*Remote Sensing for Science, Education, and Natural and Cultural Heritage*
Rainer Reuter (Editor)
EARSeL, 2010

# Mapping Urban Change to Plan the Future: Maputo City Change Model and the Municipal Structure Plan

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**Abstract.** The transformation process of Maputo City (in Mozambique) was observed and mapped over 5 decades (between 1964 and 2008) based on several different data sources (historical aerial photos, digital base maps, Quickbird and Ikonos satellite images). As a first result the time series of maps and mapping process in GIS will be presented. Special attention will be given to the fact that the nomenclature includes a morpho-functional semantics incompatible with an automated process using digital image processing. The Land Change Modeler for ArcGIS and for Idrisi Taiga was used for the quantification and localization of land use change. A second result will point out a dichotomy between the urbanized colonial city and the sprawling suburbs, which corresponds to the general model of land use organization and its change. Two types, which are also categories of change, can be identified: the central land use changes which have little significance but are important from a functional point of view; and the suburban land use changes, which involve vast areas of dominant residential land use. The third result corresponds to the analysis of these changes in the context of the Municipal Urban Master Plan, recently approved. The guidelines of this plan and the relevance of the thematic cartographic information on which it was based are discussed in this paper. The significance of the land use change model calculated for the plan proposal and the simulation of future scenarios for urban expansion will also be discussed. This paper focus on the importance of the land use maps produced, in the absence of other maps, to supply the Municipal Urban Master Plan and its permanent update based on satellite images that provide territory monitoring.

**Keywords.** Mapping, Urban land use, Change model, Maputo, Urban planning

## Introduction

The core idea of this paper is to demonstrate that the mapping of land use change for urban planning is very dependent on the thematic accuracy. In fact, the automatic extraction of geographical information by digital image processing is not currently adapted to the operational demands of master plans.

The various approaches to digital image processing (pixel per pixel, object oriented image analysis, feature extraction) are insufficiently developed to use their results for mapping the proposals for urban planning, and for modelling urban change trends. Map production based on visual image is still a very efficient solution mainly in geographical contexts where the urban heterogeneity is very high and where the results cannot have high levels of uncertainty.

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## 1. Land use maps 1964 – 2008

The elaboration of 6 land use maps of Maputo city (concerning the last 5 decades) was the first stage to understand the space-time pattern of the city's land use. These maps were produced with geographic information technologies, which enable a more dynamic analysis than the simple tabular data would.

The production of the land use maps of Maputo required a set of specifications, namely the minimum mapping unit, a classification system, and the criteria for individualizing different object categories.

### *1.1. Data*

The transformation process of Maputo City was observed and mapped over 5 decades (between 1964 and 2008) based on several different data sources (historical aerial photos, satellite images, and digital base maps).

#### *1.1.1. Historical aerial photos*

For the observation of the city over 5 decades we have resorted to existing panchromatic aerial photos for the years 1964, 1982, and 1991, and to orthophotomaps for the year 1973.

These images were available in analogical format and were later digitized with an appropriate scanner. Since flight parameters were inexistent it was not possible to orthorectify the aerial photos. However the distortions introduced by the relief in Maputo are of little significance given that it is a very flat city.

