UNIVERSITY OF NEWCASTLE

MONITORING, MODELLING, AND MANAGING URBAN GROWTH IN ALEXANDRIA, EGYPT USING REMOTE SENSING AND GIS

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ABSTRACT

Alexandria is the second largest urban governorate in Egypt and has seen significant urban growth in its modern and contemporary history. This study investigates the urban growth phenomenon in Alexandria, Egypt using the integration of remote sensing and GIS. The study has revealed some significant findings that can help in understanding the current and future trends of urban growth in Alexandria. For demographic analysis, growth rates dropped off between 1976 and 1996. In the same manner, Alexandria's population decreased from 6.33% of total country in 1976 to 5.6% in 1996. Family size and crowding rates are declining as well. Moreover, the role of internal migration has changed and the city sends out more population than it receives. In addition, there is a clear decline in population density in the city's core, while city fringes have witnessed increases in their density.

For physical expansion, Alexandria experienced a long history of deterioration from the end of the Roman era until the French expedition's departure in the beginning of the 19th century. Alexandria began to revive again from the first half of the 19th century during Mohamed Ali era up to date. The city expanded in all available directions. Therefore, the side effects of urban growth commenced to develop in some parts such as informal housing on the cultivated land in the east and southeast of the city.

The urban physical expansion and change were detected using Landsat satellite images. The satellite images of years 1984 and 1993 were first georeferenced, achieving a very small RMSE that provided high accuracy data for satellite image analysis. Then, the images were classified using a tailored classification scheme with accuracy of 93.82% and 95.27% for 1984 and 1993 images respectively. This high accuracy enabled detecting land use/cover changes with high confidence using a post-classification comparison method. One of the most important findings here is the loss of cultivated land in favour of urban expansion. If the current loss rates continued, 75% of green lands would be lost by year 2191. These hazardous rates call for an urban growth management policy that can preserve such valuable resources to achieve sustainable urban development.

The starting point of any management programme will be based on the modelling of the future growth. Modelling techniques can help in defining the scenarios of urban growth. In this study, the SLEUTH urban growth model was applied to predict future urban expansion in Alexandria until the year 2055. The application of this model in Alexandria of Egypt with its different environmental characteristics is the first application outside USA and Europe. The results revealed that future urban growth would continue in the edges of the current urban extent, which means the cultivated lands in the east and the southeast of the city will continue to lose more day by day from their area. To deal with this crisis, there is a serious need for a comprehensive urban growth management programme that based on the best practices in similar situations. Good urban governance, public participation, using GIS and remote sensing, and decentralisation (among others) are found to be the most important principles for such programme.

Dedication

I would like to dedicate this work to my father who died just before seeing the harvest of his life journey. May Allah forgive and show mercy to him, Amen

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1. CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter acts as an approach to introduce the basic elements of the whole Thesis. Clarifying definition of urban growth comes in the beginning making a clear distinction between similar terms. The history of urban growth will be reviewed briefly to understand the spatial differences of this phenomenon between the world regions. As the main methods of investigating urban growth in this study are remote sensing and GIS, definitions and applications of both, especially in urban applications, will be underlined. A further discussion about the potential of integrating remote sensing and GIS follows. The statement of the problem of this study is presented, followed by the research objectives and questions. The context of the area of study is presented also. The chapter ends with the thesis plan.

1.2 Urban growth definition

There are many tangled terms used in the context of urban studies such as urban development, urban growth, and urbanization. It is instructive in this introduction to draw a clear and firm distinction among these terms. Clark (1982) defined *urban development* as the process of emergence of a world dominated by cities and urban values and the main processes of urban development are urban growth and urbanization. *Urban growth* is a spatial and demographic process and refers to the increased importance of towns and cities as concentrations of population within a particular economy or society, while *Urbanization* is a spatial and social process which refers to the change of behaviour and social relationships which occur in society as a result of people living in towns and cities (Clark 1982). This study aims at dealing with urban growth with its spatial and demographic elements.

1.3 History of urban growth

This review of urban growth history is based mainly on Clark's study (1982). There are two major changes in urban growth history; the first is the agricultural revolution, which occurred in the Near and Middle East around the fifth millennium BC and is linked with the first emergence of towns and cities such as urban centres in the Nile, Tigris and Euphrates valleys. The second is the industrial revolution that occurred first in Britain in the late eighteenth century and led to the growth of the large modern metropolis.

The agricultural revolution means the system of organized agriculture, which replaced a nomadic and predatory way of life. This organized agricultural system led to a significant increase in food production that was used to support the establishment of houses for people who worked in non-agricultural activities, and this led to the emergence of early urban centres along the river valleys. These first urban centres were smaller than many villages today, but were more densely populated. The level of agricultural productivity in the local area closely governed the size of cities. If there were any agricultural surpluses, these excesses were exported to other areas using early transport means. Within the city walls, the early cities tended to be divided into sections by walls and the distribution of population from the city centre was directly linked with power and wealth, with the poorest living furthest out.

The industrial revolution led to rapid urban growth as a direct response to the consequence of changes in the nature and scale of industry. The economics of manufacturing and transport favoured the closest industrial locations to energy sources leading to the emergence of coalfield cities first in Great Britain and subsequently in northwestern Europe and the northeastern USA.

At the beginning of the 20^{th} century, 150 million people lived in urban areas, representing less than 10% of the world's population. At the end of the 20^{th}

century, the world's urban population has increased twenty fold to nearly 3,000 million (UN 2001).

Africa and Asia are expected to experience rapid rates of urbanization and urban growth between 2000-2030. By year 2030, 55% of African population will live in urban areas. In the Middle East and North Africa, 70% of the population will be urban by 2020. Therefore, cities of the region will have to face sustained high rates of growth. The current and estimated growth has been related to political turmoil and dependence on exports of oil and labour (UN 2001).

In Egypt, 43% of population was urban in 1996 (CAPMAS 1999), and it is expected to be 59.9% by 2030 (UNCHS 2002). Alexandria is one of the four Egyptian governorates that are urban 100%.

Contemporary urban growth in the developing countries differs from the early 20th century trends in Europe and the United States in at least five key respects: It is taking place at lower levels of economic development; it is more dependent on changes in the international economy; it is based on lower mortality and higher fertility (high natural increase); it involves larger overall numbers of people; and finally governments have intervened to modify it (UN 2001).

1.4 Remote sensing and GIS urban applications

1.4.1 Remote sensing applications

There are many definitions for Remote Sensing as almost every textbook on the subject carries a definition. All agree on identifying the central concept of remote sensing as "the gathering of information at a distance". (Campbell 1996, Lillesand and Kieffer 1994, and Lo (1986).

Campbell (1996) refined his remote sensing definition in terms of exclusion of some applications that could be involved in wide-ranging definitions (such as sensing the earth's magnetic field, cloud patterns, or the temperature of the human body) and omission of some instruments that collect data at a distance but do not form images (such as certain lasers). The aim of this definition is to focus only on the surfaces of land and water of the earth. Campbell (1996:5) defined what we can call "*the earth's remote sensing*" as;

> *"... the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface."*

As the field of this study is part of the Earth's land and water, and we apply images acquired from certain sensors, therefore, it is convenient to adopt such a definition in this study.

