Applied GIS

a free, international, refereed e-journal

(ISSN: 1832-5505)

URL:

http://www.appliedgis.net

Volume 6, Number 2

October, 2010

CONTENTS:

All papers published during 2010 are part of *Volume* 6.

Each paper constitutes one *Number.*

Hence this paper should be cited as:

Boori, M.S. & Amaro, V.E. (2010) – Land use change detection for environmental management: using multi-temporal satellite data in the Apodi Valley of northeastern Brazil, *Applied GIS*, 6(2), 1-15

Land use change detection for environmental management: using multi-temporal, satellite data in the Apodi Valley of northeastern Brazil

Mukesh Singh Boori[1]

Venerando Eustáquio Amaro

Geo-processing Laboratory, Geodynamic & Geophysics Division,
Department of Geology, Center of Exact Sciences and Earth,
Federal University of Rio Grande do Norte,
Natal–RN,
Brazil

[1]msboori@gmail.com

Abstract: In this study maximum-likelihood, supervised classification along with post-classification change detection was applied to satellite images for 1986, 1989, 1996, 2001, and 2009, in order to map land-cover changes within the Apodi Valley region of northeastern Brazil. The supervised classification was carried out on the six reflective bands and ground truthed. The classification results were then further refined using ancillary data, visual interpretation and expert knowledge of the area along with GIS. Post-classification change detection then generated a change image in the form of cross-tabulations. Fifteen land cover classes existed within the area, and reclamation processes during the 1990's changed them substantially, with conflicting changes being caused primarily by lack of both stability and consistency in the government's land use policies. The result was extensive vegetation degradation and water logging in parts of the study area.

Keywords: Land cover classification; multi-temporal; change detection; remote sensing; GIS

1. Introduction

Changes in the earth's surface can be related to the natural dynamics of human activities and they can occur either suddenly or gradually (Coppin et.al., 2004). Timely and accurate change detection of the earth's surface features provides a better understanding of the interactions between human and natural phenomena to better manage and use resources (Lu et.al., 2004). Over the last 25 years northeast Brazil has been subjected to a series of major disturbances, both natural and manmade - drought, civil disturbances leading to migration, large population increases and globalization. Each of these has had implications for land use requirements, with subsequent impacts on natural vegetation cover, biodiversity, socio-economic stability and food security. The modification of the vegetation cover, especially clearing, can have a long-term impact on sustainable food production, freshwater and forest resources, the climate and, last but not least, human welfare (Foley et al., 2005). It is important, therefore, that the changes occurring in land cover are reliably documented at periodic intervals.

Encroachment of urban settlements upon agricultural land may pose dire consequences, such as land degradation and desertification (Shalaby et.al., 2004). The ever increasing population produces growing pressure on areas that are already inhabited and causes a decrease in area per capita (Suliman, 1991). Food scarcity and continual loss of agricultural land are issues of global concern (Aboel Ghar et.al., 2004). The government of Brazil adopted policies aimed at self-sufficiency in food production, such as extension of cultivated land and maximization of production on the existing agricultural land. The principal purpose was, and still is to overcome Brazil's overwhelmingly unfavorable population to agricultural land ratio (Springborg, 1979).

Accurate and up-to-date information on land cover change is necessary for understanding and assessing the environmental consequences of such changes (Giri et.al., 2005), and although remote sensing is capable of capturing such changes, extracting the change information from satellite data requires effective and automated change-detection techniques (Roy et.al., 2002).

The objectives of this study were to:

1. provide a recent perspective of different land-cover types
2. monitor 1986-2009 land-cover changes using supervised classification, and
3. describe problems and make brief suggestions for improved management of natural resources.

2. Study area

The study area is located along the Apodi River valley in the northwestern portion of the state of Rio Grande do Norte. The Apodi River rises near Apodi city in the semiarid region of northeastern Brazil, flows northeastwards through the Mossoro, Areia Branca and Grossos districts and discharges directly into the Atlantic Ocean (Figure 1). Geographic coordinates range from a latitude 04°55'46".77 to 05°13'39".41 south and from longitude 37°01'30".79 to 37°22'42".42 east. The area has a semi arid tropical type of climate, with a mean annual temperature of around 28°C. The average rainfall of 700-900 mm/y mostly falls in February to April inclusive, often at high intensity, and is accompanied by very high potential evaporation in excess of 2,000 millimeters per year.

Initially, forested areas were encroached upon by the oil- and natural gas-exploration industry and also used for agriculture purposes by the local peoples. More recently it has been encroached upon by the salt industry and over the last ten years it has been slowly replaced by shrimp farms due to market demand. Despite the high levels of current effort in forest conservation, degradation of forests caused by its unsound exploitation is still a serious threat. Also, urbanization is inevitable due to economic development and rapid population growth.

