Land cover characterization and change detection using multispectral imagery for the Beira area, Mozambique: a preliminary approach

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Abstract –The Beira area, in eastern Mozambique, is characterized using multispectral imagery, in a two fold purpose: *i*) identification of the geo-environmental units, based on an adapted CLC2000/2006 nomenclature, and *ii*) evolution of the area in order to identify and forecast environmental problems. Three multispectral data sets collected between 1991 and 2007, from Landsat and ASTER sensors, are analyzed. Atmospherical corrections are performed in FLAASH (ENVI software). A combination of algorithms is used to classify the imagery, taking into account geological knowledge and Digital Elevation Model, for land cover mapping and evidence of environmental concerns. Validation is based on visual interpretation as well as partial field checking. Results of change detection show the trends of erosional/depositional dynamics of fluvial and marine systems, with sediment load and displacement of areas. The final land cover mapping contributes to an adequate land-use planning and mitigation of foreseen environmental problems.

Keywords: Land cover, Landsat, ASTER, multitemporal, environmental concerns

1. INTRODUCTION

The Beira area, in eastern Mozambique, has a large interface with estuarine and marine water, forming deltas, dunes, beaches and lagoons. This involves a complex regime of erosion and depositional dynamics in systems with high environmental vulnerability. Additionally, these coastal systems have a huge potential in terms of mineral resources (heavy minerals, construction material, ceramics and glass industry) as well as tourism exploitation. Thus, it is a key-issue to increase the knowledge how they work in order to promote an adequate sustainable management, taking into account natural as well as human induced activities.

Another identified environmental concern is related to the significant increase in the population in the last decade without adequate urban planning. This fact raises human health issues, including insalubrities. To tackle with these issues, a land cover mapping is undertaken. In fact, this is the most important element for description and study of the environment, providing the most useful indicator of human interventions on the land. Land cover changes quickly over time and is a good proxy for dynamics of the Earth surface resulting from a variety of drivers and factors (Herold et al. 2006). Thus, a multitemporal analysis is carried out for a comprehensive understanding of evolutionary processes considered herein in the perspective of shoreline change and vegetation alteration in the Beira area. To support governmental policies related to the sustainable development of mineral resources and groundwater, as well as land-use planning and environmental concerns, a study was conducted in the area of Figure 1.

2. DATASET AND METHODS

The imagery collected for this work is displayed in Figure 1 and Table 1 for three different sensors:

1. Two from the Landsat missions, a) Thematic Mapper 5 (TM5), and b) 7, Enhanced Thematic Mapper Plus (ETM+)
2. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), plus derived Digital Elevation Model (DEM)

All dataset were provided with orthorectification, in Projection: UTM, Datum: WGS84, Zone 36S. The numbers of bands are variable, as well as pixel sizes. To minimize the latter, the ETM+ image is sharpened using a Gram-Schmidt sharpening algorithm (Laben & Brower, 2000) reducing the pixel size to 15m. From the three, the Landsat TM5 was captured during the rainy season. The ASTER image has a smaller area and does not encompass the all project area (54.8%) (Figure 1).

Table A. Image Datasets

Multispectral data /(sensor)	Date of capture	GMT
AST14DMO SC:AST_L1A 003:2043342206/(ASTER)*	24/05/2007	07:59:18.73
ELP167R074_7T20010507 (Landsat 7 ETM+)**	07/05/2001	not available
ETP167R74_5T19910301 (Landsat TM5) ***	01/03/1991	07:50:00.00

Source *NASA Land Processes Distributed Active Archive Center User Services **www.landcover.org *** USGS Earth Resources Observation & Science (EROS)

The imagery was atmospherically corrected using the FLAASH module incorporated in ENVI software (ITT, 2008). The atmospheric model was tropical using a maritime aerosol model. For the case of 2001 ETM+ image the correction was undertaken on a pan-sharpened image.

A combination of algorithms was used to extract homogeneous information from the images including: 1) unsupervised and supervised classification, 2) compression algorithms, 3) vegetation NDVI, and 4) band ratios for thresholding. Enhancement tools and textural or morphological analysis were also used for definition of some classes. Final refinement was undertaken with mathematical morphologic operators. Other classes were extracted by combining

