

MONITORING AND ANALYSIS OF URBAN TRENDS OF GREATER CAIRO USING MULTITEMPORAL SATELLITE IMAGERY

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ABSTRACT

LANDSAT and SPOT satellite imagery are valuable tools to monitor and analyse trends in complex urban regions. In this study, the metropolitan area of Greater Cairo was examined because of serious problems caused by the rapid increase in population and the resulting dynamic development. The monitored period of 10 years required different sensor data for the time points in 1979, 1982 and 1988. Due to the necessity, a method was developed using a combination of unsupervised classification, image interpretation and overlay techniques to perform a post classification comparison. The resulting land-use/land-cover changes provide accurate information about regional development patterns. Thus, it is possible to point out some differences in development concerning trends on arable land and on desert land, as well as for different political units within the conurbation. Possibilities for the involvement of the results in the planning process are given.

This feasibility study shows that, especially for large urban areas with uncontrolled development, monitoring with multitemporal satellite data is, indeed, appropriate to meet planners needs if there is a lack of fundamental and up-to-date data.

Key Words: Multitemporal Satellite Imagery, Multisensor Data, Change Detection, Urban Development, Regional Planning

INTRODUCTION

Like many other metropolitan areas of the developing world, Cairo has had such a large increase in population that its inhabitants and its infrastructure are suffering the effects of uncontrolled development. For this reason, the fertile Nile valley, on which the Egyptian agricultural production is dependent, is getting progressively degraded as well. In response, the government has instituted master plans to decentralize the metropolitan area. The aim is to establish surroundings with dignity for people and to reduce the illegal use of arable land within the Nile valley. However, there is - as in similar regions - a substantial lack of fundamental information concerning the dimensions of the recent agglomeration as well as the speed and direction of the growth. Since the area is so large and is broken into a number of political units, this information is currently difficult to obtain.

In several studies concerning the same type of problems, aerial photos were used for the analysis of spatial development as well as a source of data within a GIS (see, for example, Lo & Shipman, 1990 or Nkambwe, 1991). Ehlers et al. (1990) used both SPOT data and aerial photographs to analyse regional growth in a similar situation. For the special situation of large conurbations such as Greater Cairo, satellite

imagery, as used in this study, provides an alternative solution to obtain adequate information for change detection.

DATA BASE

LANDSAT TM data were selected because of their high spatial and spectral resolution and because their coverage was large enough for our purposes. Unfortunately, prior to 1982 only MSS data is available. This imposed restrictions on spatial and spectral content which we had to deal with. Consequently, data from different satellite systems were used for the multitemporal image analysis: these are Landsat-MSS data from 1979, Landsat-TM data from 1982 and 1988. Additionally, panchromatic SPOT data from 1988 were used as a supplementary information source because of their higher spatial resolution.

The data acquisition dates for all these images are within a time span of three months as shown in Table 1. This means seasonal differences in vegetation or exposure may be ignored.

This data sequence provides a good profile through the 10-year development of the urban region as recorded by the satellites.

Satellite System	Acquisition Date
LANDSAT-MSS	03-22-1979
LANDSAT-TM	12-28-1982
LANDSAT-TM	01-11-1988
SPOT pan	01-22-1988

Table 1: Acquisition Dates for Satellite Imagery for the Case Study

In addition to these satellite data, topographic maps in the scale 1:25,000 were used, along with descriptions from the literature, photos and town plans, to obtain further information about the study area. Of particular note is that the most recent maps in the scale of 1:25,000 were produced during the years 1942-46.

DIGITAL DATA PREPROCESSING

For the combined digital processing of multiple images, geometric registration is necessary. First, the absolute registration of the SPOT data to the national Egyptian cartographical system was performed. Although the maps were out of date, 18 control points could be located both on the maps and in the satellite data. The georeferenced SPOT image was then used to co-register the other satellite data sets with an average root mean square error of less than ± 0.7 pixel. During resampling, the pixel sizes were also reformatted to 25 x 25 meter pixels to facilitate interpretation of the digital image. This pixel size is a good compromise between the ground resolution of MSS (79 meters), TM (30 meters) and SPOT (10 meters). Nearest neighbor resampling was used to assure that only original grey values were used for the subsequent classification.