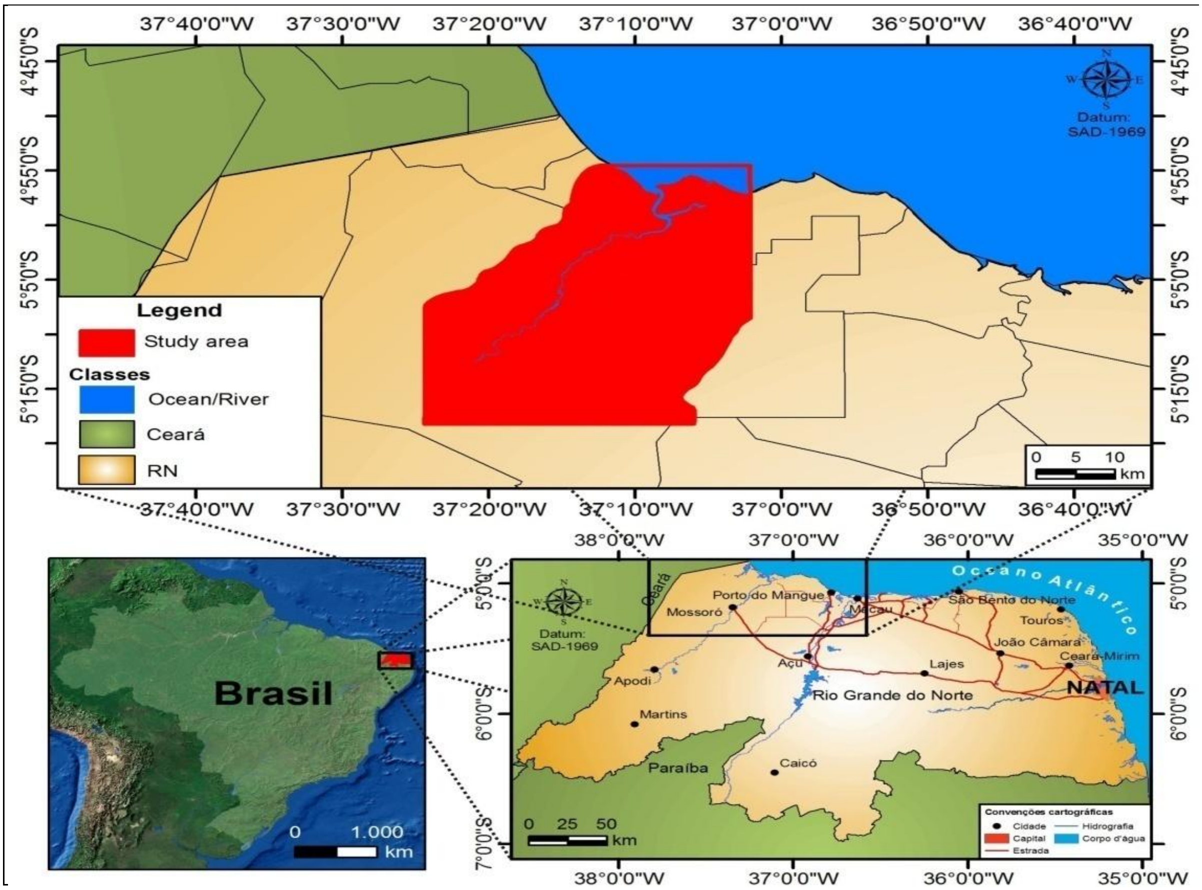

Figure 1 - Study area location, in the state of Rio Grande do Norte, northeastern Brazil.

Northeast Brazil covers an area of about 1.5 million square kilometers. The semi arid part of this region corresponds to approximately 60% of the total area of northeastern Brazil. This extensive area is inhabited by more than 30 million people and the economy is mainly based on subsistence-style, rain-fed crop production and industrialization – oil, natural gas, shrimp and salt. Overpopulation causes serious socio-economical problems, such as an undermining of rising living standards, high unemployment and crime.

Accordingly, new policies must aim to reduce the pressure on old and highly productive agricultural and forest land, decrease population density in the inhabited areas and decrease pollution by establishing industrial areas outside the valley region. It follows that determining both the trend in, and the rate of land-cover conversion are necessary if the development planner needs to establish rational, land-use policies. Here the temporal dynamics of remote-sensing data can play an important role in monitoring and analyzing land-cover changes.

3. Methods

There are many techniques available for detecting and recording differences, such as image differencing, ratios and correlation (Singh, 1989; Stow et.al., 1996; Yuan et.al., 1999). However, the simple detection of change is rarely sufficient in itself: information is generally required about the initial and final land-cover and land uses - ''from-to'' analysis as described by Khorram et al. (1999).

Furthermore, detection of image differences may be confused with problems in penology and cropping, and such problems may be exacerbated by limited image availability, poor quality in temperate zones and difficulties in calibrating poor images. Post-classification comparisons of derived, thematic maps go beyond simple change detection because they attempt to quantify the different types of change. Their degree of success depends upon the reliability of the maps that have been made by image classification. Broadly speaking, both large-scale changes such as widespread logging and major urban development, and small-scale changes like shrimp farming, might be mapped reasonably easily.

3.1 Data sets

Any study of land use changes will involve the analysis of both conventional and remotely sensed data. Conventional data is more accurate and site specific, but its collection is time consuming, expensive, manpower hungry and difficult to extrapolate over a larger area. Remotely sensed data, on the other hand, has several advantages due to its repetitive and synoptic coverage of large and inaccessible areas in a quick and economical fashion. In the present study both conventional and remotely sensed data were used.

The main remote sensing products used were orbital images of *Landsat TM*, *ETM+*, *Spot 4-HRVIR*, *IKONOS* and *CBERS 2B* satellite data. For secondary data we used *SB-24-XB-IV*, *SB-24-XDI*, *XDI-SB-24-1-2* and *MI-897-2* topographic sheets. Digital image processing was performed using the *ER Mapper 7.1* software, which involved geo-coding using the UTM cartographic projection zone 24S-Datum SAD-69 with the Root Mean Square (RMS) error being less than 1.0 meters. A *Trimble* hand-held GPS with an accuracy of 10 meters was used to map and collect the coordinates of important land use features during pre- and post-classification field visits to the study area in order to prepare land-use and land-cover maps.