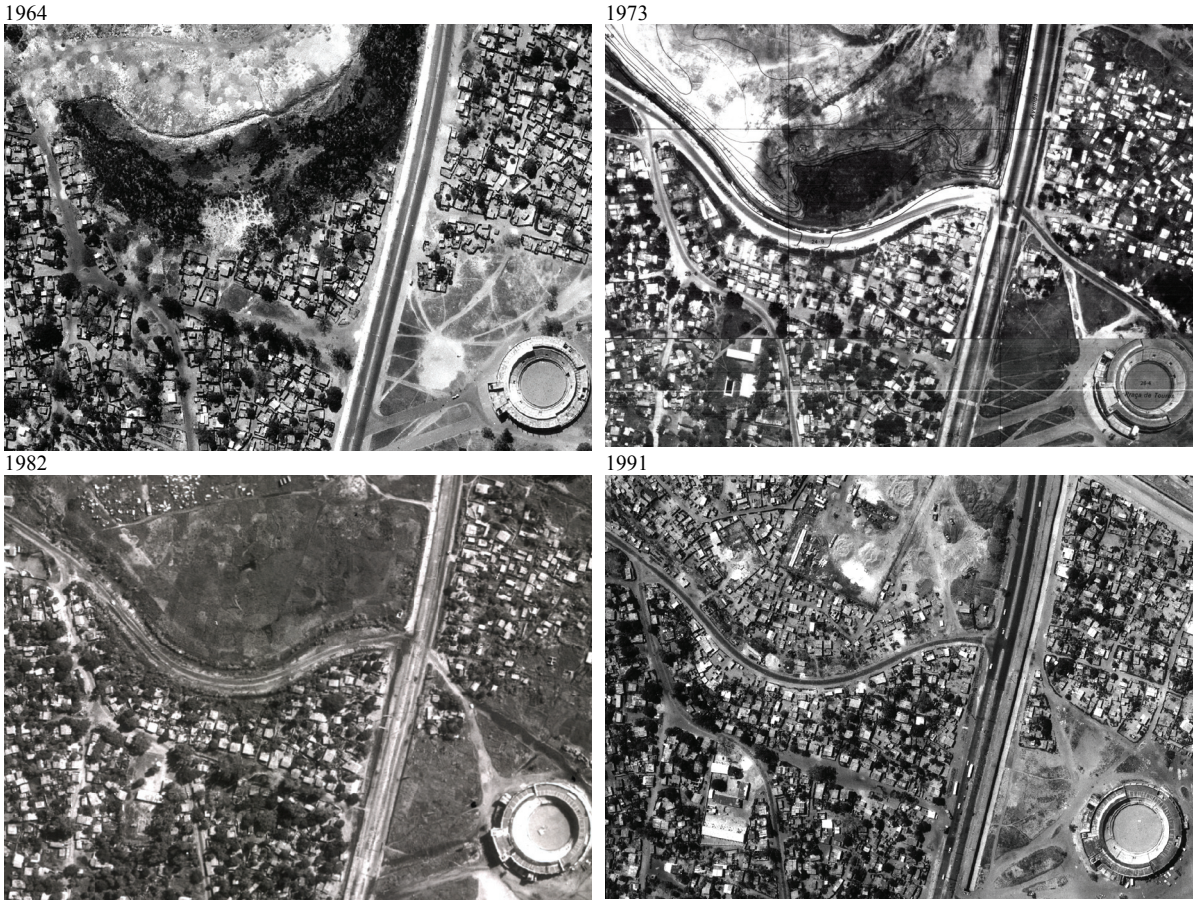


**Figure 1.** Sample of the aerial Photos.

### *1.1.2. High resolution imagery*

High-resolution satellite images were chosen to complete the data set for the observation of Maputo. For the year 2001 images from the panchromatic sensor of IKONOS were acquired providing a 1m spatial resolution image of the territory; for the year 2007 the QuickBird panchromatic sensor provided us with a 0.7 m spatial resolution image.


**Figure 2.** Sample of the satellite images

### *1.1.3. Digital base cartography and ancillary data*

Other geographical data, namely the topographical vector data and the former master plans, were used as a complement to the interpretation of the remotely sensed images and as a reference for the land use polygon digitizing.

### *1.2. Methodology*

The methodology followed a set of manual procedures of polygon digitizing of the land use polygons for all the studied periods.

Special attention will be given to the fact that the nomenclature includes a morpho-functional semantics incompatible with an automated process using digital image processing.

### *1.2.1. The nomenclature model oriented for urban planning*

The nomenclature developed for these land use maps is organized into two levels for planning and mapping purposes and also desegregated into a third level for a GIS database. This nomenclature is hierarchical; it includes both descriptive and parametric classes; and it assumed the following characteristics:

- Applicable to different types of source data and analysis periods
- Applicable to land use maps with different scales
- Based on the function associated with each land use
- Based on the genesis of the land use classes (organic or demarcated by public administration)

The second level, with 26 classes, could only be obtained by visual interpretation using deductive analysis from the primitives (shape, size, pattern, hue, texture, site, shadow, association) and in some cases resorting to ancillary data and field work.