Remotely sensed images provide a universal resource that is able to supply repetitive data for any area of interest. The availability of such resources offers a great chance to remote sensing applications especially urban applications. Remote sensing data can replace traditional data that is in use by urban planning departments especially in the developing countries. Therefore, urban planning departments will have to learn to utilize these useful properties and make changes in their current approaches to planning.

There are very few endeavours to review remote sensing urban applications. In this study, the review of such studies is mainly based on the research carried out by Usher (2002). Remote sensing can provide answers to urban studies needs. Remote sensing with multi-temporal analysis gives a unique perspective of how cities evolve. Moreover, remote sensing methods can be employed to classify urban land use types in a practical and economical mode over large areas. Each satellite image characterises the land use/cover situation at a certain time, while comparing images of different dates (temporal analysis) helps in assessing changes within an area of interest. Moreover, satellite images can be used to establish land suitability for future development, monitor urban physical expansion and identifying changes in land use/cover.

In traditional planning approaches, land use data is assembled manually from hard copy maps; therefore, it consumes an extensive time to acquire complete and accurate information, and due to the changing dynamics in the land use patterns the results were not applicable for very long. Therefore, remote sensed data can be a valuable tool for the same applications.

Urban remote sensing applications involve mainly land use/cover classification and change detection applications. Classification studies focus on distinguishing the areas according to a predefined land use/cover classification scheme, while change detection applications are concerned with producing sensible information about land use/cover changes and monitoring urban expansion for preparing policies in order to foresee problems that may result from growth.

Remote sensing urban applications started as early as 1858 when parts of Paris were studied by a camera carried on a balloon (Sherbinin *et al.* 2002). Forster (1983) claimed that the first attempt to examine the full potential of aerial photography in urban analysis was in 1948 by Branch (Branch 1948). In the 1950's, aerial photographs were used to classify land use and provide a source for generating detailed information on land use such as the type (e.g., commercial, industrial, residential), density, size, distance between structures, and vacant land area (Coleman and Rogers 1956). In addition to aerial photos, satellite and multi-channel radar imagery have been revealed to be convenient resources for classification of urban areas (Carter and Gardner 1977) and (Bryan 1975).

Classification of land use/cover using remote sensing imagery forms a significant part of remote sensing research. Classification studies have been focused on developing methods for supervised and unsupervised classification from imagery using predefined computer-based algorithms. The main intention is to categorise spectral and spatial features that can be used to classify land use/cover classes in the image. The major obstacle here is there is no one method or mixture of methods is best suited for all sensor imagery or applications.

Erb (1974) reported the early urban research using Landsat data (Forster 1983). He used both supervised and unsupervised classification techniques to define land use/cover categories. He found that separating residential classes with an acceptable accuracy was impossible because of the confusion with other land uses (Forster 1983). Forster (1983) reported the results of study carried by Todd and Baumgardner (1973) where innovative numerical techniques such as mean, range, and standard deviation were used to distinguish different classes. They found that using means and standard deviations in the infrared bands was useful for land use separation.

In terms of sensors, Williams *et al.* (1984) claimed that the spatial resolution of Landsat (TM) images (30 meter) presents considerable enhancements in classification accuracy when compared to Landsat (MSS) data due to the added spectral bands. Toll (1984) assessed simulated Landsat TM data comparing it to Landsat MSS in its capability to classify land use/cover using the first two levels of the Anderson classification scheme (ANDERSON *et al.* 1976). The classification accuracy of those levels was higher for the Landsat TM simulator channels than for the Landsat MSS channels. This was due to the increased accuracy of the TM channels for vegetation, agricultural and rangeland. However, there was no difference in accuracy of classification of urban areas at Level I for both TM and MSS. Toll (1984) claimed that the higher classification accuracy of MSS for the residential classes was accredited to the decrease in the urban area complexity. This was achieved through the averaging of the spectral response that was derived from the enlarged field of view of the Landsat MSS when compared to the simulated Landsat TM. Landsat TM data provided higher classification accuracies for less heterogeneous classes, such as commercial and industrial complexes, rangeland. Toll (1985) confirmed that use of image processing methods such as median filtering, subclass categorization, and bi-temporal classification would improve the classification accuracy of the Landsat TM where there is spectral heterogeneity between classes.

Khorram (1987) claimed that Landsat TM image data produced better classification accuracy than Landsat MSS data. Landsat TM data added better spectral and spatial resolutions to provide additional land classification information over Landsat MSS data. These improvements are apparent when Landsat TM data is used for regional land use mapping and planning activities. In general, Landsat satellite data (MSS or TM) presents many benefits over aerial photography in accessibility, cost, data processing, and statistical analysis.

SPOT Multi-spectral data was recommended by several research studies for use in distinguishing and classifying urban areas (Baraldi and Parmiggiani, 1990; Martin and Howarth, 1989). In spite of the resolution of the SPOT data (20 meter) was better than that of Landsat TM (30 meter), these studies demonstrated that this enhanced resolution was satisfactory for urban change detection applications but insufficient for classification of urban areas. Bessettes *et al.* (1996) unified multi-spectral and panchromatic SPOT data to produce a panchromatic imagery of improved spatial resolution of 10 meter. However, the investigators faced difficulties in classifying minor classes within urban areas. The similar trouble was experienced by Alwashe *et al.* (1988) and Baudot *et al.* (1988) in their investigations of combining SPOT panchromatic data with Landsat TM data to accomplish enhancements in both spatial resolution (from SPOT-PAN) and spectral resolution (from Landsat TM).

The overall resolution of the sensors has improved over the years. However, researchers yet struggle with identifying appropriate approaches for accomplishing accurate classification. That is because enhancements in resolution result in spectral heterogeneity in urban areas demeaning classification (Martin and Howarth, 1989). The diversity of surfaces with different spectral reflectance resulting in an overlap of the spectral signatures of the various land use/cover classes can cause this spectral heterogeneity. Sadler (1991) suggested smoothing the images before classification using a 3x3 or 5x5 median filter as this led to achieve 15% accuracy improvement in his work with SPOT-HRV images. Hung and Ridd (2000) used an approach based on the V-I-S model (Ridd, 1995) that classifies the percentage of each type of six classes that is implied in each pixel in an image presenting further information not obtainable from other approaches which consider a pixel is a member of only one class.

In addition, spectral heterogeneity reduces the utility of per-pixel approaches for urban areas classification. Fung and Chan (1994) tackled this trouble by suggesting the idea of spatial composition of spectral classes utilising spatial and structural data to present information required to investigate structural composition of heterogeneous land use and land cover types. The major improvement of this method is that various land use/cover types have different spatial composition of spectral classes. This information helps in distinguishing land use/cover types which are heterogeneous and whose spectral properties are identical.