3.1.1 Image classification

Land cover classes are typically mapped from digital remotely sensed data using some sort of supervised, digital image classification (Campbell, 1987; Thomas et.al., 1987). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land-cover classes or themes, and the maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category's spectral response patterns whenever it classifies an unknown pixel. This is why it is considered to be one of the most accurate classifiers - it is based on statistical parameters. Supervised classification was performed here using ground checkpoints and digital topographic maps.

The area was classified into fifteen main classes:

1. Wetland - land whose soil is saturated with moisture either permanently or seasonally, so such areas are covered either partially or completely by shallow pools of water.
2. Agriculture - areas cultivated with annual crops, vegetables, or fruit
3. Forest (CAATINGA) - small trees and shrub vegetation area except for savanna vegetation.
4. Exposed soil - land areas of exposed soil surface influenced by human impacts and/or natural causes, containing sparse vegetation with very low plant cover due to overgrazing and woodcutting
5. Fixed dunes - vegetation has developed on dunes so that it forms a more or less complete cover of the substrate
6. Industry – shrimp, salt and other economic activities
7. Pond - permanent or temporary water body
8. Mangroves - small trees and shrubs grow near the saline coast line and river
9. Mobile dunes - dunes without vegetation
10. Ocean & river - the Apodi River and its mouth to the Atlantic Ocean
11. Petroleum - oil and natural gas
12. Salt - transitional areas between land and water, occurring along the intertidal shore of estuaries and sounds where salinity ranges from near ocean strength to near fresh in the river area
13. Shrimp - aquaculture sites that cultivate marine shrimp or prawns for human consumption.

14. Stabilized pond - permanent water bodies for industrial purposes
15. Urban - includes construction activities along the coastal dunes (summer resorts) as well as sporadic houses of the Bedouins within the local villages and some governmental buildings in the main cities of Mossoro, Areia Branca and Grossos

3.1.2 Land use change-detection maps

Following the classification of imagery from each individual year, a multi-date, post-classification comparison, change-detection algorithm was used to determine changes during four intervals - 1986–1989, 1989–1996, 1996–2001, and 2001–2009. This is perhaps the most common approach to change detection (Jensen, 2004) and it has been successfully used by Yang (2002) to monitor land use trends in the Atlanta, Georgia area. The post-classification approach provides ‘‘from–to’’ change information which facilitates easy calculation and mapping of the kinds of landscape transformations that have occurred, as shown in Figure 2. Figure 3 then charts the spatial breakdown of all the land-cover classes that are used in Figure 2.