Another preprocessing step was the reduction of redundant information. This was necessary due to the huge amount of data. The combined database contained seventeen bands for a study area of about 250,000 ha (even without the use of the thermal TM bands). For the reduction of the data, we followed an approach described by Chavez (1984) using a selective principal component transformation for TM data. In this approach, the first principal component of bands 1, 2 and 3 was calculated, as well as the first principal component of bands 5 and 7. These new bands were taken and used together with the original band 4 for the following image processing.

A modification of this transformation was used for the MSS data: the first principal component of the two visible bands was calculated, the other two bands were used in their original form. As a result, the basic data used in the image analysis described below were three sets of LANDSAT data with three bands each plus the panchromatic SPOT data. The result of these transformations was a data reduction of about 65 %.

Several digital methods for multitemporal image analysis or, rather, change detection are described (see, for example, Howarth & Boasson, 1983; Ueno et al., 1986; Singh, 1989). Most of them were developed for bitemporal analysis and only for data from the same satellite system. Therefore, the simple application of one of these methods was not appropriate. Another impediment was the special situation of the study area. For instance, a comparison of vegetation indices was not usable in this study for several reasons. The loss of vegetation on particular ground segments during one time period does not automatically indicate the build-up of these sites, as is usually interpreted. Because of the arid climate and the irrigation agriculture, the distinction of periods of vegetation is not clearly possible, especially since there are three to five harvests per year in the Nile valley. In addition, there are land acquisition projects at the margin of the valley with confusable signatures. It is also not possible to monitor the development of urban areas on desert land by comparison of the vegetation index.

Some other methods were tried, such as multitemporal band ratios of the transformed bands of the visible light. However, the poor results obtained for development on agricultural land as well as on desert land showed that no image enhancement procedure was appropriate.

In the end, a post classification comparison method was used. For that, the data first needed to be separated into the same land-use classes. Using an unsupervised maximum-likelihood method, each data set was classified into forty classes. It was then possible to interact by recoding, masking and re-classifying. With the help of cross-tabulations and supervised combinations of classes, the individual classifications were made as comparable as possible. The resulting classes were: water, arable land, built-up area and desert.

The classes resulting from the MSS data varied slightly from those obtained from the TM data because of the difference in spatial and spectral resolution. For this reason, an additional class had to be introduced. This class was then reversed in accordance with the multitemporal classification results of the TM data. For example, if one pixel of the additional mixed urban and agriculture land-use class has been classified as agricultural within the TM data for the subsequent time points, we reclassified it according to the more accurate and recent data.

Using the panchromatic SPOT data, the classification result was verified with a sequential statistical method described by Köhl (1989). Accordingly, the classification of the TM data from 1988 resulted in an accuracy of 82 %.

Because of shadows or because of the use of the indigenous building material, similar signatures for built-up and desert areas resulted in misclassifications. Therefore, the SPOT data were used to mask the rocky regions of the desert, resulting in further improvements.

Using this procedure, we obtained a combined accuracy of the three individual classifications of about 97%. That means that 97% of the pixels had been classified into a land-use class which directly represents a sensible sequence of utilization. The remaining 3% of the pixels were interpreted according to their most likely class or were declared as unclassified.

By overlaying the individual classification results, the multitemporal post classification comparison was obtained: the final change detection data comprise 13 classes of land-use/ land-cover changes (Table 2).

Cl.	1979	1982	1988
1	water	water	water
2	arable land	arable land	arable land
3	arable land	arable land	arable land
4	arable land	built-up area	built-up area
5	built-up area	built-up area	built-up area
6	med.den.b.u. area	built-up area	built-up area
7	arable land	built-up area	arable land
8	built-up area	built-up area	arable land
9	desert	desert	arable land
10	desert	built-up area	built-up area
11	desert	desert	built-up area
12	desert	desert	desert
13	unclassified		

Table 2: Multitemporal Land-Use/Land-Cover Classes

ANALYSIS OF RESULTS

For a planning basis, it is not only important to know the quantities of changes which are obtainable by statistical data, but also their spatial patterns. Imagery, as used in this study, provides this essential information as well.

As shown in Figure 1, the development of the urban area was along three main axes of the conurbation: a)

from the center to the pyramids of Giseh; b) from the center along the Nile to the suburb of Helwan and c) from the center into north east direction to the international airport.

Along the boundaries between the conurbation and the land under irrigation, the urban development was more or less like annual rings in trees. This is the result of the informal settlements which are always placed at the new boundary of the conurbation, particularly on arable land, to assure access to any existing infrastructure network. Here, the construction takes place on privately owned land but without official approval. Actually, the use of agricultural land for construction is forbidden by a law first passed in 1966 (Chaline, 1984).

