DETECTIND AND UNDERSTANDING DRIVERS OF NATURAL AND ENVIRONMENTAL VULNERABILITY DUE TO ECOSYSTEM AND LAND USE CHANGE THROUGH MULTISPECTRAL SATELLITE DATA SETS IN APODI VALLEY REGION, NORTHEAST BRAZIL

Mukesh Singh Boori – Dept. of Geology, Federal University of Rio Grande do Norte – UFRN. msboori@gmail.com

Venerando Eustáquio Amaro - Dept. of Geology, Federal University of Rio Grande do Norte – UFRN. poliana.linhares@gmail.com,

Poliana Linhares Silva Minora - Dept. of Geology, Federal University of Rio Grande do Norte – UFRN. amaro@geologia.ufrn.br.

ABSTRACT: The upper reaches of Apodi River-valley, located in the north coast of Rio Grande do Norte State; it is a typical and key valley region with apparent upland ecosystem vulnerability and sensitivity. In order to analyze natural and environmental vulnerability, remote sensing (RS) and geographical information system (GIS) technologies are adopted and an environmental numerical model is developed using DIP techniques. The objective of this study was to improve our understanding of natural and environmental vulnerability; it´s causes basically show the intensity, its distribution and human-environment effect on the ecosystem in the Apodi Valley Region, so that a strategy of sustainable land use could be established. The model contains some basic factors like geology, geomorphology, soil, vegetation and land use/cover. According to the numerical results, the vulnerability is classified into six levels, unrated/potential, very low, low, medium, high, and very high levels, by means of the cluster principle. Vulnerability maps have the aim to show the intensity, and its distribution in the study area, of the susceptibility of the environment. The results show that the natural vulnerability in the study area was at medium and high level, and environmental vulnerability is quite more sensitive in maximum part of the study area. However, the ecosystem quality had become worse over the thirty years in some regions. In the study area, population growth, encroachment, industrialization, vegetation degradation, and governmental policies for eco-environmental protection were found to be the major factors that caused the environmental changes over the thirty years.

Keywords*:* Natural and environmental vulnerability, Remote sensing, GIS

1. INTRODUCTION

The study region is located in an area of high environmental sensitivity zone; subject to great pressure of human activities, resulting is an environmental degradation mainly due to its most economic activities. In Apodi valley region unmanaged industrialization, vegetation degradation, grassland degeneration, sandy desertification, high rate oil and natural gas exploration; utilization of harmful pesticides in tropical fruit farms; unmanaged shrimp and marine salt industry; encroachment of agricultural land; land reclamation; silt deposition in river; severe flooding; costal dynamics, rapid growth of urbanization, water erosion and government policies for eco-environmental protection are main factors led to an increased pressure on ecosystem and primary natural resources: soil, water and biomass. Especially in semi-arid regions with erratic rainfall, these land use changes and vulnerability may result in an irreversible deterioration of the natural environment due to processes of land degradation.

The future capability of ecosystems is mainly depend on natural, environmental and human impacts, to provide good services and these impacts are determined by following basic factors

A) Natural impact:

1. Climatic impact: drought index, rain fall, wind, temperature,

2. Topographic impact: slope, elevation,

3. Physical impact: geology, geomorphology, soil, vegetation, land use/cover, hydrology,

B) Environmental impact: hazards, water-soil erosion, atmospheric composition, biogeography and biodiversity

C) Human impact: road density, population density, socio-economic characteristics,

Research shows the impact assessments of vulnerability of the human–environment system under such environmental changes and gives the answer of important multidisciplinary policy relevant questions such as: which are the main regions or sectors that are vulnerable to environmental change? How do the vulnerabilities of two regions compare? Which scenario is the least, or most, harmful for a given region or sector?