This level allows a diachronic analysis required for urban planning and management, namely the production and monitoring of master plans.

### *1.2.2. Why visual image interpretation?*

The complexity and the heterogeneity of the African urban landscape as well as the detail needed for planning purposes were not compatible with image automatic classification. Some tests were made using commercial software with different classification algorithms (pixel oriented, object oriented), but the results obtained revealed an inventory of land occupation (Figure 3). The function and the genesis of the land use are omitted with this kind of classification, which made it useless for planning purposes (a master plan, for example).

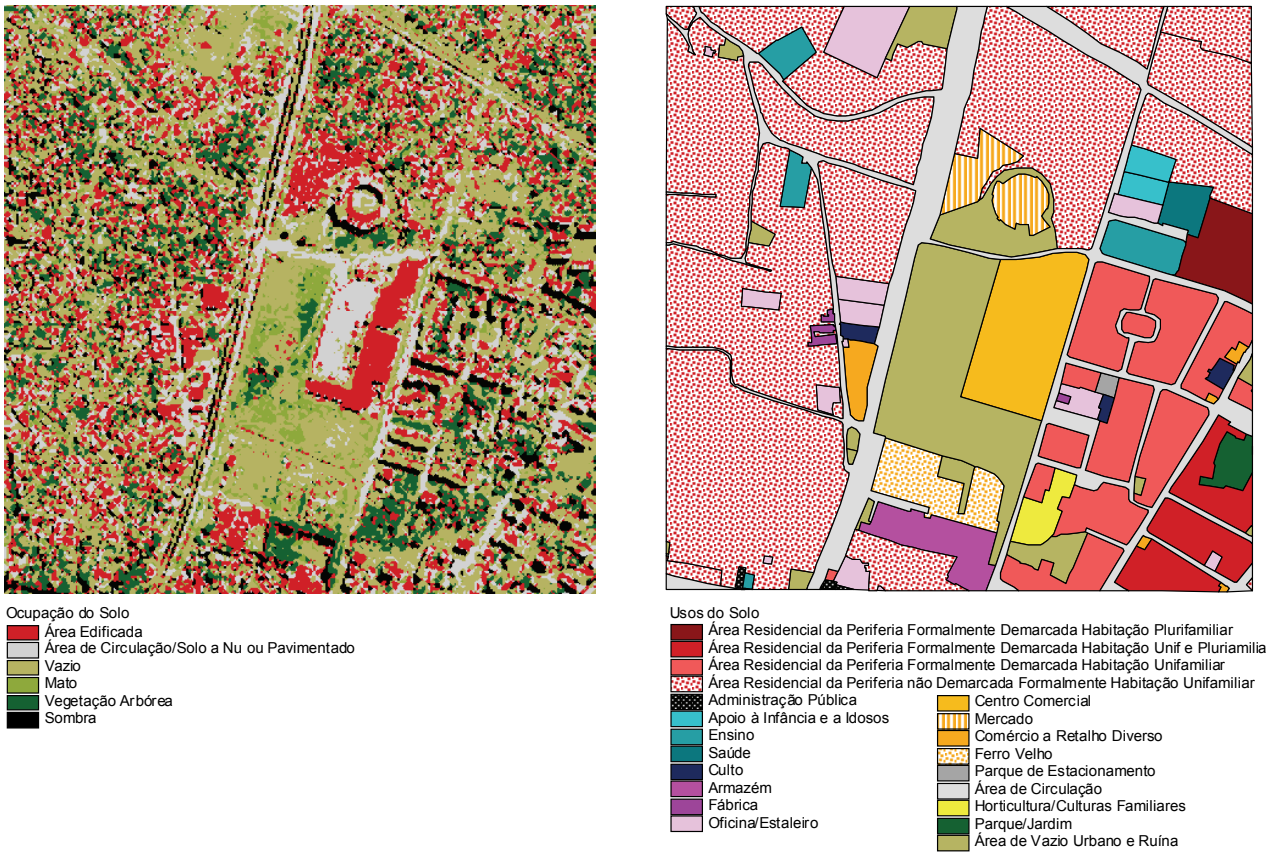


**Figure 3.** Land occupation obtained by ISOCLUST (left) *versus* land use obtained by visual interpretation (right) [1].

