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INTRODUCTION

Over the past three decades discussions have been held regarding environmental issues including evaluations and studies on natural and social sustainability with the purpose of mitigating the increasing degradation of the environment. The UN Conference on the Human Environment in Stockholm in 1972 and the UN Conference on Environment and Development in Rio de Janeiro in 1992 are worthy of mention in this respect.

Scientific and governmental authorities, as well as the technical media, have been discussing and announcing the results of reseacrh work on the subject of environmental degradation, especially with regard to dry ecozones susceptible to desertification, considered a problem of worldwide proportions (Rubio, 1992).

Agenda 21, Chapter 12.2, of the United Nations Environment Programme, defines desertification as “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”.

In Brazil, the Northeastern region―the country’s largest arid ecozone―has been the focus of political and economic interventions for the mitigation of the effects of drought-induced desertification since Vasconcelos Sobrinho’s pioneering studies on the subject in 1976 up to the establishment of the National Program for the Prevention of Desertification and Mitigation of the Effects of Drought (PAN-Brasil, 2004). Thus, the Brazilian government

[1] This paper is part of the project “Rational management of river basins in semiarid ecozones for sustainable irrigated agriculture”, developed by *EMBRAPA – Tropical Agroindustry*, Fortaleza, Ceará.

has developed a macropolicy for the protection and sustainability of semi-arid and dry sub-humid areas as well as contiguous ecozones such as those located in the northern reaches of Minas Gerais, in Maranhão and above all in the northeastern drylands—the so-called 'areas suceptible to desertification' (ASD).

In the Northeastern state of Ceará, 92.1% of the territory is subjected to a semi-arid climate (136,000 out of 148,000 km²). The aridity index—a parameter used worldwide to classify ecozones—is very helpful in identifying areas susceptible to desertification; however, most environmental degradation is due to human activity and not to inherent environmental vulnerability.

This phenomenon may be abundantly illustrated by technical, theoretical and empirical facts gathered by the Center for Environmental Management and Planning of the Acaraú River Basin (ARB). The river basin—object of the present study—is located in northern Ceará (with points extremes: N= -40:13:11,9310; -2:48:18,8512 ; S= -40:08:35,7781; -4:58:42,1882 E= -40:52:13,5858; -4:04:46,7013; W = -39:40:59,0025; -4:34:13,1589) covering approximately 15,000 km². After flowing northward for some 315 km, the river drains out into the Atlantic Ocean.

METHODOLOGY

The theory and methodology of the present study are holistic in outlook in that they tend toward a synthetic and multicomponent approach in alignment with Bertrand's geosystems theory (1968) and integrated geo-environmental analysis (Souza & Oliveira, 2003) and supported by studies on society and nature. Geo-environmental components are physical and biotic factors of the environment—geological and geomorphological conditions, hydroclimatic conditions, soil and vegetation, and human beings shaping the landscape.

Indeed, the natural regions and ecozones that make up the ARB may be regarded as environmental systems composed of a number of landscape subunits. For each region identified by satellite remote sensor, the natural resources were quantified in a set of environmental elements and the mutual interaction of forms of land use and occupation was described in a holistic-systemic manner.

The basic factors used to identify and distinguish classes of desertification-related environmental degradation were the aridity index and major natural features, especially those relevant to the preservation of the vegetation. Analyses partly aided by satellite imaging and field work made it possible to define and examine the main environmental problems of the area, producing a map depicting the current state of vegetation conservation and degradation/desertification. The ratio between rainfall and potential evapotranspiration (R/PET) is incorporated into the aridity index and helps classifying areas whose climatic characteristics make them suseptible to desertification: extremely arid: < 0.03; arid: 0.03-0.2; semi-arid: 0.21-0.50; dry sub-humid: 0.51-0.65; wet sub-humid: > 0.65 (absence of aridity).

Satellite remote sensing scenes 217/63, 218/62 and 218/63 (from TM LANDSAT-5 and ETM+ LANDSAT-7) were analyzed in several ranges of the electromagnetic spectrum and matched with available geo-referenced data. The images were processed by the remote sensing module *SPRING* v.3.6 using the *ENVI* v.3.6 software. The geo-referencing was done using control points obtained from charts (DGS) in the scale 1:100.000, or using points acquired, corrected and confirmed by GPS.