The model uses a new approach to ecosystem assessment by integrating the potential impacts in a vulnerability assessment, which can help answer multidisciplinary questions, such as those listed above. Research presents the vulnerability assessment of the geology, geomorphology, soil, vegetation and land use scenarios. Fifteen land use types, discussed in detail, can be related to a range of ecosystem services. For instance, forest area is associated with wood production and designated land with outdoor recreation but forest area encroached by the oil and natural gas exploration and also for agriculture purpose by the local peoples then it´s again encroached by the salt industry and now since last ten years it´s slowly replaced by the shrimp farms due to market demand. So directly applying the vulnerability methodology to the land use change scenarios helps in understanding land use change impacts across the Apodi Valley Region, Northeast Brazil. Scatter plots summarizing impacts per principal unit zone, help in interpreting how the impacts of the scenarios differ between ecosystem services and the environments.

We used three terms (exposure, sensitivity and adaptive capacity) inside the vulnerability. While there is considerable heterogeneity in both the potential impacts of environmental changes, and the adaptive capacity to cope with these impacts, this assessment shows that study area in particular will be vulnerable to ecosystem and land use change. Projected economic growth increases adaptive capacity, but is also associated with the most negative potential impacts. The potential impacts of more environmentally oriented developments are smaller, indicating an important role for both policy and society in determining eventual residual impacts.

2. OBJECTIVES

The natural and environmental vulnerability distribution and its dynamic change were analyzed and discussed. The main objective of the research is to detect the spatial and temporal patterns of natural and environmental vulnerability due to land use/cover, ecosystem and socio-economic change in the Apodi valley region and to get a deeper insight in the mechanisms of these changes and then reclassified vulnerability into six levels.

3. METHODOLOGY

The terminology developed by the IPCC forms a suitable starting point for explaining the different elements of the vulnerability assessment presented here. This section first defines and explains the various elements of the vulnerability concept, including exposure, sensitivity and adaptive capacity, and how these elements are combined to form vulnerability maps. Then the derivation from the basic factors such as geology, geomorphology, soil, vegetation and land use scenarios (Rounsevell et al.) is explained. Finally, the vulnerability assessment of these scenarios is presented, based on ecosystem and land use indicators.

3.1 The concept of vulnerability - The vulnerability is a function of the character, magnitude and rate of eco-environment change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. Landscape condition is determined the susceptibility of a community to the impact of hazards the degree to which a system is susceptible to, or unable to cope with, adverse effects on eco-environment, including variability and extremes. So we can say vulnerability is a function of exposure, sensitivity and adaptive capacity. Where potential impacts are a function of exposure and sensitivity Therefore, vulnerability is a function of potential impacts and adaptive capacity

As Vulnerability include the three dimensions: exposure, sensitivity, and adaptive capacity. Where exposure components characterize the stressors and the entities under stress; sensitivity components characterize the first-order effects of the stresses; and adaptive capacity components characterize responses to the effects of the stresses. These measures can be quantitative (e.g., precipitation variability, distance to market) or qualitative (e.g., political party affiliation, environmental preservation ethic). Another slightly different view favored by the hazards and disasters research community is that adaptive capacity consists of two subcomponents: coping capacity and resilience. Coping capacity is the ability of people and places to endure the harm, and resilience is the ability to bounce back after exposure to the harmful event, even if the people and places suffer considerable harm. In both cases, individuals and communities can take measures to increase their abilities to cope and bounce back; again depending on the physical, social, economic, spiritual, and other resources they have or have access to.

Another basic issue for the evaluation a model is to assign weights to each factor according to its relative effects of factors considered on the eco-environmental vulnerability in a thematic layer. The analytic hierarchy process, a theory dealing with complex technological, economical, and socio-political problems (Saaty, 1977; Saaty and Vargas, 1991), is an appropriate method for deriving the weight assigned to each factor. The degree of membership within different levels of different indices was integrated using weight and the total degree of membership for different tematic layers were used to calculated the whole study area natural and environmental vulnerability. The application of subjective weightings on the one hand gives us some indication of how the relative importance of different factors might vary with context, and can also tell us how sensitive eco-environmental vulnerability ratings are to perceptions of vulnerability in the expert community.