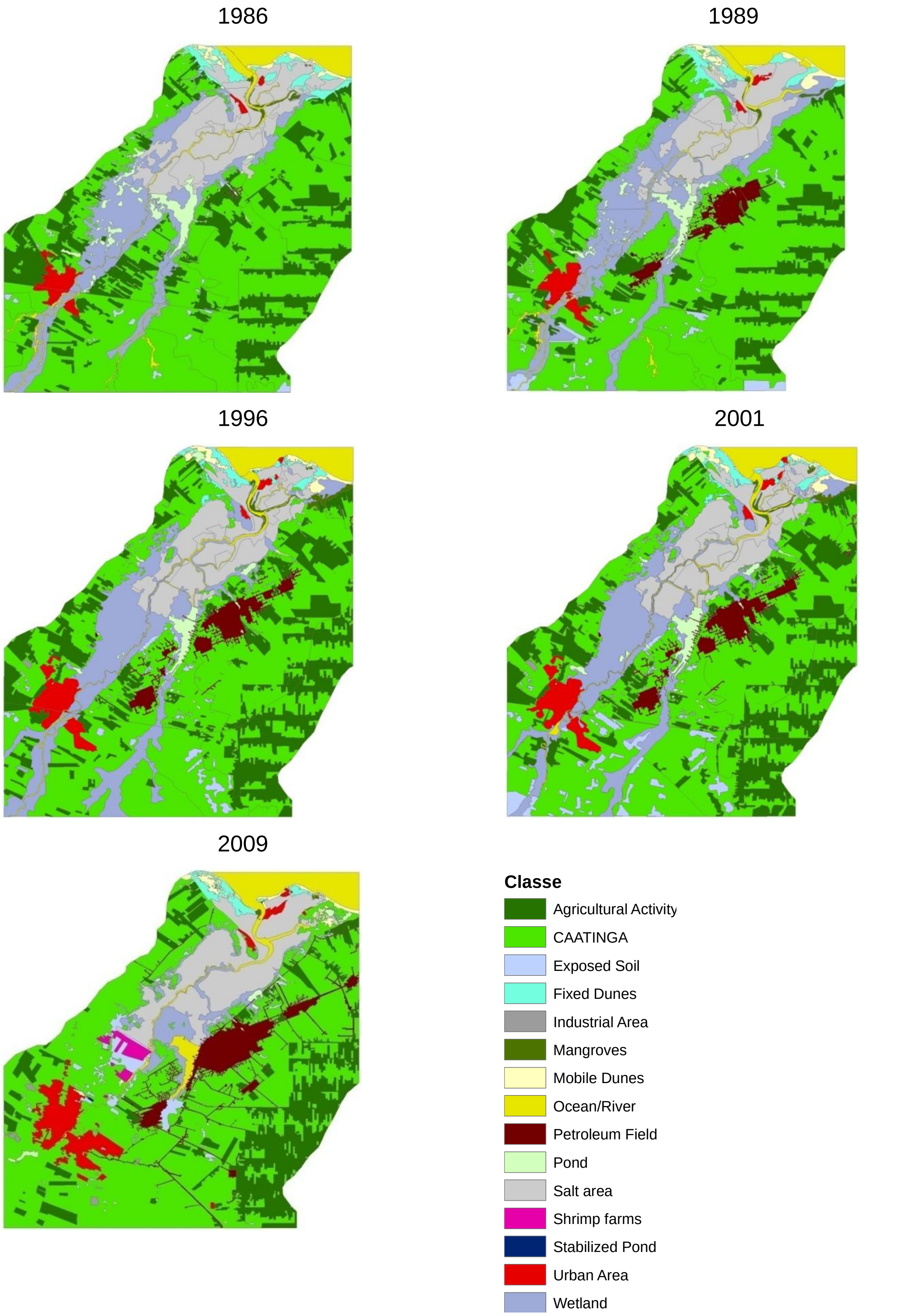

Figure 2 - Thematic maps representing the spatial distribution of different land-cover classes, on different dates, with in the Apodi Valley region of northeast Brazil

Figure 3 - The spatial breakdown of the different land-cover classes, on different dates, in the Apodi Valley region of northeast Brazil

Accuracy assessment was then carried out at 85 points, 65 from the field data and 20 from existing topographic maps and the land cover map. Specification of these 85 points used a stratified, random method so that all of the different land-cover classes would be represented. In order to increase the accuracy of the land-cover mapping of the two images, ancillary data as well as the result of visual interpretation was integrated with the classification results using GIS. The aim of this was to improve the classification accuracy of the classified image.

4. Results and discussion

Classification maps were generated for all of the five years shown in Figure 2 and the individual class area and change statistics are summarized in Table 1. In 1986 the urban area covered 18.74 km² (1.36%), but by 2009 it had increased to approximately 53.50 km² (3.88%). The agricultural area initially increased from 243.20 km² (17.05%) in 1986 to 244.62 km² (19.58%) by 1996, but it then decreased to 189.51 km² (13.8%) by 2009. The forested area decreased from 1986 (692.93.20 km² and 50.46%) to 616.46 km² and 45.40%) by 2001, but due to government interference and protection rules it then increased to 724.29 m² (52.76%) by 2009.

The wetland area was 151.83 km² (11.05%) in 1986, but now it is only 48.52 km² (3.51%). Although the extent of wetlands may change from year to year due to varying precipitation and temperature, and although variation is also likely due to classification errors, because of the high classification accuracy for water small fluctuations in water are believed to be related to varying lake levels.

Class name	**1986**		**1989**		**1996**		**2001**		**2009**	
	(km²)	***(%)***	**(km²)**	***(%)***	**(km²)**	***(%)***	**(km²)**	***(%)***	**(km²)**	***(%)***
Agriculture	234.2	*17.1*	192.6	*14.0*	244.6	*19.6*	242.3	*17.8*	189.5	*13.8*
Forest	692.9	*50.5*	677.3	*49.4*	623.9	*49.9*	616.5	*45.4*	724.3	*52.8*
Exposed soil	6.8	*0.5*	25.0	*1.8*	17.0	*1.4*	41.1	*3.0*	28.9	*2.1*
Fixed dunes	21.9	*1.6*	18.9	*1.4*	14.4	*1.2*	14.4	*1.1*	11.9	*0.9*
Industry	---	*---*	---	*---*	0.6	*0.0*	0.8	*0.1*	3.3	*0.2*
Mangroves	3.3	*0.2*	2.5	*0.2*	7.2	*0.6*	6.1	*0.4*	0.8	*0.1*
Mobile dunes	9.1	*0.7*	12.2	*0.9*	10.8	*0.9*	10.6	*0.8*	11.0	*0.8*
Ocean & river	53.3	*3.9*	53.6	*3.9*	49.4	*4.0*	48.6	*3.6*	67.0	*4.9*
Petroleum	1.11	*0.1*	34.0	*2.5*	41.1	*3.3*	42.3	*3.1*	77.9	*5.7*
Ponds	30.5	*2.2*	23.93	*1.7*	17.8	*1.4*	19.7	*1.5*	8.9	*0.7*
Salt area	149.2	*10.9*	126.3	*9.2*	134.6	*10.8*	135.8	*10.0*	137.0	*10.0*
Shrimp farm	---	*---*	---	*---*	---	*---*	---	*---*	10.5	*0.8*
Stabilized pond	---	*---*	---	*---*	---	*---*	---	*---*	0.2	*0.0*
Urban area	18.7	*1.4*	22.9	*1.7*	29.9	*2.4*	31.3	*2.3*	53.3	*3.9*
Wetland	151.8	*11.1*	182.7	*13.3*	58.2	*4.7*	148.2	*10.9*	48.2	*3.5*
Total	1372.8	*100*	1372.8	*100*	1372.8	*100*	1372.8	*100*	1372.8	*100*

Table 1 - Summary of satellite classification statistics for 1986, 1989, 1996, 2001 and 2009

Industry first appeared in 1996 with approximately 0.6 km² (0.04%), and it then continuously increased to reach 3.3 km² (0.2%) by 2009. The biggest change occurred in the petroleum area; it was 1.1 km² (0.1%) in 1886, it is now 77.9 km² (5.7%) and it is still continuously increasing. The salt area is approximately stable but, due to market demand, it has been slowly replaced by shrimp farms since 2001. Fixed dunes have continuously decreased and mobile dunes have continuously increased, which is an indication of climate change in the area.