Thus, once the areas susceptible to or currently undergoing degradation/desertification had been identified, quantified and charted, the abovementioned map was produced assuming a holistic conception of the environment, according to potentialities and limitations of use and occupation of the respective landscape sub-units, with special emphasis on the most vulnerable ecosystems.

The Acaraú river basin: sinopsis of geo-environmental attributes

Historically, as known from so many other locations in the northern reaches of Northeastern Brazil, the disordered relationship between society and nature and inefficient public policies have laid heavy pressure on the natural resources in the ARB. In some cases the biotic and abiotic components of the environmental units bear visible marks of such stress. The geo-environmental vulnerability of the area and the rapid exhaustion of water, soil and geo-botanic resources taking place under the current political and economic situation have only inflated the proportions of the problem, magnifying the area's susceptibility to climatic contingencies and vulnerability to drought.

However, the causes of environmental degradation in Ceará are more often tied up with socioeconomic and cultural interventions than with environmental factors and their natural dynamics. Non-compliance with land management policies, especially policies enforcing protective forms of land use and occupation, tends to produce serious problems of environmental deterioration compromising the environmental quality and the productive capacity of the soil.

The ecological of the ARB is a result of the interplay between ecological potential, biologic exploitation and forms of land use and occupation. Geomorphologic and climatic conditions constitute the main contributing factors to the shaping of the landscape.

In fact, the sub-equatorial, tropical semi-arid climate of the region, with its irregular rainfall pattern (scarcity, delays or droughts)—particularly in the central drylands—is perhaps the main factor responsible for the way the geo-environment looks. The morphogenetic processes are therefore in this case for the most part of physical nature; the surface drainage consists of seasonal rivers, the hydro-geological potential of which is significant only in and near the river delta. Rock outcroppings and immature topsoils abound.

The biodiversity is best described by the geo-botanic response of the *caatingas* (dry brushwoods), the flowers and anatomy of which are admirably adapted to the contingencies of water and weather. However, plant size increases as one ascends the more humid highlands and soils become more fertile (eutrophic ultisols and luvisols) or as one approaches the river plains of the Acaraú river and its main tributaries characterized by their somewhat taller riverside vegetation and carnauba groves (*Copernicia cerifera*), a species endemic to Northeastern Brazil.

The coastal and precoastal areas of the region are characterized by the accumulation of sandy quartz sediments (beaches, dunes and river delta plains) or sandy clay sediments (the Cenozoic Barrier Formation of the coastal tablelands). Quartz-holding neosols are found on the coastal plains, salty gleysols occur in mangroves while gray ultisols abound in the cosatal tablelands. These aspects show that the Acaraú river delta is not exactly a homogeneous landscape.

Land occupation at the coastal end of the basin is characterized by tourism, shrimp farming, mariculture and plant extraction, while subsistence agriculture and plant extraction predominate on the tablelands.

Highlands and residual crests such as *Meruoca*, *Machado* and *das Matas* affect the local climate considerably: in no other part of the basin is rainfall more abundant; the clayish soils here are naturally eutrophic lying as they do upon the crystalline Precambrian bedrock complex deformed by tectonic disturbances induced by selective erosion processes. The vegetation is more lush in these parts, featuring a number of evergreen species and even some pockets of the original Atlantic Rain Forest, although extensive land use and occupation by country homes, controlled burning (observed all over the river basin) and the practice of itinerant agriculture have contributed significantly to land erosion. Finally, inselberg knicks and small massifs rising out of the flat plains witness the geomorphogenesis of the Pliocene.

The Acaraú river drainage area extends into the mid-front of the *Ibiapaba* cuesta: a Silurian/Devonian sedimentary plain with coarse quartz sand, conglomerates, silt and shale in transversal stratigraphy. This is where the basin's oldest soils—the oxisols—are found, along with ultisols covered by humid forest. The area is popular among fruit croppers and subsistence farmers.