3.2 Data analysis - The multispectral image used is the product of the satellite CBERS_2 CCD camera with spatial resolution of 20m. The path and row of the image are 149/106 and was obtained by the satellite on 25/06/2008 and released by the National Institute for Space Research - INPE. Digital image processing was performed using the ER Mapper 7.1 software, involving the geocoding in UTM cartographic projection Zone 24S - Datum SAD-69 and the Root Mean Square (RMS) were less than 1.0, standardizing the data and increasing the reliability of products obtained.

Maps of geo-environmental units (geology, geomorphology, soils and vegetation) were prepared on scale of 1:150.000, from the interpretation of satellite imagery using Arc GIS 9.3 software and field applications. We used different weights for the different landscape units based on the concept of stability of each unit, considering to the analysis concept of Ecodinâmica Tricart 1977 and Barbosa 1997**,** where stability is classified according to Table 1. The weights of a landscape unit indicate the importance of any factor in relation to others (XAVIER - DA-SILVA et. al. 2001). Spatial analysis techniques were used to integrate the thematic maps. The memberships of each thematic layer were based on the sensitivity or its effectiveness in the study area (Grigio et. al. 2004 and 2005).

Table 1: Stability values of landscape units. (Motta et al., 1999, modified in Tricart, 1977).

Unit	Pedogenesis / morphogenesis Relation	Value
Stable	prevails pathogenesis	1.0
Intermediate	balance between pedogenesis and morphogenesis	2.0
Unstable	prevails morphogenesis	3.0

For the allocation of the values of each theme class was required establish some criteria for the definition of each class. Which were used by Barbosa and Crepani et al., (1996). The degree of vulnerability to each prescribed class was distributed in a range from 0.0 to 3.0 (Ex. wetland and coast plains 1.0, barriers formation, fixed dunes, settlements and quartz sand 2.0, temporary and permanent culture 1.8, production of marine shrimp 2.8, temporary pond 1.0, ocean/river and area without vegetation 0.0, oil and gas exploration well 2.9, Salina 2.7, thermoelectric, fluvial-marine plain, alluvial and eluvial deposits 2.5, Jandaíra formation, fruit corps and dune vegetation 1.5, fluvial-estuarine plain, sodic soil, mangrove and carnauba palm tree 3.0 etc.). The value 1.0 prevails pedogenesis, in 2.0 a balance between pedogenesis and morphogenesis, and 3.0 prevails morphogenesis. This criterion was used for maps geomorphology, geology and simplified soil/soil system. For case of vegetation/ biodiversity map, the criterion was established: 3.0 environments with very low species diversity/incipient formations, usually pioneers, 2.0 for environments with low diversity of species, corresponding to formations in the intermediate stage, and finally, to 1.0 in stage environments advanced-climax, that is, with high species diversity. For the water surface tide channel was given a degree of vulnerability of 1.0 for geomorphology, geology and simplified soil/soil system maps. For vegetation/biodiversity maps and land use and land cover, was awarded the 3.0 degree of vulnerability.

To develop a natural vulnerability map (Figure 1), we correlated the natural aspects of geology, geomorphology, soils and vegetation. Than natural vulnerability map has been integrated with the land use and land cover map to generate the environmental vulnerability map (Figure 4), considering the anthropogenic influence in the area. The degree of vulnerability varies from 0 to 3 and is ranked Unrated, very low, low, medium, high and very high. The weights of compensation indicate the importance of any factor in relation to others, as can be seen in the formula below for natural vulnerability map.

[(Theme 1) + (Theme 2) + (Theme 3) + (Theme 4)] /4

Where: theme 1 geomorphology map, theme 2 simplified geological map, theme 3 soil/soil system map, and theme 4 vegetation/biodiversity map. The result mean was distributed in six natural vulnerability classes: Unrated/potential (less than or equal to 0.99); Very low (from 1.0 to 1.50); Low (1.51 to 1.85); Medium (from 1.86 to 2.10); High (from 2.11 to 2.50), and Very high (greater than or equal to 2.51).

To obtain the environmental vulnerability map was carried out crossing between the map of natural vulnerability and the statement of use and occupation of soil in the year 2008. The criteria established for the land use map were focused on main degree and type of human disturbance found in the study area. For beam we adopted the same scale applied previously, Ex, from 1 to 3, with range of 0.1 (Table 1). We gave weights of each factor according to their sensitivity (Barbosa and Crepani et al., 1996) and then membership according to following formula to generate environmental vulnerability map.

