in the pictures above, it is havening a growing environmental degradation in the main areas of the municipal districts of the study area, with significant devastation of *Caatinga* Arbustive Dense and considerable increase of degraded areas with Exposed Soil.

From field work, six thematic classes were identified: (1) Dense *Caatinga*, (2) Semi-dense *Caatinga*, (3) Open *Caating*a, (4) Degraded areas in desertification process, (5) Urban areas, and (6) Water.

Photo 01- Dense *Caatinga* vegetation, with some trees and a soil cover of scrub vegetation;

Photo 02- Semi-Dense *Caatinga* vegetation dominated by bushes, shrubs, and herbaceous plants;

Photo 03- Open *Caatinga* vegetation, with large areas of bare soil with ephemeral plants, and disperses scrub vegetation patches, or isolated cork-oaks;

Photo 04- Degraded *Caatinga* vegetation in desertification process;

4. RESULTS AND DISCUSSION

The spatial patterns associated with significant clusters of low and high vegetation values were obtained with the local association measure. Table 01 illustrates the spatial arrangement of the meaningful spots of vegetation values. Spots of low vegetation values and degraded areas represent about 25 to 30% of the overall natural vegetation areas, while the clusters of high vegetation correspond to 15 to 20%, which stands for a skewed distribution of the vegetation for the low values, which is according to the histogram analysis. The pattern of the low vegetation values is very disperse, while the extent of the high clusters is usually large, which reveals that water proximity is an important constraint for the design of natural vegetation landscapes. Although field studies have demonstrated that the biomass content is three times more than a diversified brush of the semi-dense *caatinga*, the Landsat-TM recognizes the last as the most "green", because scrub areas are usually associated with bare soil, which confuses the satellite sensor, considering its spatial resolution (30 m).

Table 01: Average for the six thematic classes identified in the area: (1) Dense *Caatinga*, (2) Semi-dense *Caatinga*, (3) Open *Caatinga*, (4) Degraded areas in desertification process, (5) Urban areas, and (6) Water.

MUNICIPAL DISTRICTS	CLASSES (Km^2)						TOTAL	% of desertification area (3+4)
	1	2	3	4	5	6		
Caicó	185,21	617,89	169,26	181,50	5,46	37,00	1.196,32	28,67%
Jardim de Piranhas	19,85	133,96	8,06	59,67	0,61	4,36	226,51	30,53%
São João do Sabugi	14,65	185,88	40,08	49,33	0,33	14,57	284,84	31,60%
Serra Negra	105,71	329,16	29,20	102,70	0,30	19,42	566,49	23,32%

Based in the analyzed data and in the maps generated from the satellite images, a Geographical Information System (GIS) was elaborated for administration of the data and monitoring of the evolution of the desertification processes. The land cover map with satellite image represents the basic elements of the environmental GIS database. The GIS (Fig. 06) was constructed in such way to envelop all necessary environmental layers (soil, geology, vegetation, elevation, temperature, moisture, albedo… etc). These layers were digitized and geo-coded to fit with latitude and longitude coordinates system as well as the original satellite images representing the study area. Based on this environmental GIS database a desertification study will be achieved, this study include drought assessment, desertification modeling and the construction of desertification monitoring system.