In the eastern part of Cairo, the urban development is occurring in a completely different manner; because of the rocky region or already existing industrial areas, it is not possible to place the new settlements adjacent to residential areas. As a result, development does not occur spontaneously on the more peripheral sites in the desert. For that reason, the state intervenes by establishing development projects on desert land (Meyer, 1989). These projects have a much greater extent than the private projects, even if they are not as efficient as the informal settlements in accommodating the inhabitants (Fig. 1).

Other spatial development tendencies are notable. They are marked with arrows in Fig. 1. The direction of these arrows depends on the distinct spatial land-use changes within the two analysed time periods.

After the image processing was completed, the built-up area of the conurbation of Greater Cairo (which was only a portion of the study area) was calculated 26,900 ha for 1979, 34,400 ha for 1982 and 39,700 ha for 1988. In the entire study area, the average annual area under construction in the desert (1979-82: 3,030 ha/yr; 1982-88: 910 ha/yr) was greater than on the arable land (Fig. 2). This is mainly due to the development along the eastern border of the metropolitan area as mentioned above. On the arable land there were about 1,050 ha/yr (1979-82) and 770 ha/yr (1982-88) which were involved in the conurbation. This proves, that the legally forbidden development on arable land still is not under control.

Governmental District	Arable Land in the Study Area					
	Total 1979	Loss 1979-82	Total 1982	Loss 1982-88		
	ha (=100 %)	in ha/yr	in %/yr	ha (=100 %)	in ha/yr	in %/yr
Giseh	33150	- 450	- 1.4	30960	- 320	- 1.3
Qualiubiah	33790	- 520	- 1.5	32230	- 400	- 1.3