To further evaluate the results of land-cover conversions, matrices of land-cover changes for the four intervals were created, and these are shown in Table 2. In this table unchanged pixels are located along the major diagonal of the matrix. Conversion values were sorted by area and listed in alphabetic order.

1986 - 1989 (kms^2) to -> from:	Agriculture	Forest	Exposed soil	Fixed dunes	Industrial	Mangroves	Mobile dunes	Ocean & river	Petroleum	Ponds	Salt	Shrimp farm	Stabilized	Urban	Wetland
Agriculture	139.4	65.4	7.7	1.6	..	..	..	..	12.3	0.3	..	..	..	2.1	5.8
Forest	48.4	588.9	9.6	1.3	..	..	..	0.5	2..	1.1	0.5	...	..	2.4	19.3
Exposed soil	0.7	2.3	3.4	..	..	..	..	0.4	0.1	..	..	..	..	..	..
Fixed dunes	0.2	0.3	..	12.5	..	0.6	2.2	0.1	..	0.8	1.2	..	..	0.6	3.7
Industrial	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mangroves	..	..	..	..	..	1.0	..	0.8	..	..	0.9	..	..	..	0.7
Mobile dunes	..	0.5	..	1.5	..	..	6.1	0.6	..	0.3	0.5	..	..	..	..
Ocean & river	0.1	0.4	0.9	..	..	0.6	0.5	43.2	..	..	2.2	..	..	0.3	4.4
Petroleum	..	0.4	..	..	..	..	..	..	0.3	0.9	..	..	..	..	..
Ponds	0.3	2.1	0.1	0.3	..	..	0.1	..	0.3	14.5	1.2	..	..	..	11.6
Salt	..	0.5	..	0.8	..	0.2	3.5	3.9	..	0.7	114.4	..	..	0.7	22.5
Shrimp farm	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stabilized	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Urban	1.1	0.6	..	..	..	..	..	0.1	..	..	0.4	..	..	16.0	0.7
Wetland	2.1	16.7	4.7	0.9	..	0.2	..	2.4	0.6	6.8	5.5	..	..	0.7	111.8

1989 - 1996 (kms^2) to -> from:	Agriculture	Forest	Exposed soil	Fixed dunes	Industrial	Mangroves	Mobile dunes	Ocean & river	Petroleum	Ponds	Salt	Shrimp farm	Stabilized	Urban	Wetland
Agriculture	136.6	47.4	1.1	..	0.1	0.1	..	..	0.5	0.3	..	..	..	3.9	2.7
Forest	94.7	522.7	10.9	0.9	..	..	0.4	..	15.3	1.6	0.3	...	..	4.5	26.5
Exposed soil	6.5	10.6	2.3	..	..	..	..	0.1	0.4	0.1	..	..	..	..	4.9
Fixed dunes	0.9	3.6	..	9.6	..	0.9	1.4	..	..	1.1	0.8	..	..	0.3	0.3
Industrial	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mangroves	..	..	..	0.1	..	1.5	..	0.5	..	..	..	..	..	..	0.5
Mobile dunes	..	0.1	..	1.7	..	..	7.9	1.1	..	..	1.0	..	..	..	0.4
Ocean & river	0.2	0.3	..	0.1	..	0.9	0.4	40.5	..	0.2	2.4	..	..	0.1	7.7
Petroleum	0.8	8.2	..	..	..	..	..	..	23.9	0.4	..	..	..	..	0.1
Ponds	..	1.9	..	0.5	..	..	0.4	0.2	0.5	9.3	3.3	..	..	..	7.7
Salt	..	1.3	..	0.6	..	1.6	..	2.9	..	0.1	111.0	..	..	0.4	7.3
Shrimp farm	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stabilized	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Urban	0.3	0.3	..	0.2	..	..	..	0.3	..	..	0.1	..	..	20.2	1.5
Wetland	5.4	28.7	2.2	0.6	..	2.5	0.2	2.9	0.3	4.5	15.6	..	..	0.3	117.6

1996 - 2001 (kms^2) to -> from:	**Agriculture**	**Forest**	**Exposed soil**	**Fixed dunes**	**Industrial**	**Mangroves**	**Mobile dunes**	**Ocean & river**	**Petroleum**	**Ponds**	**Salt**	**Shrimp farm**	**Stabilized**	**Urban**	**Wetland**
Agriculture	202.4	29.7	8.3	..	..	0.1	..	..	1.1	0.1	..	..	..	0.7	0.7
Forest	31.4	559.7	9.9	0.8	0.2	..	..	0.1	7.2	1.5	0.7	...	..	1.0	8.0
Exposed soil	2.4	1.0	13.0	..	..	..	..	..	..	..	..	..	..	..	..
Fixed dunes	..	0.7	..	11.6	..	..	0.9	..	..	0.1	0.7	..	..	0.2	0.2
Industrial	..	..	..	..	0.6	..	..	..	..	..	..	..	..	..	..
Mangroves	0.8	0.9	..	0.1	..	4.1	..	0.8	..	0.1	0.6	..	..	..	0.3
Mobile dunes	..	..	..	1.1	..	..	8.8	0.3	..	0.1	0.1	..	..	..	0.2
Ocean & river	0.1	0.1	..	0.1	..	0.3	0.4	42.7	..	..	1.4	..	..	0.2	2.6
Petroleum	0.5	5.6	..	..	..	..	..	..	33.5	0.2	..	..	..	..	0.1
Ponds	0.1	1.0	..	0.1	..	..	0.1	..	0.2	14.9	0.2	..	..	..	0.9
Salt	..	0.7	..	0.5	..	1.0	0.3	0.7	..	0.1	128.6	..	..	0.2	1.7
Shrimp farm	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stabilized	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Urban	0.2	0.6	..	0.1	..	..	..	..	..	..	0.1	..	..	27.9	0.7
Wetland	4.1	17.2	9.8	0.1	..	0.4	0.1	2.9	0.1	2.2	3.6	..	..	1.1	132.9