0.2 X [Theme 1] + 0.1 X [Theme 2] + 0.1 X [Theme 3] + 0.1 X [Theme 4] + 0.5 X [Theme 5]

Where: theme 1 geomorphology map, theme 2 simplified geological map, theme 3 soil/soil system map, theme 4 vegetation/biodiversity map, and theme 5 land use /land cover map. In the case of the environmental vulnerability map, after the crossing, calculated the average weighted of the vulnerability of each class, and divided into six environmental vulnerability classes: Unrated (less than or equal to 0.99); Very low (from 1.0 to 1.39); Low (1.4 to 1.79); Medium (from 1.8 to 2.29); High (from 2.3 to 2.59), and Very high (greater than or equal to 2.60).

3.3 Land use scenarios in vulnerability assessment - Natural and environmental vulnerability is most easily associated with types of land use and ecosystem like food production can be directly related to agricultural land use, shrimp farm, salt and fruit industry in the study area, fiber or timber production to forestry and cropland, and energy production to the area used for bio-energy crops and oil and natural gas exploration, costal and industrial area. In the land use change scenarios, reductions in agricultural land are an effect of intensification of production in optimal regions. Hence, total food or energy production or exploration availability will not decrease. Nevertheless, decreasing regional production does have consequences for consumers, because regional products are associated with variation as well as traditional foods or other productions. Furthermore, regionally produced food or energy is frequently associated with high quality and safety standards. A more limited choice of productions, mass-produced in optimal locations will be seen as negative impacts by parts of society. The actual ecosystem service provision, in crop yield, timber or energy increment, greatly depends on biophysical growing conditions. However, as discussed in previous Section, in order to compare ecosystem services across the study area, differences caused by inherently different environments were removed using the stratification. Therefore, for the vulnerability concept used here, the land use types form appropriate indicators for ecosystem service provision.

4. RESULTS AND DISCUSSION

Natural and environmental vulnerability maps is an effective relationship between ecosystem, land use and vulnerability and making comparisons between ecosystem, service sectors, scenarios and regions to tackle questions such as: Which regions are most vulnerable to change? How do the vulnerabilities of two regions compare? Which sectors are the most vulnerable in a certain region? Which scenario is the least harmful for a sector? How, where, why and in which direction vulnerability goes?

4.1 Natural vulnerability map

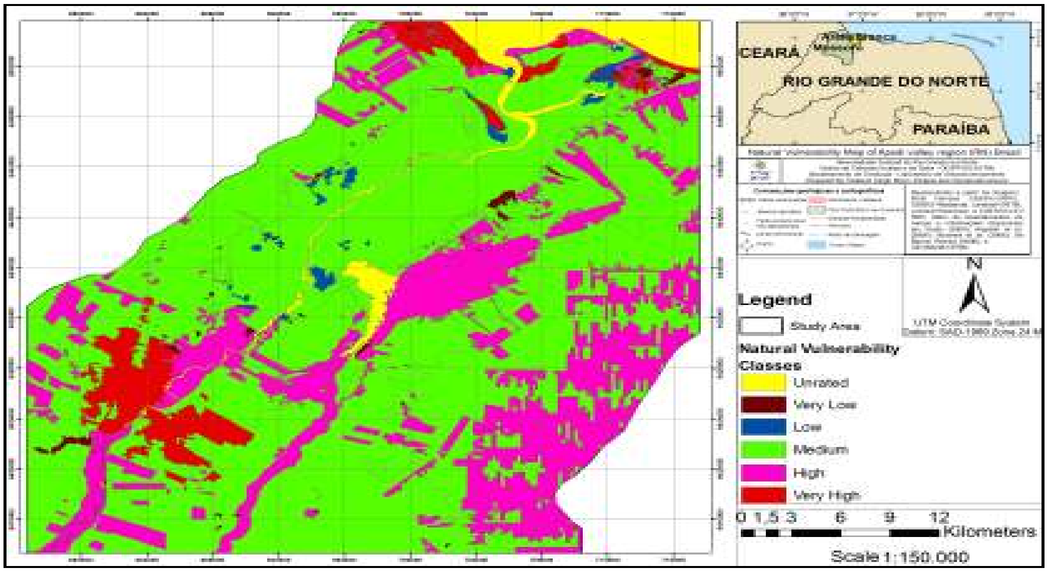

Figure 1: Natural vulnerability map of Apodi Valley region, Brazil for the year 2008.