## 2. Land use change 1964 – 2008

Monitoring and qualitative and quantitative evaluation of the space-time transformations of land use is a fundamental stage to understand the dynamics of the processes that lead to urban landscape change, and therefore also essential for the geographic framing of planning actions.

### *2.1. Change quantification*

**Table 1.** Changed Area between 1964 and 2001

| Temporal Interval | Changed Area (%) |
|---|---|
| 1964-1973 | 16.4 |
| 1973-1982 | 17.7 |
| 1982-1991 | 23.3 |
| 1991-2001 | 23.0 |
| Total (1964-2001) | 80.4 |

Between 1964 and 2001 almost 80% of the territory of Maputo City changed its land use. After the 1980s the transformation process was more intense, mainly from the natural bush areas to the residential areas of the periphery.

### *2.2. A 'model' of land use change between 1964 and 2008*

A dichotomy between the urbanized colonial city (Residential Areas – Centre or *cement city*) and the sprawling suburbs (Residential Areas – Periphery) corresponds to the general model of land use organization and its change. Two types, which are also categories of change, can be identified: the central land use changes which have little significance but are important from a functional point of view; and the suburban land use changes, which involve vast areas of dominant residential land use.

- The land use persistence

The persistence analysis (Figure 4) shows that the formal Residential Areas in the *cement city* (centre of the colonial city) and the informal Residential Areas (Periphery) are the core of Maputo's urban structure.

In fact, the colonial city is the origin of urban growth in Maputo (concentration of economic activities and the political power) and the contiguous Residential Areas (*slums*) are the first fact of informal territorial expansion.

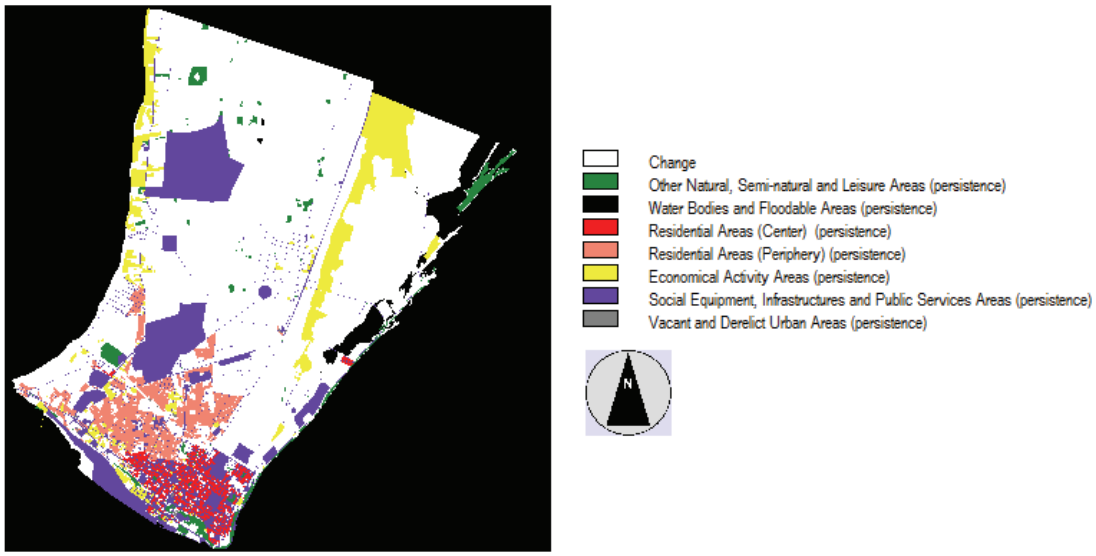


**Figure 4.** Persistence of land use classes between 1964 and 2008.

- The land use transition

The most important transition of land use (Figure 5) between 1964 and 2008 was from Natural, Semi-natural and Leisure Areas to Residential Areas (Periphery). The periphery of Maputo is an enormous coalescent city based on an informal residential land use not structured by any master plans. The urban growth was 'organic' and very dependent on the social and economic conditions (migration from rural areas to Maputo) of the population, and on the political system before and after the Independence in 1975.