The integration of the georeferenciated data relative to the environmental indices selected has resulted in the identification of five different susceptible levels to Desertification (Very high, High, Moderate, Low and Very low), and the delimited area of geographical domain assumed by the obtained classes. The validation of the reached results, starting from the space modeling in regional scale, it was accomplished, in a semi-detail scale, in the pilot area identified as Desertification Nucleus of Seridó, taking as base analyses of the dynamics of the vegetable covering (acted by orbital images) and evaluations of field data. The obtained results allowed a direct association between the different susceptibility levels and varied forms of environmental administration. Where, the areas with "Very high susceptibility" they are linked to the practices of recovery of the degraded areas; "High susceptibility", to the practices of recovery of degraded areas, as well as the adoption of techniques and control procedures to combat the desertification; "Moderate susceptibility", to the prevention, control and combat of the processes of Desertification; and "Lowers to Very low susceptibility", to the adoption of prevention measures to the development of desertification processes.
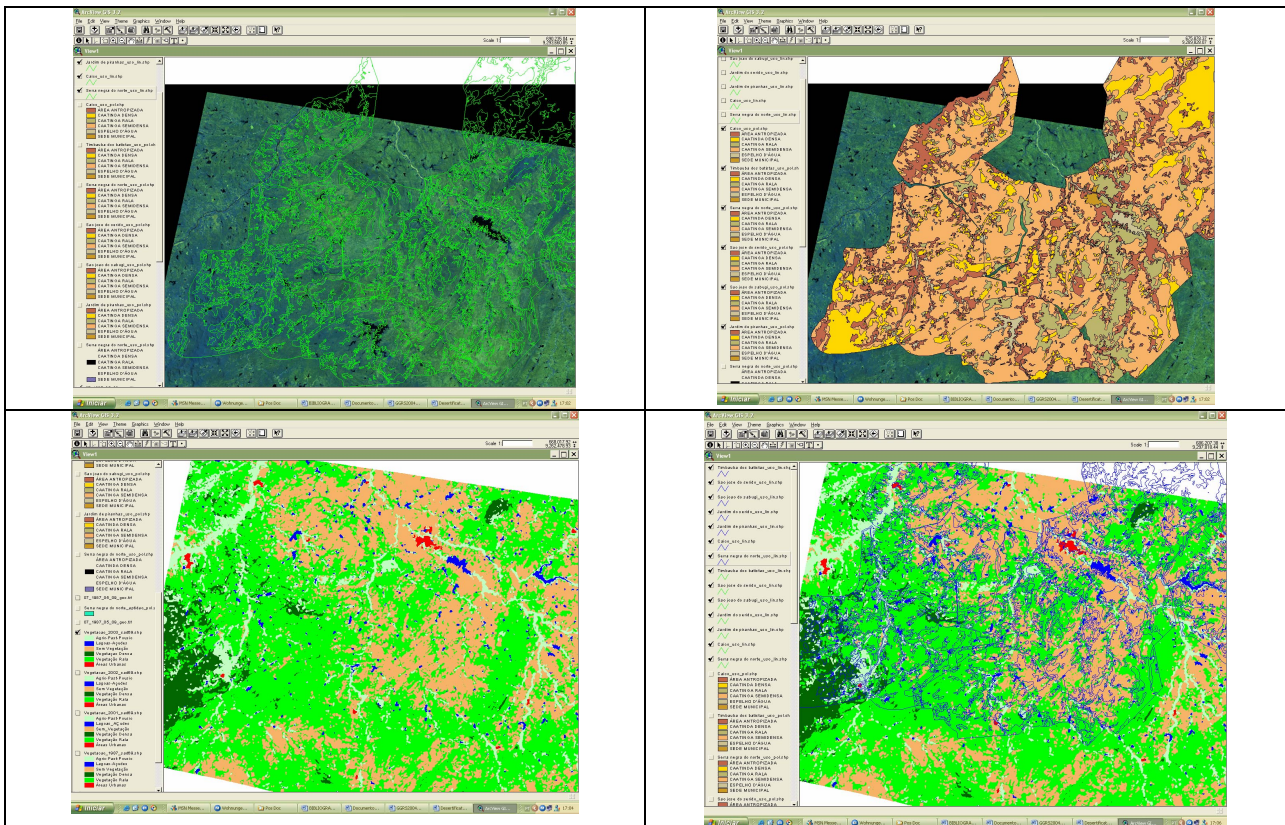
Fig. 06: Some different aspects of the GIS System showing the image analysis done

5.CONCLUSIONS

The information generated from spectral mixture analysis of Landsat images has show valuable to monitor signs of desertification processes connected to land use patterns and soil characteristics.

In agreement with the parameters used in this study, the area of Medium Seridó present level of relevant environmental degradation with an average of 15% of her area, committed with this process.

Analyzing the over position of the vegetation maps and of the land use, an increase of the degraded areas was detected in the period of sixteen years in the class *caatinga* (dense and semi-dense). In 1984, that unit was with 16% of its vegetable covering attacked, what was intensified in 1994, when that number increased for 19% and in 2003 with 26% of degraded area. That growth can be justified for the increase of the number of agricultural establishments in the area corresponding to that class.

In the last sixteen years analyzed the average value of the soil component for the whole study area increased from 21,34% to 36,22%, which implies that a larger component of the study area had lost its vegetation cover. Although part of this difference is related to conversion of some pasture areas in crops, it is also due to the extension of vegetation degradation in other sectors where grazing was intensified. This explains that, in spite of having greater moisture, the *caatinga* species do not re-vegetate but on the contrary these areas enlarge between the images studied.

The Jardim de Piranhas municipal district constitute the most affected, with 26,10% of the municipal area committed of the environmental point of view. The severity of the degradation there reached is verified starting from the devastation of the native vegetable covering and intensity of the phenomena erosive, as it is well observed from the analysis of the orbital images and verification in the field.

The current fragilities of the components geo-environmental that constitute the area focused, allied to the inadequate use of the lands motivated by an anthropic disordered action seeking immediate results, that unchained the verified environmental imbalance. In this context, it becomes necessary more detailed researches aiming at the determination of the specific causes

and consequences of the degradation processes, besides being taken into account the socioeconomic factors, for an including diagnosis of the problems here treaties.

The prevalence in the area of soils with morphologic, physics and chemistries characteristics that they favor the several erosion types and the proportion reached by this phenomenon in accordance observations in field, it turns priority the procedure of campaigns of soils mapping in more detailed levels, with the purpose of evaluating the capacity of the use of these soils, defining the most appropriate use of the same ones, the handling techniques recommended, besides the indispensable conservationist practices to maintain them productive.

Based on the analysis of the dynamics of the vegetation cover and on the evaluation of field data, we can establish that the main results refer that there is a decrease of the biomass at the region, associated either with the dense *caatinga* vegetation areas, but more important, with the scrub and degraded areas. From an environmental perspective, the decreasing biomass level associated with scrub and degraded areas is according to the negative feedbacks of the desertification process. Considering the last ten-year periods of comparisons, the spatial variances leave almost different, which means that heterogeneity pattern, is increasing very considerably. This fact means an explicit expansion of spatial heterogeneity of the desertification landscapes, during the last years.

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