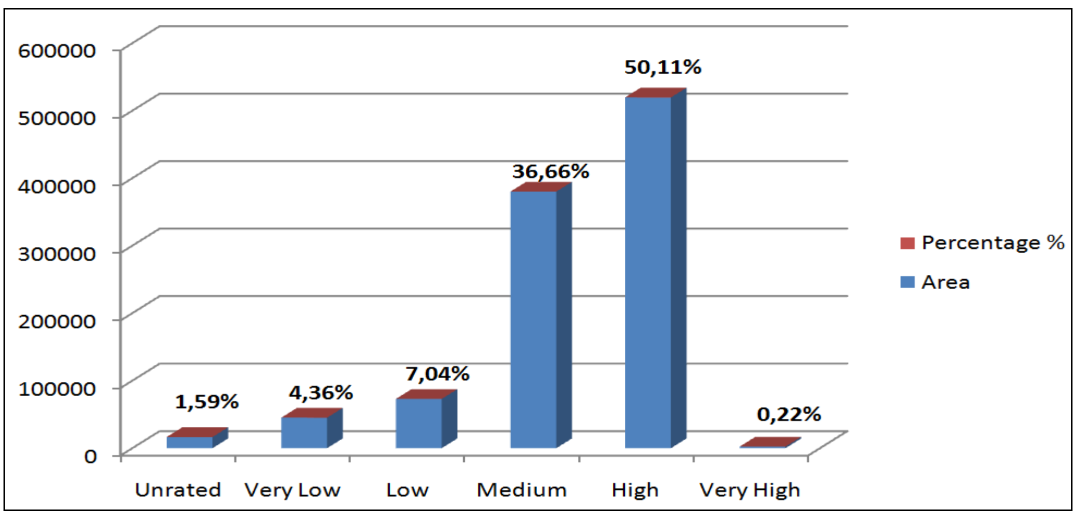

Figure 2: Natural Vulnerability Graph of the Apodi Valley Region- RN, Brazil.

Fig. 1 shows the natural vulnerability in the study area. The total area of the study is 1372.79 Km². The values found in the natural vulnerability map reflect the susceptibility of the environment because the stability conditions of morpho-pedogenesis of the area. The area of natural vulnerability corresponds to very high and high in river plains, tropical fruit agriculture part, oil and natural gas exploration fields, mangrove, dune fields, beach and urban area. An area of 687.50 km², accounting for 50.11% of the total area of the Apodi valley region, belongs to the high vulnerable zone, and 0.22% to the very high vulnerable zone in the Valley. This means that more than half (50.33%) of the total area of the Apodi valley region is very vulnerable and show a high sensitive zone, so police makers must be calculate it for future land use scenario/police. The medium and the low vulnerable zone accounted for 36.66% (498.85 km²) and 7.04% (96.58 km²) and is present in caating forest, agriculture land, salt and shrimp farm respectively, whereas the very low and unrated vulnerable zone has only a small proportion of 5.95% (81.63 km²) (Fig. 2). The profile of the Apodi Valley region natural vulnerability showed an asymmetry normal distribution but the center of the profile lean to the 'high' level (Fig. 2).