The peripheral depressions of *Ibiapaba* and mid-northern Ceará are a good example of the region's ecological diversification. Here, rocks from the Northeastern Complex —especially gneisses and migmatite—dominate the Precambrian Crystalline Complex, forming occasionally dissected pediplanes and convex hilltops and tables surrounded by level-bottomed valleys covered by alluvial sediments from the river plains. The altered granite material and the bioclimatic conditions eventually gave rise to luvisols (the most important soil type in the valley), planisols, fluvial or lithic and regolithic neosols, and rock outcroppings.

The semi-arid drylands, which were originally covered by prickly *caatinga* brushwood, have to a great extent become occupied by intensive agriculture, subsistence cultures of corn, beans and cassava, and by plant extraction activities. Inefficient drought management policies, overall poverty and lack of technical support for small-scale farmers concur to perpetuate land ownership concentration, extensive burning and the use of rudimentary culture techniques, leading to soil erosion, exhaustion of water resources and silted-up creek beds.

However, the central drylands is where the socioeconomic interventions have produced the highest degree of degradation and desertification. Satellite images of the land adjoining the municipality of Santa Quitéria and the Groaíras river confirm that these areas are among the most desertified in the ARB, followed by the dry sub-humid highlands.

Environmental degradation and desertification

Degradation leading to desertification stems from inadequate human activities exploiting vulnerable ecozones. Unfavorable economic and social conditions are therefore likely to potentialize desertification. Rash environmental degradation weakens geo-environments and leads to the destructuion of a significant part of the natural resources and to the impoverishment of the economic sectors relying on agricultural activities. The loss of the productive capacity of the economic systems is eventually reflected in social pauperization, migration and the loss of cultural identity.

With the decline of the components at multiple levels of the biosphere and the semi-arid climatic conditions, natural resources become visibly exhausted in the environmental systems that make up the river basin—especially in the drylands exposed to desertification.

According to PAN-Brasil, the ARB's drainage area lies mostly within the ASDs. Now, disquietingly, several studies have reported severe levels of desertification from these areas compared to the rest of the country (MMA, 2002), caused by disordered socioeconomic activities (Nascimento et al., 2004) with special attention to local wholesale deforestation practices (Martins et., al. 1992). In addition, the aridity index falls within the intermediately critical (0.41-0.45) or less critical range (0.46-0.50) (Leite et al., 1993).

Conti (2002) described an axis running through the state of Ceará from northeast to southwest which he termed the 'Ceará drought line'. It departs from Itapajé in the north, on the lee side of the Uruburetama massif, and stretches as far south as Campos Sales, to the foot of the Araripe tablelands.