Using knowledge-based systems is another direction to enhance classification accuracy. These systems allow the use of spectral, geometric, and/or contextual information to carry out the classification providing a method that approximates visual interpretation methods (Argialas and Harlow, 1990; Mehldau and Schowengerdt, 1990; Tailor et al., 1986; Johnsson, 1994). Johnsson (1994) developed a knowledge-based system that can classify urban areas from multispectral SPOT data. This developed system is based on the idea of describing built-up areas by the composition of small segments that correspond to the different land cover classes not by its overall spectral signature as it is spectrally heterogeneous. Frate and Lichtenegger (1999) employed neural networks to classify radar (SAR) imagery and they achieved some success but the final number of classes was limited to four, which is not a feasible for planning purposes.

Change detection is the method that has been used to identify the variations in the situation of an object or phenomenon by monitoring it at different stages in time (Ridd and Liu, 1998). Traditional method of change detection is performing visual comparison of multi-date large-scale aerial photographs. This approach can map changing patterns within an urban area and provide planners with a means for analysing urban growth dynamics and managing potential expansion based on models developed to predict growth (Witenstein, 1956; Richter, 1969). Nevertheless, this method is time-consuming, exhausting, and subject to such problems as errors of omission, unavailability of specific photographs and expensive interpretation mechanisms (Ridd and Liu, 1998). Land use data can also be updated using population and housing data obtained from census and local government records such as property tax assessments (Parson *et al.* 1995), but again, these approaches also experience from the same problems of traditional change detection method.

Monitoring urban growth using satellite images provides a means for acquiring imagery on a regular basis presenting timely information that can be combined with ancillary data to monitor urban change and distinguish expansion models (Khorram 1987), (Harris and Ventura, 1995). Acevedo et al. (1999) used satellite images and aerial photography along with historic maps to create database representing land use change to model urban growth and land use change for predicting growth scenarios.

Change detection methods using satellite images can be categorised as either pair wise (using two images from different dates) or multi-temporal (using many images from more than two dates) (Dunajcik and Hipple 1999). Universal approaches for detecting land use/cover change comprise image overlay, image differencing, image ratioing, change vector analysis, image deviation, principal components analysis, direct multi-date classification and post-classified comparison (Coulter *et al.*, 1999; Dunajcik and Hipple, 1999).

Ridd and Liu (1998) evaluated the performance of four methods in their ability to detect land cover/use changes, particularly the transformation from farmland to residential and commercial developments. They used bands 1, 2, 3, 4, 5, and 7 of Landsat TM imagery utilizing image differencing, image regression, tasselled-cap transformation, and their new method based on chi-square transformation. They identified seven various categories of change (e.g., land to construction site, construction site to new residential, etc.). The methods were tested in their capability to detect each category. The result illustrated that there is no method functioned best in all cases and performance was quite mixed specifying the complexity in developing a single dynamic method.

Because of the limitations of conventional change detection methods, an artificial neural network (ANN) method was used in some studies with positive results (Gopal and Woodcock 1996), (Bruzzone *et al.* 1999), and (Dai and Khorram 1999). However Liu and Lathrop (2002) claimed that ANN methods requires intensive training with high costs. This represents a restriction for their practical applications.

In the same manner of using different sensors in classification applications to determine the appropriate spatial and spectral resolution, several studies have been carried out over the years using a diversity of sensor systems. Ehrlich *et al.* (1999) used IRS-C satellite images with 5.8-meter spatial resolution to produce land use/cover data by machine-assisted photo interpretation. Declassified intelligence satellite imagery and aerial photographs provided historical data. They succeeded in identifing changes for a number of urban areas throughout Europe using automatic change detection techniques based on texture analysis. However, they also discovered that ancillary data was necessary to distinguish between the dense residential class and the commercial and services classes.

This approach characterizes pressure indicators as a basis for comparing features of urban growth across multiple cities.

In addition, Coulter *et al.* (1999) used imagery of three different spatial resolutions (1, 5, and 10 m) to evaluate the ability to detect, define, and compute changes in specific features (e.g., roads and commercial, residential, and office buildings). Changes in features were underlined using multi-temporal differencing, but the boundaries of these features could not be accurately decided. They observed that detection of changes in the specific features requires highly precise geometric registration of the imagery. In addition, they tested semi-automated processing procedures for change feature extraction and found that most problems were associated with incomplete classification of the whole extent of a feature.

The merging of SPOT Multi-spectral and panchromatic data led to enhanced Multi-spectral images of 10m resolution that can be used for visual land use/cover interpretation and urban growth detection. These combined images provide land use/cover data at enhanced spectral and spatial resolution (Ehlers *et al.* 1990).

Park and Tateishi (1998) investigated the combination of the spectral information from Landsat TM with spatial information from the Russian 2-meter satellite DD-5 and 5-meter panchromatic data from IRS-1C. They suppose that multi-source imagery with moderate spatial resolution may improve the final output made available to policy makers and planners. They endeavoured to detect the change in land use/cover from agricultural land to a construction site or housing development using the combined images. The DD-5 image was used to register the data from IRS-1C and Landsat TM and assisted as a foundation for detection of the different buildings and other constructions. They faced frequent difficulties involving spectral heterogeneity and the uncertainty caused by the attendance of shadows in the imagery.

Masser (2001) claimed that some of the available sensors such as the SPOT panchromatic system (10m resolution) and the Indian IRS (5.8m resolution) can produce maps from a scale range between 1:50,000 and 1:25,000, while the IKONOS system (1m resolution) can produce maps at 1:10,000 scale. Therefore, he expects the possibility of monitoring urban land use changes throughout the world with high accuracy over the next 10-20 years. This expectation is very important for many rapidly growing urban areas in less developed countries that suffer lack of information resources.

1.4.2 GIS applications

A Geographical information system or GIS is essentially a collection of computer hardware and software designed to capture, store, retrieve, analyse and display large volumes of spatial and tabular data obtained from a variety of sources (Aronoff 1989).

Urban planning is one of the main applications of GIS. Urban planners use GIS both as a spatial database and as an analysis and modelling tool. The applications of GIS vary according to the different stages, levels, sectors, and functions of urban planning. With the increase in user-friendliness and function of GIS software, and the marked decrease in the prices of GIS hardware, GIS is an operational and affordable information system for planning. It is increasingly becoming an important component of planning support systems. Recent advances in the integration of GIS with planning models, visualization, and the Internet will make GIS more useful to urban planning. The main constraints in the use of GIS in urban planning today are not technical issues, but the availability of data, organizational change, and staffing (Longley *et al.* 1999). For this study, GIS is specifically linked with remote sensing.

1.4.3 Integration of Remote sensing and GIS

Mesev (1997:167) claimed that the term "Remote sensing and GIS integration";

> *"..has been used to refer to any type of linkage between RS and GIS, ranging from seamless and hybrid RS-GIS databases, through implicit Boolean links, to cursory discussions on data sharing."*

During the 1980s, the integration between remote sensing and GIS was very difficult as there were several technical problems such as the lack of compatible data structures between GIS and digital image analysis computer programmes (Jackson, 1986; Wilkinson and Fisher, 1987; Ehlers *et al.*, 1990) as most GIS systems at that time were vector based. Therefore, remotely sensed data with its raster features were excluded from such systems (Zhou 1989). However, the 1990s saw the integration possibility between Remote Sensing and GIS as there are many GIS systems that can manipulate raster-based data such as Arc/Info, and many image processing systems such ERDAS Imagine incorporate GIS functions.