Table 3: Development in Political Units on Arable Land

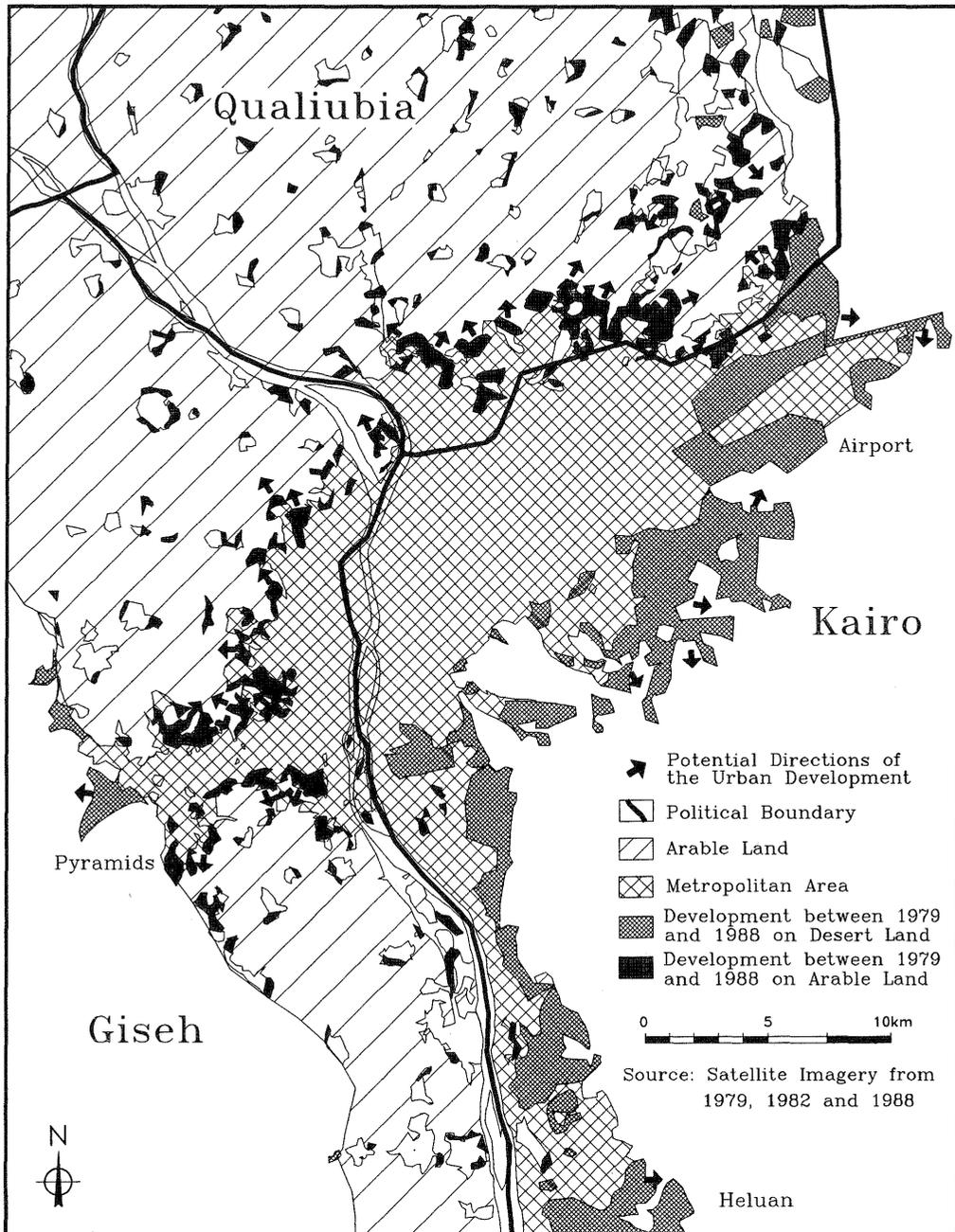


Figure 1: Urban Development of Greater Cairo

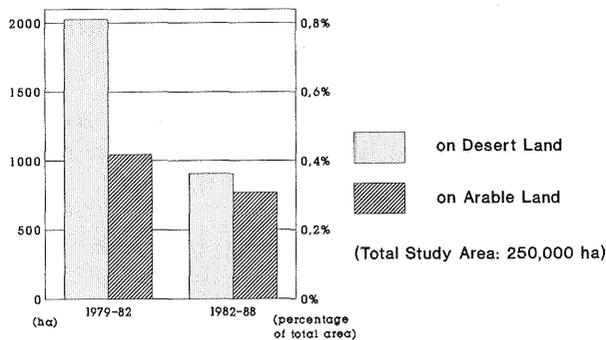


Figure 2: Average Annual Increase in Development

The metropolitan area of Greater Cairo consists of three different governmental districts: a) Cairo, b) Giseh, on the west shore of the Nile and c) Qualiubia in the north (see Fig. 1). There are some differences in development particularly concerning the actions on irrigated or desert land for these administrative parts. In the metropolitan area of the government of Cairo there is almost no irrigated land left for agriculture. However, the consumption of arable land still is going on in the two other governmental districts. The large areas under construction in the agricultural land at the periphery of the agglomeration and around the smaller towns and villages in the vicinity underline the severe problem of the loss of arable land (Table 3).

It should be noted that ground truth of the results is necessary for definite change detection. Aerial photographs of the monitored periods should be used to prevent erroneous interpretations. However, for this study it was not possible to obtain accurate land-use information for the time points due to a lack of resources.

INTERPRETATION CONCERNING PLANNING AND OUTLOOK

To remedy the multiple effects of the uncontrolled development of the conurbation, the planning authorities have prepared three master plans (the most recent dated in 1981). Several planning strategies are being followed to solve the land-use conflicts and to improve the living conditions by relieving the population pressure in the urban center through the establishment of new cities and settlements.

One important strategy for the control of the development of the conurbation is the "ringroad". The primary aims of which are to provide relief for the traffic infrastructure in the center of the conurbation, to open the eastern desert areas up to development and, most important, to form a barrier to the development of arable land. In the area encompassed by the road, development may continue. Beyond the ringroad, the destruction of the remaining agricultural land should be stopped. The ringroad will finally enclose approx. 42,000 ha, of which 66% was already built up in 1988 (1982: 58%; 1979: 49%). In 1988, there was still 9% used for agriculture and 25% was desert land. Because of rough terrain, however, this desert land is only partly a potential area for development.

Making a scenario using the current speed of development and the increase of population, all the included area would be exhausted by the year 2000. Continued in this direction, the effects of easing the development process by some other planning strategies, such as new towns in the desert, might be examined. With an increased density of information from ancillary source and continuing monitoring by satellites, it is possible to make more definite statements concerning the tendencies of spatial development.

This study indicates that effective techniques can be developed to use multitemporal and multisensor data to establish a database for inclusion in a GIS which can then be used to address the problems of uncontrolled development in complex urban regions.

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