4.2 Environmental vulnerability map

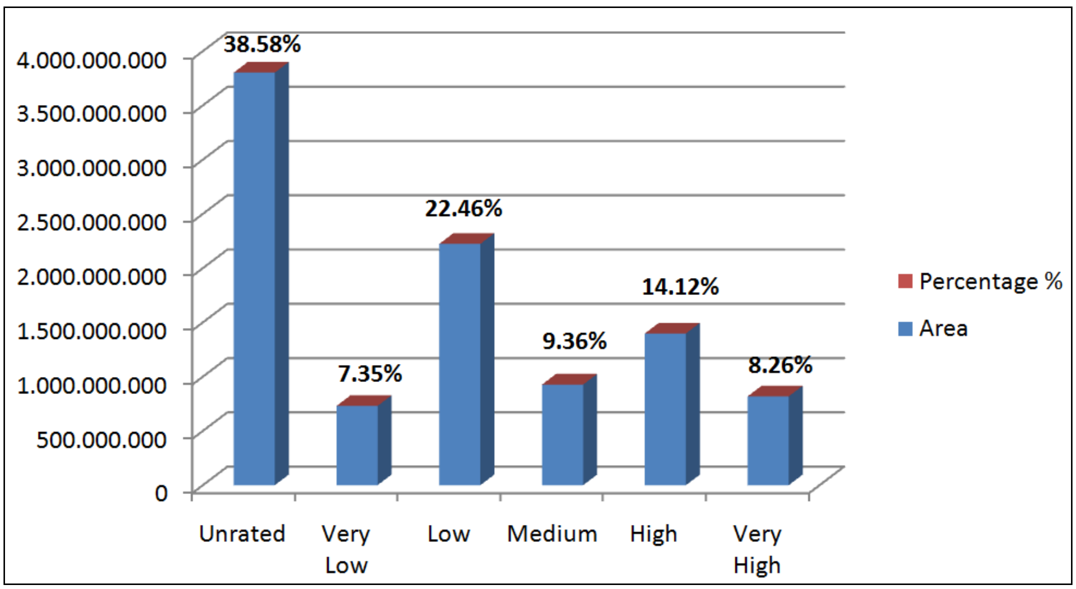

Figure 3: Environmental Vulnerability Graph of the Apodi Valley Region- RN, Brazil.

The evaluated results for environmental vulnerability are shown in Fig. 3. Overall regions with potential/unrated, very low and low status were made up 68.39% of the total area of the Apodi valley region, indicating moderate overall integrated environmental vulnerability. An area of 193.88 km², accounting for 14.12% of the total area of Apodi valley region, was classified as having high vulnerability, and 113.39 km² (8.26%) as very high vulnerability. Thus one sixth of the total area of the Apodi valley region is very vulnerable. The medium vulnerable area made up 9.36% (128.41 km²), and low vulnerability area is

22.46% (308.15 km²), whilst the area of very low vulnerability and potential vulnerability accounted for 7.35% (100.84 km²) and 38.58% (529.31 km²), respectively. In general, the environmental vulnerability of the Apodi valley region exhibited an asymmetrical normal distribution centered on a 'high' vulnerability level.

