Remote Sensing, GIS Application and Simulation of Coastal Land Use Changes Based on Cellular Automata: A Case Study of Maputo, Mozambique

C. Henriques and J. A. Tenedório
1 e-GEO, FCSH-UNL/FA-UTL, Lisbon, Portugal
cdh@fa.utl.pt
2 e-GEO, FCSH-UNL, Lisbon, Portugal
ja.tenedorio@fcsh.unl.pt

ABSTRACT

Remote Sensing and GIS are widely known as tools/means for capturing and analysing geographical information which is indispensable for modelling land use changes in coastal areas. Many authors have written about this subject, but it rare to find applications which demonstrate three crucial aspects: the quality of the sparse geographical information existing in the official African institutes, the alternative technical means to obtain it, either by Remote Sensing or by GIS, and the relevance of using Cellular Automata (CA) simulation in very permissive contexts concerning land use change when there is a lack of environmental planning.

In this context this proposal for an oral presentation is based on the following items:
- Analysis of the quality of the existing geographical information and its consequences on the structuring of the information in a GIS for the simulation of scenarios of land use change.
- Using CA for the simulation of urban growth in coastal areas, namely the environmental fragile floodable areas. This presentation should, therefore, be structured through the following topics: presentation of the study area, nature and quality of the data, spatial analysis using GIS (land use change matrix), analysis of the conditions and determinants of the change, simulation with CA and conclusions where the potentials and limits of CA in coastal areas of Maputo City are outlined.

ADDITIONAL INDEX WORDS: Land use change, Model, Urban growth, African city

INTRODUCTION
The spatial expansion of cities and the concentration of population in urban areas are phenomenon associated with economic, social and environmental problems in an increasing number of countries, namely the African ones.

The spatial and temporal dimensions of land use changes in littoral areas of African cities are, however, poorly known.

Modeling land use changes along the coastal areas of these cities can provide useful findings and information for politicians and planners, anticipating and planning future uses.

This study advocates the use of GIS, Remote Sensing and Cellular Automata Technologies for promoting the sustainable development of the coastal areas of African cities, taking as reference the coast of Maputo City.

Maputo City is located in the southern part of Mozambique and lies between the River Infulene, the Espírito Santo estuary and the Indic Ocean and it has almost 30 km of coast line (Figure 1).

Figure 1. Maputo City location.
NATURE AND QUALITY OF THE DATA

In order to achieve the sustainable development of the coastal area of Maputo City we need to understand and characterize the variety and complexity of the different functions and interactions between the components which produce them.

The production of 5 land use digital maps (from 1964 to 2001) of the coastal area of Maputo (defined here as a 1 km buffer from the shoreline) was a stage in the process of understanding the social and temporal pattern of the land use along the coast of this city.

These maps were produced through geographical information technologies and therefore allowing different perspectives from the simple statistical analysis.

Among a large set of geographical documents existing for Maputo we had recourse to remotely sensed data namely aerial photos and high resolution satellite images for the production of the referred land use maps. There were available aerial photos for all the decades of the studied period but the scale was not always appropriated for the needs (to low in detail). Two satellite images from Ikonos (for the years 2000 and 2001) were also bought and together covered the study area.

Other sources of information available like topographical and thematic maps were used as a complement to the photo interpretation process and as a reference to the delimitation of the land use polygons.

The aerial photos were obtained in analogical media and scanned afterwards. As there were not available any flight parameters for the different set of photos it was not possible to orthorectify these images. However the distortion caused by the relief is not, in this case, very significant as it is a quite plane area.

The digital map of 1997 at 1/5000 was the main source for the terrain control points.

In spite of the automatic classification of digital images are actually very developed and spread through commercial software, its application in the identification of urban land use is still limited. In urban systems we can find social and economic activities with visible spatial repercussions which are complex and the existing software (even the more recent ones with object oriented algorithms) are insufficient for the level of interpretation required in this study.

Therefore we had recourse to the visual interpretation of the remotely sensed images with on screen digitizing of the land use polygons using a GIS software and going through 4 stages: the identification of the objects considering its basic characteristics; the interpretation through the analysis of relationships and observation of regularities and through the deduction of associations and correlations; the synthesis expressed by the delimitation of the polygons classified with a specific use; the registry in the alphanumeric database of the land use class of each polygon.

The guaranty of the quality of the land use maps, mainly concerning the thematic completeness and semantic accuracy is strongly dependent on the regular application of these procedures on the visual interpretation of the images. Deduction is the correct basis of the correct semantic identification and the identification of the objects from the primitives is the necessary condition to determine area of equal appearance. These areas of equal appearance should express the morphological and functional homogeneity that characterizes each land use polygon.

SPATIAL ANALYSIS USING REMOTE SENSING AND GIS

The qualitative and quantitative monitoring and assessment of the temporal and spatial transformations of the land use is a fundamental step for the understanding of the dynamics of the processes which lead to changes along the coastal areas and therefore to the geographical framing of the planning actions.

GIS and Remote Sensing are nowadays indispensable tools for the systemization and analysis of the land use change processes. In 1976 Anderson et al. (1976) already referred that: “Remote sensing techniques, including the use of conventional aerial photography, can be used effectively to complement surveys based on ground observation and enumeration, so the potential of a timely and accurate inventory of the current use of the Nation’s land resources now exists. At the same time, data processing techniques permit the storage of large quantities of detailed data that can be organized in a variety of ways to meet specific needs.”

Thus these technologies we produced 5 land use maps of the coastal area of Maputo City (Figure 2) and 4 maps of the land use change (Figure 3).