Remote sensing technology provides a useful means for supplying up-to-date information on the activities within an urban environment. However, there is a need to interface remote sensing with geographic information systems (GIS) technology to provide the information and analysis capabilities that would best benefit planners and modellers (Baker *et al.* 1991; Sadler 1991).

Therefore, researchers have explored the use of ancillary data in combination with satellite images to improve change detection and classification of urban areas. A possible source of this ancillary data is the multiple data layers stored in GIS databases maintained by users such as the metropolitan planning organizations (Coulter *et al.* 1999).

Assessment of the various approaches used demonstrates that the different methods can be regarded as either pre-classification stratification, classifier modification, or post-classification sorting (Hutchinson, 1982). Harris and Ventura (1995) used a post-classification method where initial classification (via maximum likelihood) is carried out using Landsat TM data. Subsequently, zoning data is used to make corrections to areas of confusion. This increased both the classification accuracy, from 77% to 85%, as well as the number of urban classes from five to thirteen. Sadler (1991) discovered that use of texture information (entropy, contrast, inverse difference moment, and angular second moment) led to a little improvement in accuracy of less than 2%, while use of spatially referenced data (e.g., population and residential density data) decreased the overall classification accuracy by anywhere from 2% to 11%.

Nevertheless, using of population density enhanced classification accuracy by 7% in urban areas of the image. Using ancillary data led to similar enhancements in other studies carried out by Lillesand and Kiefer (1987), Treitz *et al.* (1992), Spooner (1991), and Turker and Ozen (2000).

The integration between GIS and Remote Sensing can be fruitful. Numerous studies have suggested that the spatial analysis and cartographic modelling techniques used in GIS, and the digital image processing techniques used in remote sensing, should be combined for enhanced analysis in urban applications (Hutchinson, 1982; Richards *et al.,* 1982; Newkirk and Wang, 1989; Wang and Newkirk, 1987). The land mass, particularly in Third World cities, is a dynamic entity whose elements are constantly changing. For example, when forests are cut, agricultural land is converted and roads and houses are built. Consequently, urban land information stored in GIS is only a static model of the real world for a particular time period and must be regularly updated. Satellite data are superior in this case because they possess a higher temporal resolution that has the potential of monitoring the dynamic changes within a GIS. An urban information system, therefore, when combined with up-to-date remotely-sensed data, can greatly improve the efficiency of change detection, map compilation and revision (Seong 1994).

Remote sensing data can be merged with the available spatial and ancillary data to present hybrid information that can be used as a base for accountable decisions for land-use planning. In the same context, GIS offers a medium for this integration of spatial data. Moreover, it presents a strong device for quantitative analysis of land use/cover.

This integration of remote sensing with GIS has boosted the attention in automating the methods used to create such information bearing in mind enhancing the reliability and repeatability when compared with traditional visual-based methods. In one example, Ehlers *et al.* (1990) claimed that SPOT data could be used in a GIS environment for regional growth analysis and local planning at a scale of 1:24,000. It was shown that SPOT image data could yield accuracies for growth detection of as high as 93% once incorporated into a GIS and the spatial growth pattern can be readily analysed (Jadkowski and Ehlers 1989). Treitz *et al.* (1992) used SPOT HRV imagery (multi-spectral and panchromatic) to update a land-use zoning map at a scale of 1:10,000. They utilized a two-stage digital analysis method that made use of spectral-class frequency-based contextual classification for eight land use/cover classes. The focal point was on the rural-urban fringe where urban change takes place rapidly. To merge the results of the classification with the zoning information for each area, a matrix-overlay analysis in the GIS was used. Finally, they succeeded in producing a map as a base for monitoring the changing landscape for large areas.

The outcomes of the literature review of remote sensing and GIS applications in this study can be summarized in the following points:

- Generally, the number of human activities remote sensing studies, especially urban areas, is relatively small compared with the other applications such as environmental subjects.

- Specifically, the field of urban applications in most remote sensing studies has examined Northern America (mainly USA) or Europe with very few studies in developing countries. This can be explained in the light of lack of the necessary data and human resources. Also the case studies in developing countries may experience complications in applying and adopting some techniques for research as these tools and techniques are not universally applicable considering the difference of the environmental characteristics between the regions.

- In terms of geographical research coverage, some regions such as the Middle East and Africa are the owners of the smallest shares, between the other regions, in most remote sensing applications including the urban applications.

- Research efforts need to focus on the development of automated or semi-automated methods that utilize sensor imagery for land use/cover classification and the updating of GIS databases particularly with the enhancements that can be obtained with the wide availability of imagery with increased spatial, spectral, and temporal resolutions. Such methods need to extract information about the large number of classes required by recent applications making use of both imagery and the ancillary data readily available in geospatial databases (Usher 2002). For example, the planners require information on 40 to 80 detailed classes of land use (APA, 1999) and modellers as many as 100 classes (Coulter *et al.*, 1999), but as Welch (1982) found in the past that remote sensing imagery only permits the accurate discrimination of from five to 15 classes.

- In the area of land use/land cover change detection, research is still needed to find a means to simplify the detection and classification of change, particularly within urban areas, as accuracies are too low to be useful.

- As well, studies must keep in mind the need to interface the results with GIS systems.

- Research is needed to determine if the incorporation of ancillary data is site specific and how this can be accounted for in the design of a general-purpose tool for use in planning (Usher 2002).

- There is a need to develop land use/cover models for use in land demand modelling to predict how urban expansion changes will affect land use. Then methods are needed that will close the loop on the forecasting process allowing the near-term forecasts of demand across the planning area to be used as the input on forecasts in the next iteration of the overall modelling process resulting in increased accuracy when making predictions further out in the future.

1.5 Statement of the problem

From its establishment until the mid 19th century, Alexandria witnessed eras of thriving and degeneration, epochs of expansion and contraction. Since that time, it commenced a period of continuous urban growth with population increase and physical expansion. Therefore, investigation of both urban population and the physical expansion of the city gives a clear picture of the pattern of urban growth and the need to catalyse or control further development as the urban growth is often accompanied by major social, economic, and physical problems such as urban poverty, the high demand for housing, infrastructure, urban and social services, environmental degradation, the depletion of natural resources, and air and water pollution (Seong 1994). Thus, there is a need to:

- Monitor the urban sprawl of Alexandria till the end of the 20th century.

- Study the population trends in the city.

- Establish a relationship between sprawl and the population to determine the pattern of population densities.

- Project the relationship to a future date to estimate the expected sprawl of the city.

1.6 Research aims

The aims of this study can be defined as follows;

- To cover many gaps in terms of adding knowledge about part of a less-studied geographical region.

- To apply and test methods and techniques and investigate their implications in an environment which is different from the environment of the original application.

- Also, this study aims to add knowledge to the field of urban remote sensing generally and urban remote sensing in developing countries in particular.