2001 - 2009 (kms^2) to -> from:	**Agriculture**	**Forest**	**Exposed soil**	**Fixed dunes**	**Industrial**	**Mangroves**	**Mobile dunes**	**Ocean & river**	**Petroleum**	**Ponds**	**Salt**	**Shrimp farm**	**Stabilized**	**Urban**	**Wetland**
Agriculture	92.0	129.3	3.1	0.5	..	..	0.3	0.2	8.0	1.2	1.1	..	..	3.7	1.7
Forest	91.2	444.7	6.6	0.6	2.2	0.1	0.5	1.8	36.7	3.0	6.7	0.1	..	14.7	9.2
Exposed soil	1.5	33.3	0.5	..	0.6	..	..	0.3	1.0	0.1	..	..	..	2.0	1.7
Fixed dunes	..	1.9	0.2	3.7	..	..	2.4	2.6	0.1	0.2	2.9	..	..	0.2	0.1
Industrial	0.1	0.5	0.1	..	0.2	..	..	..	..	..	..	..	..	..	..
Mangroves	..	1.1	..	0.1	..	0.1	1.1	1.6	..	0.2	1.8	..	..	..	..
Mobile dunes	0.1	1.4	0.1	1.7	..	..	2.3	4.0	..	1.0	..	..	..	..	..
Ocean & river	0.1	1.7	0.3	0.1	..	0.4	0.2	36.4	..	..	5.9	0.3	0.1	1.1	0.4
Petroleum	1.3	12.1	0.1	..	..	..	..	0.5	28.0	0.1	0.2	..	..	..	0.4
Ponds	0.2	3.9	0.5	0.9	..	..	0.8	6.3	0.9	0.2	2.8	0.5	..	0.1	2.8
Salt	0.2	8.2	0.5	4.1	..	0.3	1.9	7.3	..	0.2	94.2	..	..	2.5	16.5
Shrimp farm	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Stabilized	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Urban	..	5.4	0.1	..	..	..	0.3	0.6	..	..	1.5	..	..	23.3	..
Wetland	1.7	74.1	16.5	0.3	0.2	..	1.3	3.4	1.5	2.7	18.2	9.1	0.1	5.1	14.4

Table 2 - Matrices of land-cover changes (km²) from 1986 to 2009

The results indicate that increases in the urban area mainly came from the conversion of agricultural and forest land in the 1986–1996 period and then again in the 2001-2009 interval. More exactly, in the 1986-1989 period 2.1 km² of agriculture and 2.4 km² of forest converted to urban, and during the 1989-1996 interval this doubled to 3.9 km² of agriculture and 4.5 km² of forest. After 1996 this trend slowed, but from 2001 to 2009 conversion from agriculture continued at the same rate but conversion from forests jumped dramatically to 14.74 km². In total, Table 2 shows that 22.6 km² of forest were converted to urban uses between 1986 and 2009.

These changes may seem to be classification errors, but forested areas are among some of the most sought after areas for developing new housing. Streets and highways were generally classified as urban, but when urban tree canopies along the streets grow and expand, the associated pixels may be classified as forest. We note that the changes from urban to forest occurred almost entirely near highways and streets. Classification errors may also cause other unusual changes. For example, between 1986 and 2009, 1.6 km² of urban changed to agriculture and 2.9 km² of urban and 10.9 km² of agriculture changed to wetland. These changes are most likely associated with omission and commission errors in the *Landsat* classifications-change map. Registration errors and edge effects can also cause errors in the determination of change and no-change.

In percentage terms, note that the dominance of agriculture and forests changed little between 1986 and 1989, but between 1989 and 1996 reclamation accelerated and the construction of new agrarian communities began. Then, between 1996 and 2001, because the whole infrastructure of the Apodi Valley regional area was now completed impressive rates of change were observed. Around 43.8% of the land (other than forests and agriculture) in 1996 was developed to other classes by 2001. Due to the remarkable change which occurred during this period, areas of no-change represented 87.0%, and the changed area represented 13.0%. Finally, from 2001 to 2009, changes in land cover also took place, but at an even faster rate of change than in the 1996–2001 period. By 2009 shrimp farms and stabilized ponds had appeared as new classes, and land degradation had increased. The unchanged area represented 56.1% (729.3 km²) of the total area, whereas the changed area represented 43.9% (643.6 km²) of the total area.