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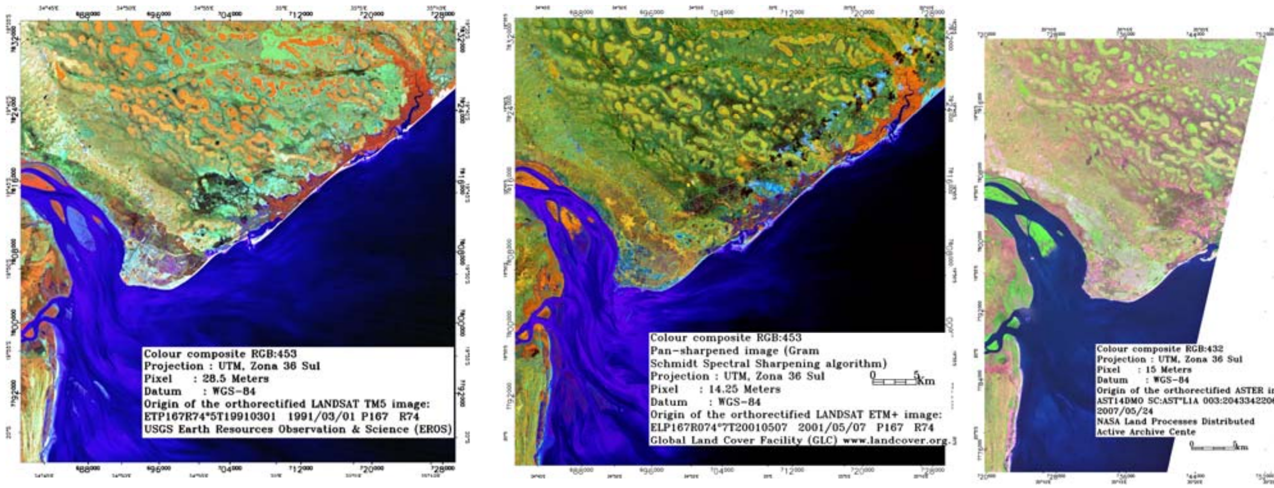


a) b) c)

Figure 1. The study area: a)Landsat TM5 (1991), b) Landsat ETM+ (2001) and c) ASTER (2007), with 54,8% of the project area

enhancement tools and textural or morphological analysis.

The nomenclature adopted to classify the images was mainly the one of the Corine Land Cover 2000 (Bossard et al., 2000) and 2006 (Büttner et al, 2007). The Minimum Mapping Unit adopted was 10 pixels. Validation of the map obtained is based on visual interpretation as well as partial field checking.

3. RESULTS AND DISCUSSION

3.1 Land cover mapping for ASTER image

The Land cover mapping results for the year 2007 ASTER image is depicted in Figure 2, and the classes are quantified in Table B. The area covered by the ASTER image is 1,334.812 Km². From this, 486.939 Km² correspond to water whether inland or maritime. An arbitrary line divides the *5.2.2. Estuaries* from *5.2.3 .Sea and Oceans.*

The northern part of the image is occupied mainly by *3.2.4 Transitional woodland-shrub* generically round shaped, surrounded by *3.2.1.Natural grassland*. The more correct term to be applied to the all area should be savanna, however this particular morphology suggests former variations in the sea level that lead to the reactivation of the fluvial dynamics of the area with the erosion of the headwaters rivers. Thus, the separation is maintained.

In the classes of the *1. Artificial areas*, which occupies 4.2% of the classified image, the urban fabric has a particularity due to the type of construction. In fact, although part of the area shows high density of urban fabric, i.e. bigger than 80%, the ground it is not impermeable and part of the houses are covered with trees. This is typical of this type of urbanization. Thus, it is considered as *1.1.2 Discontinuous urban fabric.* This is more relevant in the areas surrounding the *1.1.1 Continuous urban fabric* of the city of Beira, and encompasses the most problematic areas concerning health issues due to insalubrities. Further discrimination is possible in the classes of *1. Artificial areas*, particularly related to the type of buildings, namely if they correspond to *1.2.1.industrial or commercial units* or *1.4.2 Sport and leisure facilities.*