1.7 Research Objectives

The main objectives of this study are to monitor, model, and manage urban growth in Alexandria through constructing an automated raster-based GIS to achieve the following sub objectives: -

1- Highlighting the demographic characteristics of urban growth in Alexandria using census data and demographic measurements.

2- Following the physical expansion of Alexandria from its establishment up to the contemporary stage and modelling growth stages.

3- Production of contemporary satellite-based land use/cover maps for the city using the available satellite images.

4- Mapping urban growth in Alexandria city, Egypt, using multi-temporal change detection techniques.

5- Locating (defining the trends) and quantifying (size and rate) the changes of urban land use in the city at the specific period using classified satellite images.

6- Defining the consequences of urban growth in Alexandria.

7- Modelling urban growth in the city using the power of integrated spatial data (raster data / vector data / ancillary data) using the SLEUTH Model to simulate the future urban growth of the city.

8- Suggesting urban growth management approach benefiting from previous and current international experiences.

The objectives of this study will be achieved through addressing the following research questions.

1.8 Research questions

To achieve the previous mentioned research objectives, it is required to formulate research questions that will lead to achieve such objectives. This study has three basic elements; monitoring urban growth, modelling urban growth, and managing urban growth. Urban growth investigation in this study means monitoring of both population growth and physical expansion. For the first element "**Monitoring urban growth**" (the first two secondary research objectives), the following research questions are prepared:

- What are the demographic characteristics of urban growth in Alexandria?

- What are the physical characteristics of urban growth in Alexandria?

- What are the stages of urban growth in the city?

- What are the boundaries and the trend of this growth?

- To what extent did Alexandria experience urban growth in the last decades of the 20th century?

- What are the shapes of urban growth in the city between the 19th and 20th centuries?

Addressing the above-mentioned research questions will be through using conventional methods such as hard copy maps and statistical data. In the mean time, this study intends to use remote sensing and GIS to monitor urban growth. Therefore, to address research objectives (3-5), the following research questions are prepared;

- What is the recent state of land use in Alexandria as a base for monitoring growth and detecting urban change using satellite images?

- What are the changes of the land use/cover during the period of study using satellite images and GIS?

Up to this level, it can be possible to define the consequences of urban growth in Alexandria (research objective No:6) by the following research question;

- What are the consequences of urban growth in Alexandria?

Monitoring urban growth in Alexandria up to the end of the 20th century will be achieved when reaching to this extent of the study. In addition, predicting the potential urban expansion is required to provide a necessary base for **Urban Growth Management.** Therefore, the second element of this study **"Modelling urban growth"** (research objective No. 7) will be addressed by the following research questions;

- Using modelling techniques, what may be the future urban growth in Alexandria?

- What is the potential of using remote sensing and GIS in monitoring, detecting, and modelling urban growth?

Once, **Monitoring and Modelling urban growth** analysis results are ready, the following stage is to think about how to **manage urban growth** (the third element) based on these results (the last research objective). The following research questions are concerned about this point.

- What is the current situation of urban growth management in Alexandria?

- What is the best practice to achieve a sustainable urban growth in the city?

When, all those research questions are addressed, this study will achieve the secondary research objectives that will lead to the main research objective **"Monitoring, Modelling, and Managing urban growth in Alexandria using Remote sensing and GIS".**

1.9 The Alexandria context

The population of Alexandria was 315,844 according to the 1897 census. Alexandria commenced its membership in the "million-city club" early in the 1950s. The current population in the city according to the final results of 1996 census is 3.3 millions which means the city population increased by ten-fold in about 100 years. The population is projected to be 5.4 millions by 2015. Alexandria's population ranked 62 at the international level in 1996 and it is expected to be 54 in 2015 (UN 1997). Its rank is the fifth in Africa (UN 1997), the third largest city in Arab world (UNCHS 2001), and the second largest urban governorate in Egypt after Cairo. It consists of 13.2% and 30.3% of urban population and urban governorates population respectively in Egypt in 1996 (CAPMAS 1998). This enormous urban population growth may lead in most cases to a significant physical expansion of the city where more land comes under urban use. Therefore, Alexandria was selected to be the subject of this study.

In addition, there are few studies conducted about Alexandria, especially in foreign languages, compared to Cairo. Cairo enjoys a large number of studies in different subjects in different languages including Arabic. Cairo enjoyed this important standing as it inherited the capital role from Alexandria. Alexandria was the capital of Egypt for about thousand years from 331 BC until the Arabs conquered Egypt in 641 AD.

Alexandria was built by the Greek architect Dinocrates (332-331 BC) on the site of an old village, Rhakotis, at the orders of Alexander the Great. The city, immortalizing Alexander's name, quickly flourished into a prominent cultural, intellectual, political, and economic metropolis. Within a century of its founding, Alexandria became the greatest and the largest metropolis in the ancient world and the world's scientific and intellectual Mecca. Such scholars as Euclid, Archimedes, Plotinus the philosopher, and Ptolemy and Eratosthenes, the geographers, studied at the Mouseion, the great research institute founded by the Ptolemies (Forster 1986).

There is some literature about ancient Alexandria but there is very little literature about modern Alexandria. One of the main parallel objectives of this study is to introduce modern and contemporary Alexandria. My MA study about urban poverty in Alexandria (Abdou-Azaz 1997) raised my awareness of the roots of the urban poverty problem. Urban growth is one of the key factors of urban poverty in Alexandria. Therefore, investigation of urban growth using remote sensing tools - including satellite images - and GIS was chosen as the subject of this study.

Alexandria is the main port of Egypt with more than 75 % of Egypt's foreign trade. Moreover, Alexandria is the second largest industrial centre in Egypt. It is also the second largest urban governorate amongst the four urban governorates in Egypt with a population of about 3.7 million in 2003. Alexandria is considered the most culturally diverse of all Egyptian cities. Her diverse experiences are clearly present in the names of her districts; Greek names such as "Bacos" (Bacchus), Ptolemaic names such as "Soter", Roman/Coptic such as "San Stefano", Arab names such as "Shatby", Jewish names such as "Semouha", modern European names such as "Stanley", and modern Egyptian names such as "Moustafa Kamel" (Sa'd al-Din *et al.* 1993). The city is the home of some important universities and academies; Alexandria University, The French University (Sengour University), and the Arab Academy for Science & Technology and Maritime Transport. Last but not the least, Bibliotheca Alexandrina, the library of Alexandria, is the most recently completed project to revive Alexandria's old library that was the most famous and largest among all ancient and medieval libraries. It was not only just a library but it was associated with scientific research and patronized by scholars from all over the ancient world.

Alexandria lies northwest of the Nile delta, (Figure 1). Alexandria, the city, occupies a T-shaped peninsula and stretches along a narrow land strip between the Mediterranean Sea and Lake Maryout (Mareotis).