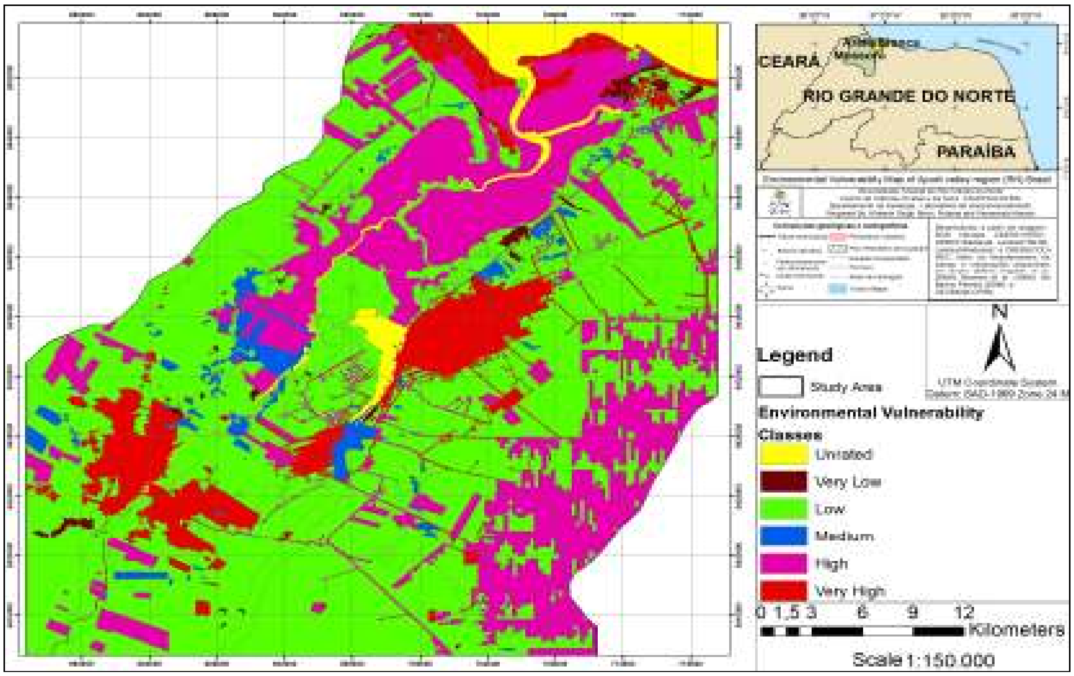

Figure 4: Environmental Vulnerability map of Apodi valley region 2008, RN- Brazil.

From the map of integrated environmental vulnerability (Fig. 4), the areas with potential, very low and low environmental vulnerability were located in three regions: caating forest, ocean/river and fixed vegetation area. In the mid part of the Apodi valley region low levels of environmental vulnerability were due to the higher vegetation condition and lower intensity of human activities. However, blocks with high or very high environmental vulnerability were visible within these areas, due to urbanization, industrial activities (shrimp farms, salt industry, oil and natural gas exploration), and steep slopes resulting in less forest protection, serious soil erosion and high rate exploration of natural resources. It was notable that the environmental vulnerability in the areas immediately surrounding Apodi River or costal area was most frequently potential to low, with only a few areas with high or very high vulnerability. Whilst better vegetation conditions and lower levels of anthropogenic interference were again factors underlying this pattern, the relatively low hypsography and the microclimate around the river were also important in providing better water heat conditions.

Three regions with very high vulnerability were located in Apodi valley region are urban area/city, centre part of valley and costal area special beach area. These areas were urban, industrial and most socio-economic activity sites with high densities of buildings and limited vegetation cover, bad geological conditions or high exploration of natural resources, which increased the environmental vulnerability. Areas with higher vulnerability were generally distributed in the north to centre and east part. Most areas with medium vulnerability, where eco-environment and human activity intensity were moderate, were located in the Basin of Apodi River and the southern part of the Valley. These are marine salt pond and agricultural areas with the main land use type being paddy fields and dry land, along with some grassland and woodland. The environment of these areas was affected mostly by human activity.

4.3 Major problems of the Apodi valley region eco-environment - Vulnerability maps demonstrate the great fragility of natural area, supported by the intense action of coastal processes and economic activities in the region. The analysis of geological and geomorphological units mapped to indicate that the region is strongly influenced by the disorderly occupation of tidal flats, river-estuarine, mangrove areas by the salt ponds and shrimp. The mangrove ecosystem in this region is in much lower proportions compared with those observed in other adjacent estuarine systems; this can be explained by the degradation of mangrove due to the growth of human activities in the vicinity of the estuarine system. The activities of oil and natural gas exploration in the region create instability of natural resources.

In the Apodi valley region, most of the 5 million residents in the upper basin are farmers/ workers, and agricultural or industrial activities are intensive and concentrated along the river and streams, resulting in non-point pollution of the water. In addition, with the excessive consumption of natural resources and the gradual increase in population, some prominent eco-environmental problems need to be solved urgently.

Among them, deforestation and forest degradation are the major environmental and ecological issues in the Apodi valley region. A substantial amount of forest has been lost due to the conversion of forest to farmlands (salt, shrimp or agriculture), high grading, industrializations and other logging practices. In Apodi valley region, forest area were first time encroached by oil and natural gas exploration industry and also for agriculture purpose by the local peoples. It's again encroached by the salt industry and now since last ten years it's slowly replaced by the shrimp farm due to market demand. Despite the high levels of current effort in forest conservation, degradation of forests caused by unsound exploitation is still a serious threat.