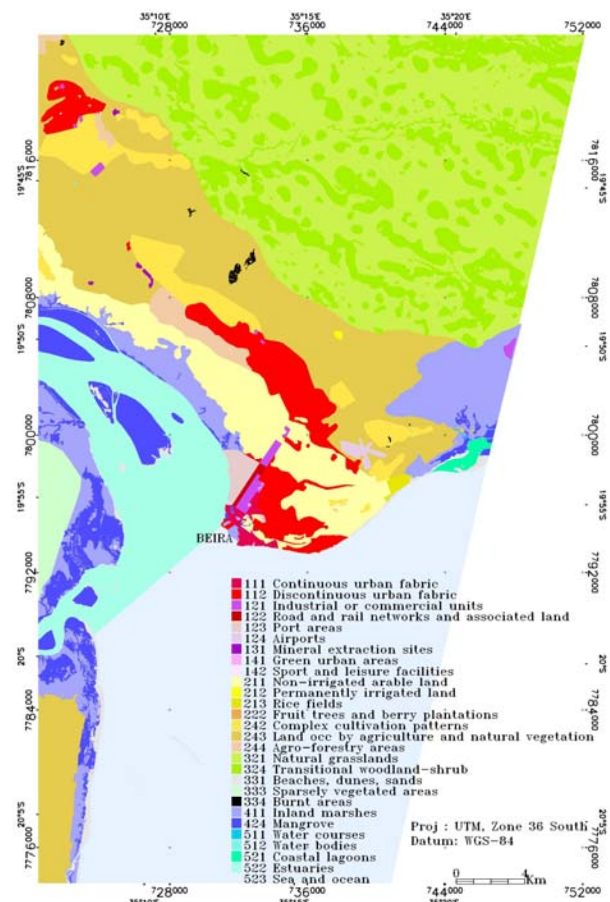


Figure 2. Land cover based on ASTER image of 2007.

The class *1.3.1 Mineral extraction sites* is related to sand mining and possibly there are more areas that will have to be included after more detailed local information. Additionally, it is not herein considered the sand mining from the beaches, which is difficult to detect in the image.

Table B. Land cover classes distribution.

Corine (Level I)	Adapted Corine (Level III)	(%)
1 Artificial areas	1.1.1 Continuous urban fabric	0.209
	1.1.2 Discontinuous urban fabric	2.952
	1.2.1 Industrial or commercial unit	0.250
	1.2.2 Road and rail networks and associated land	0.061
	1.2.3 Port areas	0.259
	1.2.4 Airports	0.137
	1.3.1 Mineral extraction sites	0.035
	1.4.1 Green urban areas	0.019
	1.4.2 Sport and leisure facilities	0.300
2 Agricultural area	2.1.1 Non-irrigated arable land	4.627
	2.1.2 Permanently irrigated land	0.015
	2.1.3 Rice fields	0.062
	2.2.2 Fruit trees	0.004
	2.4.2 Complex cultural systems	2.487
	2.4.3 Agriculture areas with natural important spaces	13.438
	2.4.4 Agro-forest areas	0.760
3 Forest and natural area	3.2.1 Natural grassland	17.833
	3.2.4 Transitional woodland-shrub	8.950
	3.3.1 Beaches, dunes, and sand plains	0.725
	3.3.3 Sparsely vegetated areas	1.457
	3.3.4 Burnt areas	0.071
4 Wetland, salt	4.1.1 Inland marshes	5.454
	4.2.4 Mangrove	3.464
5 Water	5.1.1 Water courses	0.011
	5.1.2 Water bodies	0.008
	5.2.1 Coastal lagoons	0.183
	5.2.2 Estuaries	6.324
	5.2.3 Sea and Oceans	29.905

The *2 Agricultural area* covers 21.4% of the study area dominated by *2.4.3 Agriculture areas with natural important spaces.* The major distribution is oriented NW-SE, encompassing the Dondo village NW of the map. The class *2.1.1 Non-irrigated arable land* covers 4.6% of the area and is located between the previous and *4.1.1 Inland marshes*. The latter is included in the *4 Wetland, salt* level I of CLC2000. Due to its importance, another class has been added to this i.e. *4.2.4 Mangrove.* Mangroves are salt tolerant plants that grow within the intertidal zone along tropical and subtropical coasts. They are important barriers for mitigating coastal disturbances provide habitat for over 1300 animal species and are one of the most productive ecosystems (Fatoyinbo et al, 2008). Although this class represents a significant area, 3.5%, this must be carefully considered, once further field checking is required.

For the *3 Forest and natural area*, excluding the two major classes above mentioned, the class *3.3.1 Beaches, dunes, and sand plains* defines the sand banks and the shoreline.

3.2 Multitemporal analysis

The analysis undertaken is partial and focused on coastal regimes and vegetation specifically located near the ocean. The comparison is based on Principal Components Analysis factors (PCA).

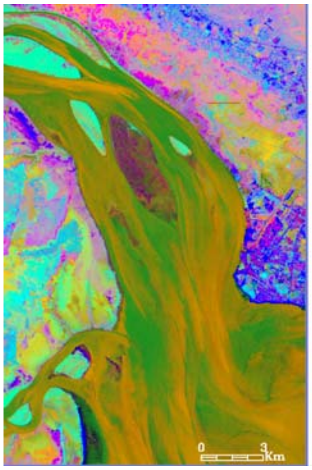
Coastal regimes - In order to obtain littoral changes it is fundamental to have the tidal movements, not yet available therefore not allowing the mapping of the *4.2.3 Intertidal flats*. Nevertheless, significant changes can be securely detected defined by the vegetation installation, particularly visible at the Pungue River (Figure 3) and in the shoreline in S and NNE of Beira city. The accrecionary regime of the delta is quite evident on the three analyzed images, focused on vegetation patterns. However, the evolution from 2001 to 2007 is more complex, despite of the eventual variation of the tidal movements, particularly evident on a regional scale. It is highlighted the establishment of narrow deeper channels, although there seems not to exist an increment of area.