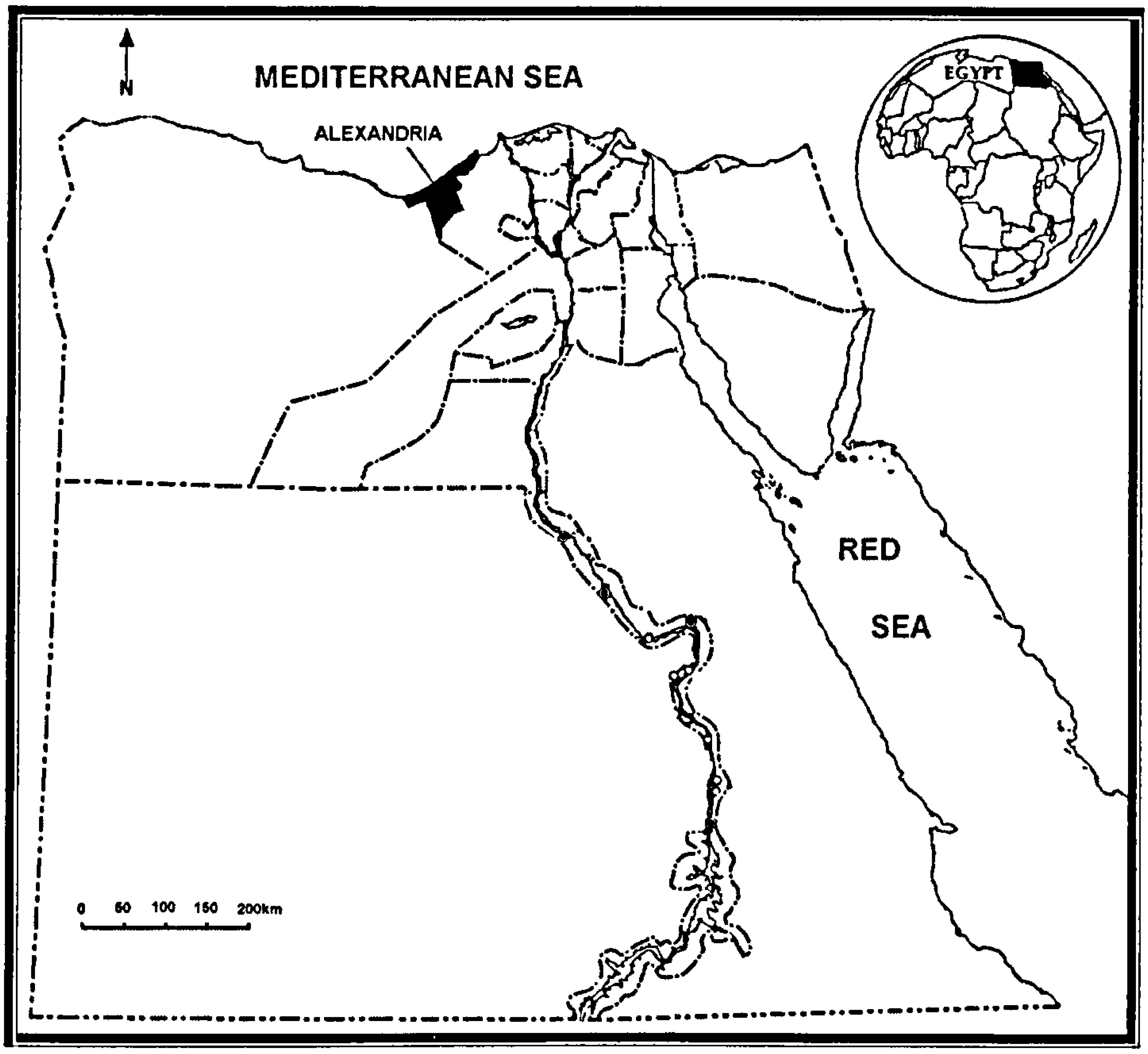


Figure 1 The location of Alexandria in Egypt

The Alexandria governorate' administration borders extends south of the lake, (Figure 2)'. It is linked to Cairo by two major highways and a railway line. It is one of the most notable summer resorts in the country. Its beaches, with white sands and magnificent scenery, stretch for about 70 km along the Mediterranean Sea, from Abu Qir, in the east, to Al-Alamein and Sidi Abdul Rahman, in the west. Alexandria is bounded by the Mediterranean Sea in the north, Buhyra governorate in the east and the south, and Matrouh governorate in the west, (Figure 2).