The analysis of this area with approximately 2690 ha was made for 26 land use classes. However we will only present here the maps and the quantified outputs obtained for 7 land use classes (as a result of a logical aggregation of the 26): Residential Areas (Center); Residential Areas (Periphery); Economical Activity Areas; Social Equipment, Infrastructures and Public Services Areas; Vacant and Derelict Urban Areas; Water Bodies and Floodable Areas; Other Natural, Semi-natural and Leisure Areas.

In 1964 the different land uses were distributed unevenly through the 7 land use classes. Almost 60% of the studied area was classified as natural land (Water Bodies and Floodable Areas; Other Natural, Semi-natural and Leisure Areas). The residential areas either from the center or periphery occupied only 10% of the 2690 ha. In 2001 a significant decrease of the natural areas and the increase of the residential areas were observed (Table 1 and Figure 4).

The coastal area of Maputo city has also an important part of its area occupied with Social Equipment, Infrastructures and Public Services Areas. In fact, the port and railway service area, the car racing circuit and the university campus represent a significant percentage of the coastal area.

Figure 2. Example of a Land Use Map of Maputo Coastal Area.
CONDITIONS AND DETERMINANTS OF CHANGE

The process of urban landscape change is directly related with complex political, economical and social systems. The actors of the urban development are variable and assuming different roles through the years. The understanding of land use change occurred in the coastal area of Maputo city needs a political, an economical and a social frame, needs the establishing of the relationships between state, market and foreign investment and needs their integration among the physical planning policies valid for each period of analysis.

In this study we only identified the main events in respect to its impact on the coastal landscape as well as the analysis of the urban legislation implementation.

SIMULATION WITH CELLULAR AUTOMATA

The production of a model that predicts the future land use based on the occurred transformations and based on some physical constrains (in the absence of a director plan) allow the construction of planning scenarios and alternative policies.

The integration between GIS and Remote Sensing allowed the detection, identification and quantification of the land use change through spatial analysis tools. Spatial modeling using Cellular Automata (CA) can be more powerful than using GIS because the spatial variables included in the CA are updated in a dynamic way during the iterative cycle which produces non deterministic results.

The model used in this study was based in 4 sequential phases: processing/codification of information to create spatial levels from the prevision variables with the land use change of each site of the area; integration of all information levels using multi-criteria analysis; temporal indexing (definition of weights and data sorting to create temporal series).

Table 1: Land Use between 1964 and 2001.

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<tr>
<td>Residential Areas (Center)</td>
<td>151,2</td>
<td>58</td>
<td>168,2</td>
<td>6,3</td>
<td>170,4</td>
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<td>Residential Areas (Periphery)</td>
<td>92,1</td>
<td>3,5</td>
<td>90,6</td>
<td>3,4</td>
<td>147,2</td>
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<td>Economical Activity Areas</td>
<td>131,0</td>
<td>5,0</td>
<td>192,0</td>
<td>7,2</td>
<td>250,1</td>
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<tr>
<td>Social Equipment, Infrastructures and Public Services Areas</td>
<td>579,8</td>
<td>22,1</td>
<td>702,2</td>
<td>26,2</td>
<td>720,8</td>
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<tr>
<td>Vacant and Derelict Urban Areas</td>
<td>84,9</td>
<td>3,2</td>
<td>61,3</td>
<td>2,3</td>
<td>54,0</td>
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<tr>
<td>Water Bodies and Floodable Areas</td>
<td>885,6</td>
<td>33,7</td>
<td>866,0</td>
<td>32,3</td>
<td>808,3</td>
</tr>
<tr>
<td>Other Natural, Semi-natural and Leisure Areas</td>
<td>704,2</td>
<td>26,8</td>
<td>598,2</td>
<td>22,3</td>
<td>526,1</td>
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CONCLUSIONS

Land cover and land use change detection is one of the most used skills for observing changes in coastal areas with very high urban growth rates. For monitoring purposes we demonstrated the use of remotely sensed data and of the still fragile capacity of the automatic processes for extracting in number and type the land use classes with an acceptable precision. This fact constrained us to visual analysis of aerial photos and of Ikonos and Quick Bird satellite images during an adequate lack of time necessary to register the coastal areas that suffered from a stronger pressure for changing to an urban land use. The GIS database provided topological coherency and precise quantification, at a 1/25000 scale, of the areas that change their land use. Until now there were not any similar studies available for the coastal areas of Mozambique.

The high rates of land use change in the coastal areas, namely in the fragile areas concerning the environmental point of view (floodable areas, beach systems, natural vegetation areas, etc.) testify the weakness of the urbanization control by the local authorities. This fact allows the spreading of the conditions that lead to the degradation of the coastal systems. Furthermore the coastal cities of Mozambique are an example of what should not be done concerning coastal protection.

Land use change observations shows: i) that the equilibrium of the coastal systems is deeply dependent on the urbanization control by the local authorities. If this local authorities do not have technical means for monitoring (GIS for example) and do not have environmental plans it will be difficult to have a coastal management based on principles accepted by the developed countries; ii) that the coastal impacts caused by urbanization, mainly by dense morphologies, aggravates the stress capacity of the systems; iii) that the human densification of the coastal areas in countries like Mozambique is twofold seriously: on one hand by the pressure it causes, on the other hand because is seldom followed by basic infrastructures to minimize the effects.

The simulation using CA reveals a great compliance with the actual trends: continuous and dense urban growth (mainly with residential areas), extensive urban occupation (suburban sprawl) with weak administrative control.

The ongoing projects look forward to test the strength of the CA model applied to African cities where legal regulation to land occupation is absent and where the mapping of the physical restrictions to land use change is inexistent.

LITERATURE CITED


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