Table 2 also allows us to track total change within individual categories. For example, the forest area covered 616.4 km² in 2001 and 724.3 km² in 2009. Moreover, out of the 725 km² that was forest land in 1986, 444.7 km² was still forest land in 2009; 91.2 km² had been converted to agriculture land by local people; 36.7 km² had been converted to petroleum, 9.2 km² had been converted to wetland and 14.7 km² had been converted to urban. At the same time the increase in the forest area, from 2001 to 2009, comprised 129.3 km² converted from agriculture and 33.3 km² converted from exposed soil.

Agriculture covered an area of 242.3 km² in 2001 and 189.5 km² in 2009. It might seem from these figure that 53.8 km² was degraded, but cross-tabulation analysis reveals that 129.3 km² out of the lost agriculture was converted to forest land, which is a positive change and not land degradation, and only 19.7 km² (converted to other than forests) was degraded.

At the same time 48.0 km² from agriculture, forest, exposed soil, fixed dunes and wetland was converted to petroleum. This explains the importance of integrating remote sensing and GIS because it provides essential information about the nature and spatial distribution of land-cover changes. We have to take into consideration the accuracy of the classification of different classes since the classification error will be affected by the accuracy of the change-detection figures.

Land-degradation processes in our study area comprised of degradation of natural vegetation due to overgrazing and the remarkable inter-annual variation in the amount of rainfall. The water logging which results from mismanagement of irrigation is another cause of land degradation. The main problems associated with irrigation schemes are their wasteful use of water, with application rates exceeding possible plant uptake, as well as poor drainage systems that lead to problems associated with water logging - salinization and alkalinization. This could be seen on the land-cover map of 2009. Finally, a third land degradation process in our study area is wind and water erosion, which accelerate as a result of the loss of vegetation cover. Also, wind and water erosion have led to the removal of the relatively fertile topsoil and this could result in desertification.

4.1 Major problems in the Apodi Valley region's eco-environment

The land use change-detection maps demonstrate the great fragility of the natural area and how it is threatened by the intense action of coastal processes and economic activities. Moreover, analysis of mapped geological and geomorphological units indicates that the region is strongly impacted by salt ponds and shrimp farms' disorderly occupation of tidal flats, estuaries and mangrove areas. Growth of human activities has ensured that the mangrove ecosystem in this region is in much lower proportions than in adjacent estuarine systems. Also, oil and natural gas exploration in the region have created instability of natural resources. In summary, most of the 5 million residents in the upper basin are farmers or workers, agricultural and industrial activity is intensive and it is so concentrated along rivers and streams non-point pollution of the water is a growing problem.

Given the excessive consumption of natural resources and the gradual increase in population, some prominent eco-environmental problems obviously need to be solved urgently. Among them, deforestation and forest degradation are a major environmental and ecological issue, with a substantial amount of forest having been lost due to conversion of forests to farmlands (salt, shrimp and agricultural), high grading, industrialization and harmful logging practices. The forested areas were first encroached upon by oil and natural gas exploration along with agriculture for local people, they were then further encroached upon by the salt industry, and over the last ten years they have been slowly replaced by shrimp farming due to market demand. Despite much current effort in terms of forest conservation, the continuing degradation of forests due to unsound exploitation is still a serious threat. Also, soil erosion has seriously affected sustainable development, with degraded land increasing at a rate of 1000 km^2 per year. Deforestation is the chief cause of soil erosion, 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. Population increases over the years has brought a demand for food, fuel and timber which exceeds local production levels. This leads to a fundamental imbalance between humans and their environment. Inappropriate land use has generated a huge area of farmland, considerable vegetation destruction and substantial soil losses which collectively add up to gross deterioration of the environment.

4.2 Suggestions for local eco-environmental management

An important goal of environmental assessment is to provide assistance to policy makers and practitioners of environmental protection, so here we suggest that to protect and maintain the ecological environment a population-control policy might be needed. Also, some regulations like "convert slope farmland into forest or pasture" along with laws like an "Environmental Protection Act", a "Land Act", a "Forestry Act" and a "Grassland Act" could be established and implemented. Areas of higher ecological sensitivity should be protected as a first priority and for moderately sensitive areas integrated, small watershed management should purposefully focus on sustainable utilization of natural resources to sustainably protect water and soil. In addition, authorities should develop a form of ecologically sensitive agriculture and industry that combines traditional and modern practices and they need to strive for coordinated development of both the environment and the economy.

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

The Apodi River has been highly threatened by land desertification. In areas where some water is available for irrigation, therefore, trees and shrubs acting as fences for small plots or grass belts should be planted. Such vegetation decreases the wind velocity near the base of dunes and so prevents much of the sand from moving. It can also protect farmland, conserve water, preserve soils and provide fuel wood. Moreover, in some regions where it is difficult to restore degraded land because of an arid climate and low rainfall, it is crucial to reduce and limit livestock numbers to prevent further degradation from overgrazing. However, just strengthening environmental protection can only be a temporary measure, because alleviation of socio-economic and environmental ignorance is also necessary. Public environmental awareness, as well as scientific understanding, needs to be boosted.

Generally speaking, proper protection of the Apodi Valley region's ecological environment would be significant not only for the protection of water resources, the ecological system and biodiversity within northeast Brazil, but also for social progress, economic development, living standards improvement, national prosperity of water-source areas and general regional health.

5. Conclusion

Over the last 25 years unprecedented land cover and land use changes have occurred within the Apodi Valley region. The area has undergone very severe land-cover change as a result of development projects of the agricultural, industrial and tourist kinds. The main drivers of such changes have been both human and natural. A high rate of population increase, economic development and globalization on one side, and natural hazards such as floods, landslides, drought and climate change on the other have continuously and are still eroding northeast Brazil's natural ecosystems and resources.