Natural, Semi-natural and Leisure Areas is the land use class that most contributes to the net land use change, namely for Residential Areas (Periphery) and Economic Activities (Figure 6). In fact, between 1964 and 2008 the urban landscape transformation took place mainly in the vast natural bush areas. After 1964 Maputo city hinterland has been supporting the main territorial expansion of residential function.

**Figure 5.** Transitions from Other Natural, Semi-natural and Leisure Areas to Residential Areas (Periphery) between 1964 and 2008.

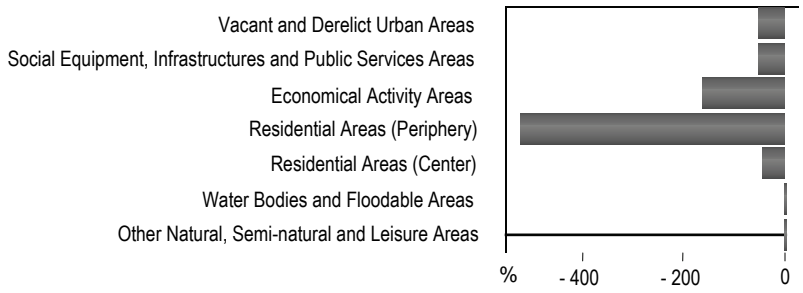


**Figure 6.** Contributions to net land use change experienced by Other Natural, Semi-natural and Leisure Areas between 1964 and 2008.

- Trends of land use persistence and transition

The general model adopted to study the land use transition was based on Land Change Modeler (LCM) for Idrisi Taiga and for ArcGIS 9.3. Idrisi's TREND function calculates a trend surface by using polynomial equations (from 1st to 9th order) for every class of land use transition and persistence, and interpolates surfaces based on those equations.

For persistence the number of cells for surface determination is 244200659, the goodness of fit (R2) is 4.77% and the F ratio is 6117630.14. For transition the number of cells for surface determination is 350044058, the goodness of fit (R2) is 4.03% and the F ratio is 7348871.47. The surface coefficients of trend surface (Table 2) are negative for all the transitions and null for all persistence.

Table 2. Surface Coefficients of Trend Surface Polynomial Equations for Spatial Data Sets (1964 and 2008)

| | b0 | b1 | b2 |
|---|---|---|---|
| All transitions | 21.7263 | -0.0004 | -0.0001 |
| All persistence's | 2.8290 | 0.0000 | 0.0000 |

In the African urban landscape the patterns of land use change can be complex and very difficult to explain. The pattern (broad overview) of all transitions and all persistence is derived from the surface created by coding areas of change with 1 and unchangeable areas with 0, and treating them as if they were values. The surface of persistence of all land use classes (Figure 6, left) shows an oriented trend decreasing from lower-left corner (major values) to upper-right corner (minor values).

Conversely, the surface of transitions of all land use classes (Figure 6, right) shows a generalized trend decreasing from upper-left corner (major values) to lower-right corner (minor values).

The simplified 'model' of land use change of Maputo between 1964 and 2008 may be described as: i) the persistence of land use dominates the south. In this urban sector the *cement city* and the slum suburbs polarize the persistence and increment the territorial expansion; ii) the transition of land use dominates the north and the center of the territory. In fact, the major transitions of land use classes may be justified with the gain of Residential Areas of Periphery (*caniço*). The spatial change trend from all land use classes (diversity of land use) to Residential Areas of Periphery (Figure 7) justifies the current mono-functional city based on an informal growth and homogeneous morphology.