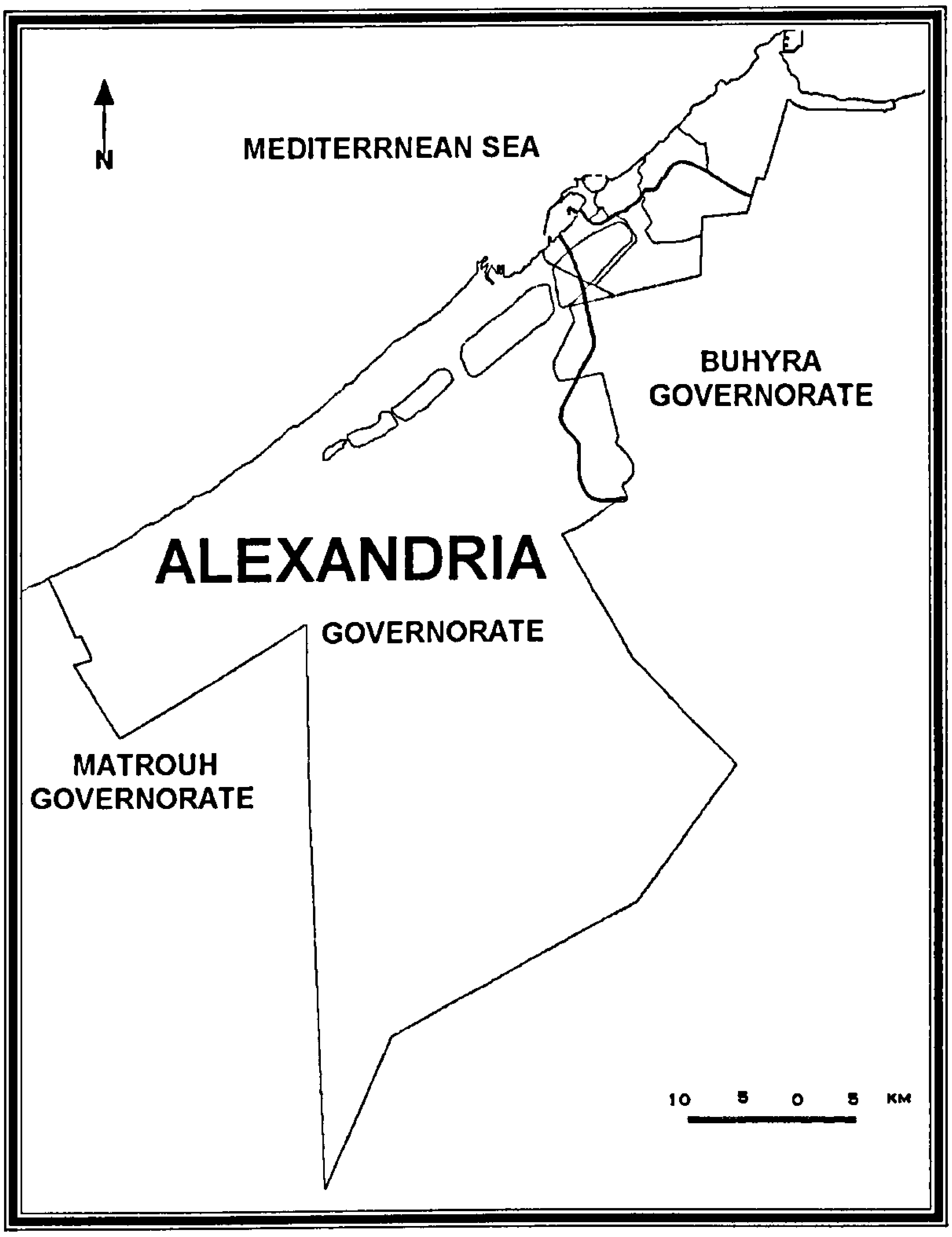


Figure 2 Alexandria Governorate

1.10 Thesis Plan

Figure 3 illustrates the thesis plan, and Figure 4 demonstrates the general outline of the research. This study can be divided into four parts:

- The first part represents the notional base of this study and includes the first two chapters. Chapter one introduces a brief background about urban growth, remote sensing, and the integration between those tools in the field of urban applications. The methodology of the research is discussed in the second chapter. In addition, the procedures of the first stage of satellite image processing, including geometric correction are presented.

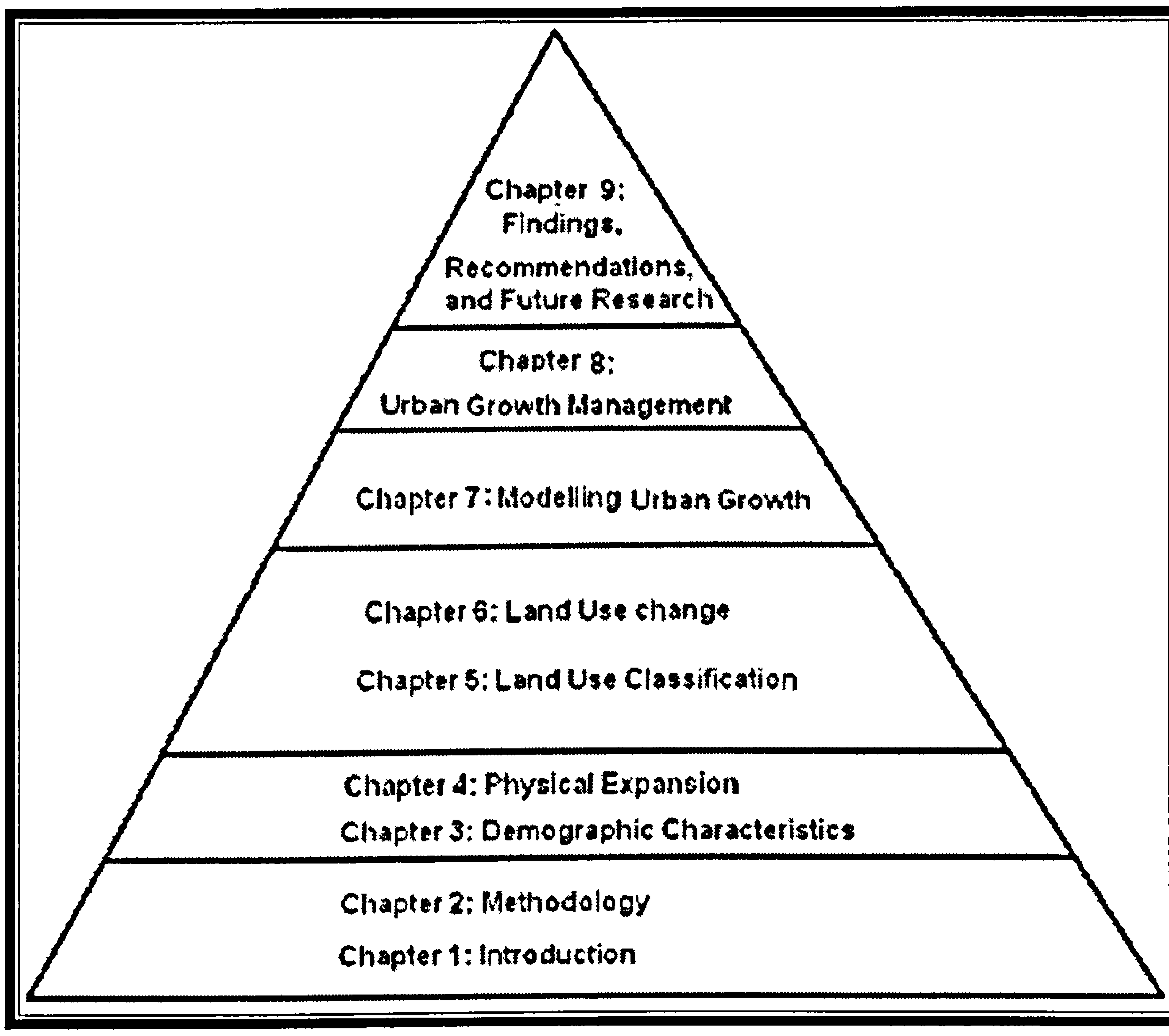


Figure 3 Thesis plan

- The second part is about monitoring urban growth. Urban growth has two basic elements: population and physical expansion. The demographic element of urban growth is discussed in Chapter three where the demographic characteristics of urban growth in Alexandria from its establishment to the most recent census of 1996 are explored. The second element, physical expansion, is monitored first using maps only in Chapter four with some reference to urban growth models. Using satellite images and GIS, urban land use change is detected in two chapters. Chapter five deals with satellite image analysis where land use classification images of the area of study were produced and accuracy assessment performed. Urban land use change is detected from the classified images using digital change detection techniques. The results of change detection are presented qualitatively and quantitatively in Chapter six.