In addition, soil erosion has also seriously affected the sustainable development of the eco-environment in Apodi valley region. Currently, this area is increasing at a rate of 1000 km^2/year. Deforestation is the chief cause of soil erosion in the Apodi valley region, and the adverse geology and climatic conditions intensify erosion.

Moreover, the Apodi valley region is one of the main unmanaged regions of Brazil with economic decline and poor environmental awareness. Over the years, with population increase, demand for food, fuel and timber has exceeded local production levels, leading to an imbalance between humans and their environment. Inappropriate land use has generated a huge area of sloped farmland, vegetation destruction, and soil loss, leading to gross deterioration of the environment.

4.4 Suggestion for local eco-environmental management - An important goal of environmental assessment is to provide assistance to policy makers and practitioners in environmental protection. To protect and maintain the ecological environment in those areas, a population-control policy might be needed, and some regulations such as "convert slope farmland into forest or pasture" and laws (e.g. 'Environmental Protection Act', 'Land Act', 'Forestry Act', 'Grassland Act', etc.) could be established and implemented. Areas of higher ecological vulnerability should be protected over all others, for moderately vulnerable areas, integrated small watershed management should purposefully focus on sustainable utilization of natural resources, water and soil and sustainable protection of the eco-environment. In addition, it should develop ecological agriculture and industry combining traditional and modern practices to realize the coordinated development of both the environment and economy.

In the areas immediately surrounding the Apodi River, the importance of environmental protection should also be emphasized because of its significant geographical position. In addition to increasing vegetation coverage, enhancing the capacity for soil and water preservation and strengthening controls on non-point pollution, the establishment of special ecologically functional reserves, such as the river national wetland nature reserve, is a matter of priority. Human migration due to the water and industry project itself must also be noted. Ecological protection measures must be adopted to prevent soil erosion, prevent and control pollution, and to protect water, air and soil quality during emigrant movement and settlement within the Apodi valley region.

Apodi River has been highly threatened by land desertification. In areas, where some water is available for irrigation, trees and shrubs as fences or small plots, or grass belts should be planted to reduce the rate of desertification and regain lost land. This vegetation decreases the wind velocity near the base of the dune and prevents much of the sand from moving. It can also protect farmland, conserve water and soils, and provide fuel wood. In some regions, it is difficult to restore the degraded land due to the arid climate and low rain. In these areas, it is crucial to reduce and limit the number of livestock to prevent further degradation from overgrazing.

However, strengthening environmental protection alone without alleviating socio-economic and environmental ignorance can only be a temporary measure. Therefore, it is necessary to address the problems of socio-economic and raise public environmental awareness as well as scientific understanding. Generally speaking, proper protection of the ecological environment of the Apodi valley region would be significant not only for the protection of water resources, the ecological system and biodiversity in northeast Brazil, but also for social progress, economic development and improvement in standards of living, national prosperity of the water source areas and the region at large.

5. CONCLUSIONS

The application of these techniques in the study area shows the influence of human activities on potential environmental risks in coastal and estuarine area, supporting the decision making regarding the deployment of environmental protection and benefiting investors with improved productivity and safety in the study area.

Vulnerability assessment provides a means of adding value due to ecosystem and land use change scenarios in terms of in between producer, taxpayers, service provider and users. This is the type of information for example that can be of interest to policy makers and society at large, and can help influence future development pathways. By extension, more detailed land use scenarios provide the opportunity to explore more detailed indicators of vulnerability provided the scenarios are constructed to a consistent framework.

Scenarios are useful for exploring uncertainties in vulnerability assessment on a regional basis, e.g. some regions show equal vulnerability to all scenarios, whilst other regions show different responses. This is an indicator for where we can be more, or less, uncertain about the future. Furthermore, it helps in indicating how society and policy can have an important role to play in future development pathways.

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