Effectively the spatial trend from all land use classes to Residential Areas of Periphery, demonstrates the central tendency: in 44 years the city of Maputo grew in the geographical centre of its territory, between the *cement city* and the north boundary of the municipality.

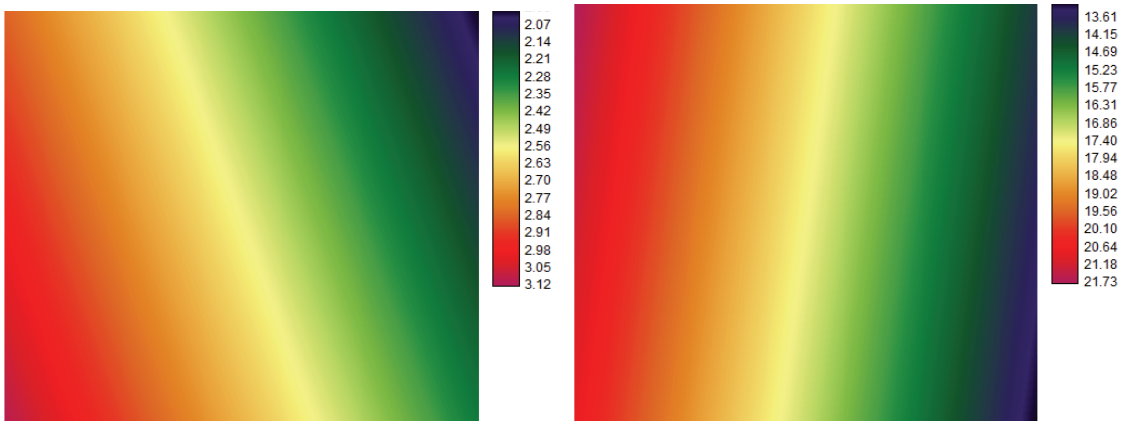


**Figure 6.** Trend surface of persistence of all land use classes (left) and trend surface of transitions of all land use classes (right) between 1964-2008.

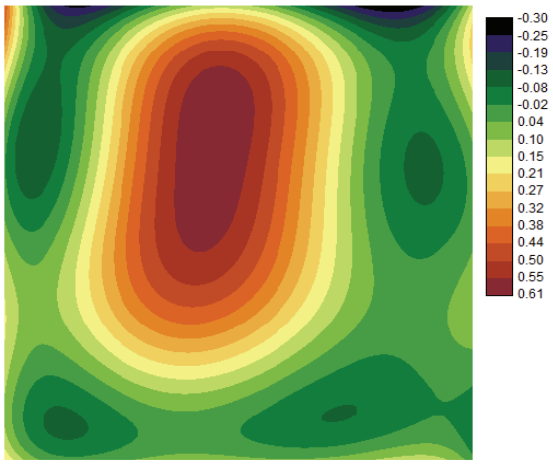


**Figure 7.** Spatial trend from all land use classes to Residential Areas of Periphery (polynomial order: 5$^{th}$).

## 3. Maputo City change model and the Municipal Structure Plan

Land use maps and land use change maps, produced within a research project, were used by the Municipal Council of Maputo to elaborate the Municipal Structure Plan (MSP). The operational use of these maps was possible due to the thematic accuracy of about 100% which could hardly be achieved with an automatic or semi-automatic extraction of the land uses from remotely sensed images.

These land use maps, based on a functional nomenclature, have given special attention to the representation of the different types of expansion of the informal residential areas. The proposals for densification of land occupation and for the supply of new urbanized areas were supported by these land use maps, and are clearly expressed both in the report of the current state of the city and in the justification report of the MSP [4].

The zoning plan of the MSP reveals planning strategies for changing the spatial trend from all land use classes to Residential Areas of Periphery (Figure 7). An example of this fact is the proposal for an expansion of the urban area in the northeast part of the city showing therefore the utility of mapping urban change through visual image interpretation.

Further research should be done to verify if the automatic image processing could be used, at least partially, for monitoring the actions established by the MSP.

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