The sediment accretion in the Pungue River delineates variations on the flow direction, with implications on the flow direction near the Beira city. Despite the changes based on vegetation, others are visible in the shoreline as depicted in the images of Figure 4, located NE of the Beira city, where the shoreline shows increase of area.

Vegetation - The considerations above related to the coastal regimes are based on the increase of vegetation. Some other observations show the variation of the vegetation particularly focused on an area NE of the Beira city, not covered by the ASTER image. While the *4.2.4 Mangrove* seems to increase in the Pungue River, fixating the sand and showing the acreccionary regime, in this area seems to be diminishing (Figure 4). The major use is in building and as firewood. Major threats to mangroves include over exploitation for firewood and clearing of mangroves for solar salt production (Barbosa et al, 2001). In this particular case, depicted in Figure 4, a major industrial unit has been implemented nearby, and should be checked the role developed by this industry on the *Mangrove* variation.

4. CONCLUSIONS AND REMARKS

The land cover mapping of 2007 ASTER image quantifies the distribution of patterns over the Beira area. It highlights the urban fabric where health issues can raise more concerns, as well as all the human induced activity. This includes the agricultural areas and sand mining sites. In a preliminary multitemporal approach it is shown the acrecionary regime of the Pungue River, W of Beira city as well as the shoreline changes located to S and NNE of the city. Further conclusions about the modifications on the shoreline are dependent of knowledge of the tidal movements. The *4.2.4 Mangrove* class introduced depicts the main distribution and the multitemporal analysis show the increase and decrease of this sensitive ecosystem over the area, the latter largely caused by human induced activities. The image has been classified with the support of field observations. Nevertheless, further field checking is still required particularly concerning the vegetation classes.



a)1991

b)2001

c)2007

Figure 3. Detail of the Pungue River.
PCA factors highligh the turbidity areas and implementation of vegetation.

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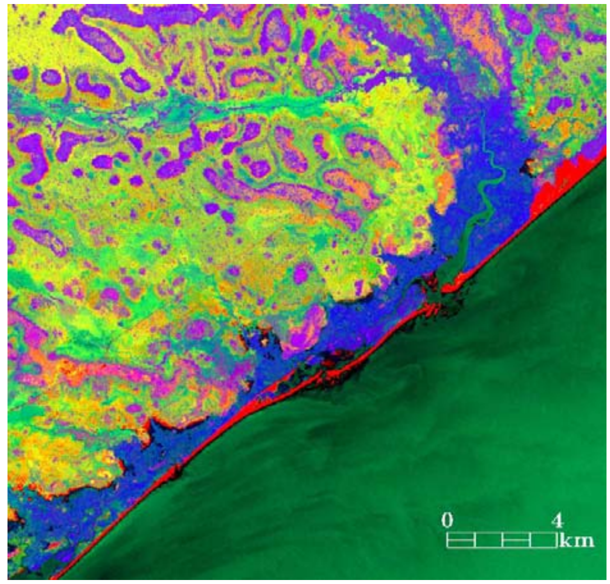
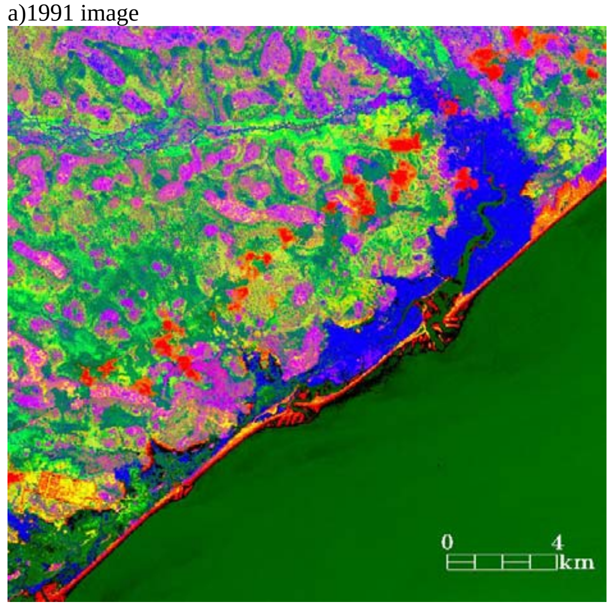


a)1991 image



b)2001 image

Figure 4. PCA defining the variation in *Mangrove* (blue/dark) between 1991 and 2001 image.

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