The reduction of natural vegetation like forest, wood and shrub lands has had environmental as well as socio-economic impacts. The decrease in natural vegetation is not only leading to loss of habitat, biodiversity and stored carbon, but also to loss of pastures, sources of fuel wood and bush meat. Furthermore, a positive feedback mechanism has led to an increase in the risk of natural hazards like floods and landslides.

From a socio-economic point of view this means not only a loss of ecosystem services, but also a decline of livelihoods and cultural values, not to mention a subsequent reduction of income from tourism. A consequence of this is to make protected areas some of the few remaining zones where fuel wood, rich pastures and game resources are left, and so they attract more and more illegal activities.

As shown by our study, land-cover change is mainly driven by the expansion of industry. The increase of agricultural areas, if poorly managed, has impacts above those previously mentioned - changes in the soil water cycle, nutrient depletion and an increased risk of soil erosion and land degradation, even though the expansion of croplands leads to a growth in agricultural outputs like food and fibers to positively impact on the country's economy and human well being. Yet the land left available for future agricultural expansion is decreasing, and with population increases the agricultural zone itself is more crowded. This will only exacerbate potential friction between agriculturalists and pastoralists.

As well as the huge increase in agricultural land there has also been a considerable increase in urban settlements, with the area of natural vegetation decreasing considerably, and the main causes of land degradation have been removal of vegetation and water logging. Such changes require rapid adjustments to land management in order to avoid crises in food security and conflicts over dwindling access to natural resources, which are becoming more in evidence.

Indeed, the concept of “environmental refugees” is receiving more attention both within the media and the scientific literature. This problem needs to be seriously studied, through a multi-dimensional approach that includes socio-economic considerations, in order to preserve the newly reclaimed land and increase food production. Further studies are required, therefore, to provide information not just on the magnitude of these changes, but also, unlike this study, to spatially localize potential trouble spots so that action can be taken.

References

Aboel Ghar, M., Shalaby, A. & Tateishi, R. (2004) - Agricultural land monitoring in the Egyptian Nile Delta using Landsat data, *The International Journal of Environmental Studies*, 61(6), 651–657

Campbell, J.B. (2002) - *Introduction to remote sensing* (3rd ed.), New York, Guilford Press

Coppin, P. et.al. (2004) - Digital change detection methods in ecosystem monitoring: a review, *International Journal of Remote Sensing*, 25(9), 1565– 1596

Foley, J.A. et.al. (2005) - Global consequences of land use changes, *Science*, 309, 570–574

Giri, C., Zhu, Z. & Reed, B. (2005) - A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets, *Remote Sensing of Environment*, 94, 123–132

Jensen, J.R. (2004). *Digital change detection and introductory digital image processing: A remote sensing perspective,* New Jersey, Prentice-Hall

Khorram, S. et.al. (1999) - Accuracy Assessment of Remote Sensing-Derived Land Cover Change Detection, *Monograph, ASPRS, Bethesda, Maryland, 64*

Lins, K.S. & Kleckner, R.L. (1996) - Land cover mapping: An overview and history of the concepts, in Scott, J.M., Tear, T.H. & Davis, F. (eds.) - *Gap analysis: a landscape approach to biodiversity planning*, Bethesda, MD, American Society for Photogrammetry and Remote Sensing, 57–65

Lu, D., Mausel, P., Brondizio, E. & Moran, E. (2004) - Change detection techniques, *International Journal of Remote Sensing*, 25(12), 2365–2407

Roy, D.P., Lewis, P.E. & Justice, C.O. (2002) - Burned area mapping using multi-temporal moderate spatial resolution data - a bi-directional reflectance model-based expectation approach, *Remote Sensing of Environment*, 83, 263–286

Shalaby, A., Aboel Ghar, M. & Tateishi, R. (2004) - Desertification impact assessment in Egypt using low resolution satellite data and GIS, *The International Journal of Environmental Studies*, 61(4), 375–384

Singh, A. (1989) - Digital change detection techniques using remotely sensed data, *International Journal of Remote Sensing*, 10, 989–1003

Springborg, R. (1979) - Patrimonialism and policy making in Egypt: Nasser and Sadat and the tenure policy for reclaimed lands, *Middle Eastern Studies*, 15(1), 49–69

Stow, D.A., Chen, D.M. & Parrott, R. (1996) - Enhancement, identification and quantification of land cover change, in Morain, S.A. & Lopez Barose, S.V. (eds.) - *Raster imagery in geographical information systems,* Santa Fe, One Word, 307–312

Suliman, M. K. (1991) - Universities and development of the desert land in the ARE, *Proceedings of the second annual university conference*, Cairo, 2–5 November

Thomas, I.L., Benning, V.M. & Ching, N.P. (1987) - *Classification of remotely sensed images*, Bristol, Adam Hilger

Yang, X. (2002) - Satellite monitoring of urban spatial growth in the Atlanta metropolitan area, *Photogrammetric Engineering and Remote Sensing*, 68(7), 725–734

Yuan, D., Elvidge, C.D. & Lunetta, R.S. (1999) - Survey of multi-spectral methods for land cover change analysis, in Lunetta, R.S. & Elvidge, C.D. (eds.) - *Remote sensing* *change detection: environmental monitoring methods and applications*, London, Taylor & Francis, 21–39