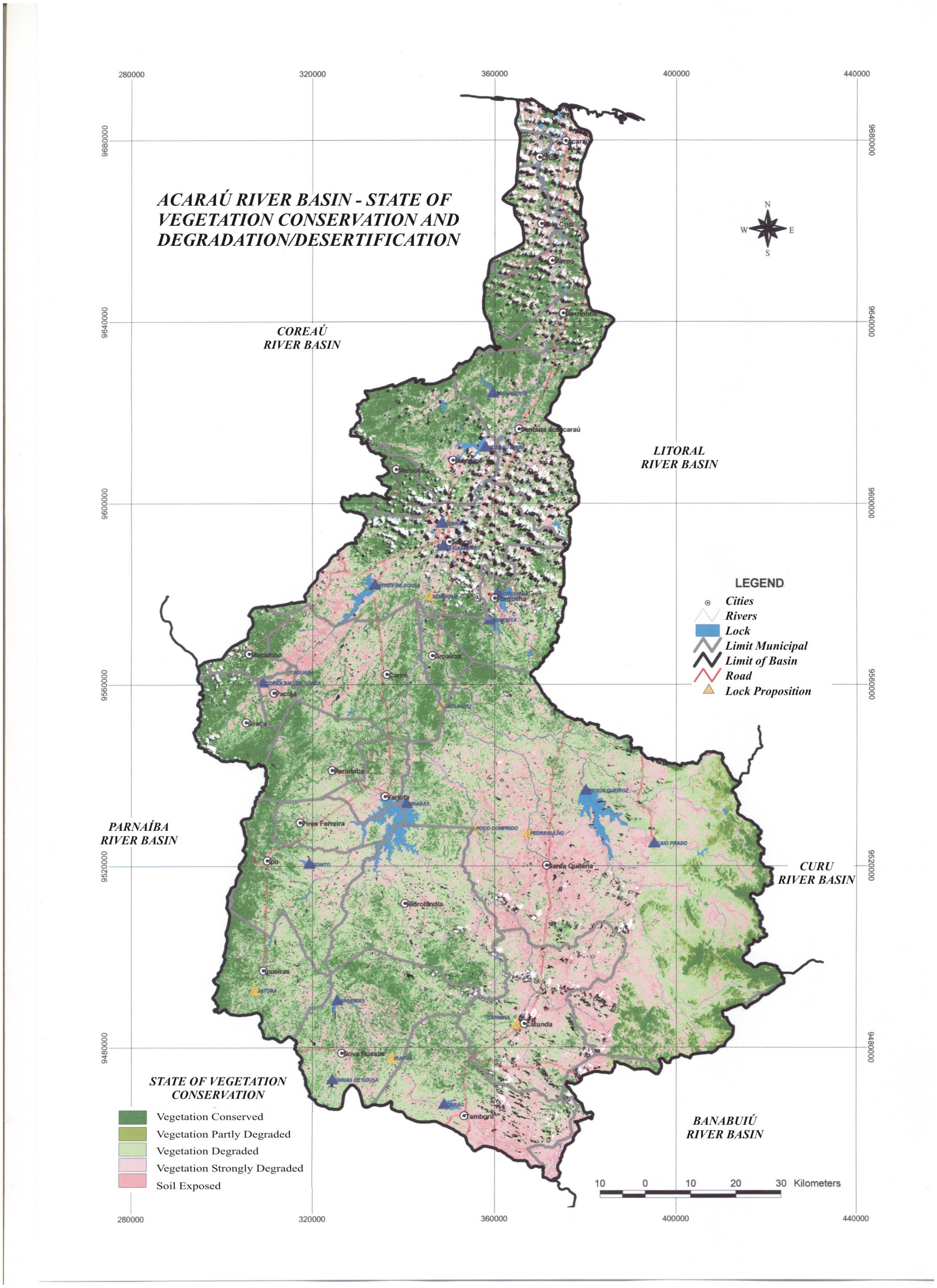
As one the main findings of this study, five classes of plant preservation were identified in the ARB: 'conserved', 'partly degraded', 'degraded', 'strongly degraded' and 'soil exposed'. Unfortunately all vegatation complexes bear signs of advanced environmental degradation threatening the area with desertification.

Thus, in order to classify ecozones by their extent of landscape degradation, associating the condition of vegetation preservation to the environmental systems, soils and aridity indices shown on the Map, we may say that:

✓ River plains and riverside vegetation x fluvial neosols lie in the range between 'preserved' and 'soil exposed'.

✓ The drylands of the peripheral depression around Ibiapaba and Acaraú with the dry brushwood (caatingas) of the hinterland depressions x luvisols, ultisols, planisols and lithic neosols are degraded and classify as 'soils exposed'.

✓ The residual massifs of *Machado*, *das Matas*, *do Pajé*, *das Cobras* and others with lithic neosols, ultisols and luvisols, covered by all the anatomical variations of the *caatinga* of the hinterland depressions, are seriously degraded, ranging from 'partly degraded' to 'soil exposed'. In the humid and sub-humid highlands the degradation of the vegetation in humid areas varies from 'partly degraded' to 'soil exposed', thus displaying the widest range of degradation classes.



ACARAÚ RIVER BASIN - STATE OF VEGETATION CONSERVATION AND DEGRADATION/DESERTIFICATION
COREAÚ RIVER BASIN
LITORAL RIVER BASIN
PARNAÍBA RIVER BASIN
CURU RIVER BASIN
BANABUIÚ RIVER BASIN
LEGEND
Cities
Rivers
Lock
Limit Municipal
Limit of Basin
Road
Lock Proposition
STATE OF VEGETATION CONSERVATION
Vegetation Conserved
Vegetation Partly Degraded
Vegetation Degraded
Vegetation Strongly Degraded
Soil Exposed
10 0 10 20 30 Kilometers
280000
320000
360000
400000
440000
9680000
9640000
9600000
9560000
9520000
9480000

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