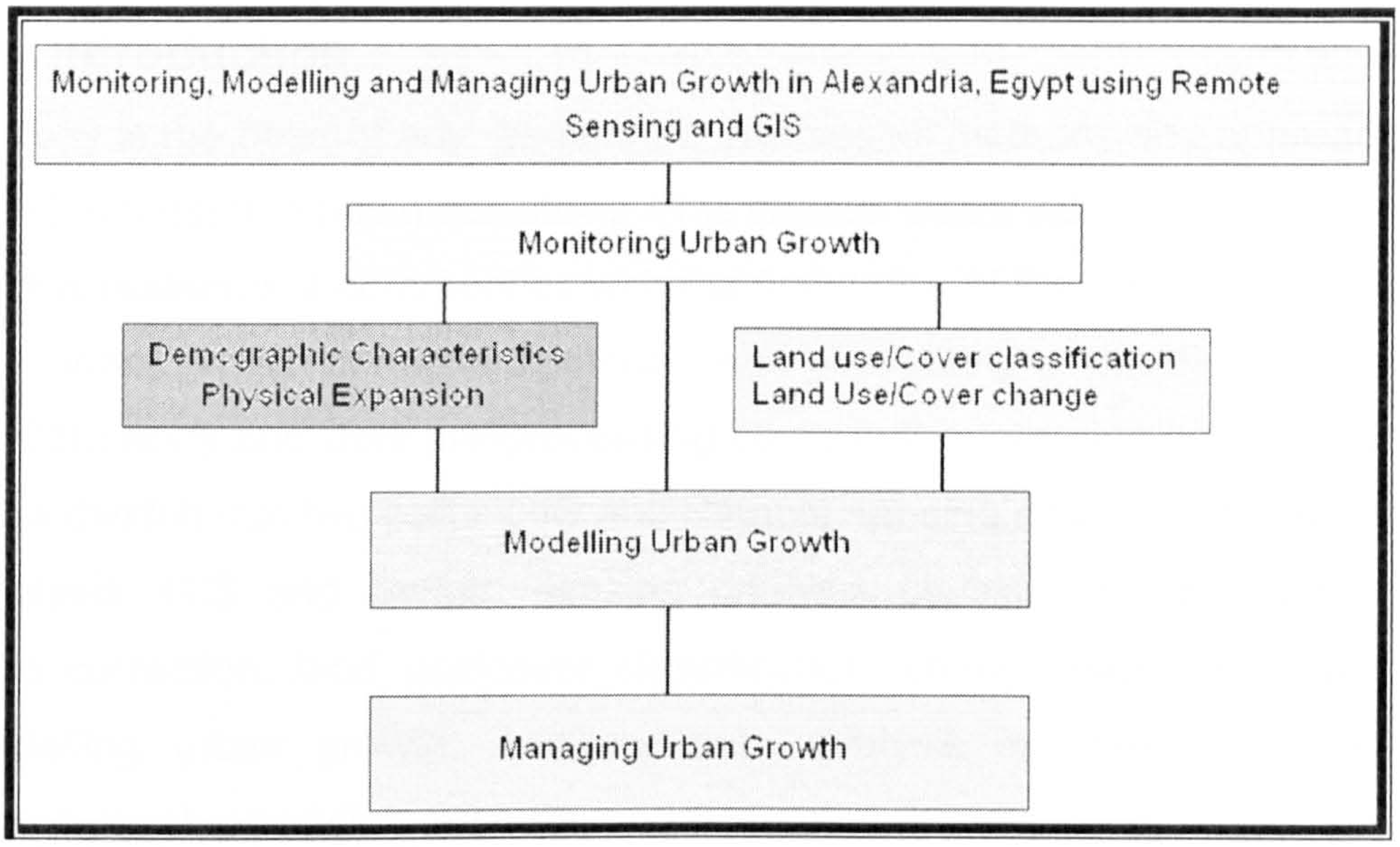


Figure 4 The general outline of the research

- The third part discuses urban growth modelling in Chapter seven. This chapter reviews urban modelling history in the beginning followed by an assessment of land use/cover models generally and urban models specifically. Because of this assessment, urban growth is projected using the SLEUTH model simulation. Future urban growth in Alexandria until 2055 is presented using the different types of model output.

- The fourth part is about urban growth management. Chapter eight discusses some international urban growth management experiences including United Nations recommendations for sustainable urban growth with a review of the planning experience in Alexandria.

- Finally, Chapter nine formulates the findings of the various chapters in an incorporated way providing the answers to the research questions of this study. Thesis recommendations and the direction of further research are stated at the end.

2. CHAPTER TWO: METHODOLOGY

2.1 Introduction

Methodology is the base of any research. It involves all methods and approaches that have been used in any given study. This chapter deals with the methodology issue of this research. It commences with the first stage of the research, the data collection phase, which contains collection, and processing of the different types of data. Data entry and data pre-processing come in the following sections. Data analysis is divided into two parts: GIS and Remote sensing analysis, and ancillary data analysis. GIS and remote sensing analysis consists of four elements: geometric correction, land use/cover classification, change detection analysis, and modelling urban growth. Ancillary data analysis includes demographic analysis, physical expansion analysis, and managing urban growth.

2.2 Data collection

Data collection is the first, most important and critical stage of any research or study as this step may control the direction of the research. In this study, data of different types were collected from varying sources. Data collection is a complicated task especially for a developing country. Many tough security checks have to be done, even for "unimportant" data. Data cost is very expensive compared to similar applications in developed countries and it has to be undertaken through complicated procedures that consume long time periods. In addition, it may be difficult to get up-to-date data. Last, but not least, it is important to evaluate the accuracy of this data before use. The following sections introduce a full description of the collected data for this study.

2.2.1 Satellite images

To select the appropriate satellite images for this study, a brief review of remote systems is necessary. The following section provides an introduction to remote sensing systems.

2.2.1.1 Remote sensing systems

Remote sensing systems can be categorised using different variables. For example, these systems can be grouped according to energy source to: *a)* active and *b)* passive systems. Active Remote Sensing systems are those that send and receive the energy from the objects. On the other hand, passive *Remote Sensing* systems are the sensors that collect energy that is either emitted directly by the objects (thermal self-emission, for example) or reflected from natural sources (the sun) (Schott 1997). In addition, Remote sensing systems can be classified into five kinds according to wavelength regions (GISdevelopment 2004):

1- Visible (0.38-0.72μm)
2- Near Infrared (0.72-1.30 μm).
3- Middle Infrared (1.30-3.00 μm).
4- Far Infrared (Thermal infrared, Emissive (7.00-15.0 μm).
5- Microwave (1mm to 1m).

A visible and infrared reflectance remote sensing system provides the best data source for urban planning applications. On the other hand, the other two types, thermal infrared and microwave, have not been used extensively in urban applications (Seong 1994).

Using orbital characteristics, Satellite remote sensing can be classified into three types (Lo 1986):

1) **Systems with near-polar sun synchronous orbits** are designed in such a way that the ascending node of each orbit of the satellite will occur at the same local time. This means that the angular relationship between the sun and the satellite's orbital plane is kept constant (Lo 1986). These satellites systems are located up to 1,000 km above the earth's surface. Landsat series, Spot series, and NOAA series are good examples of these satellite systems.

2) **Systems with Geo-synchronous orbits** are those systems that remain directly overhead a specific point on the earth's surface; because of this, they are also known geostationary. The orbit of these systems occurs over the equator. The examples of these systems are American series of Application

Technology Satellites (ATS), Geostationary Operational Environmental Satellites (GOES) and METEOSAT system.

3) **General systems** are those satellites which have neither sun-synchronous nor a geostationary orbit. Seasat is a good example of those systems.

Generally, remote sensing data acquired by sun-synchronous orbits are the most commonly used in urban planning. Landsat 4 and 5 platforms operate from a Sun-synchronous, near-polar orbit at an altitude of approximately 705 km. These lower orbits (if compared with the orbits of the predecessor satellites) provide better ground spatial resolution. Landsat Thematic Mapper (TM) 4 and 5 image area of 185 km X 185 km ground swath every 16 days (Figure 5). The TM data are received directly from Landsat 5 by a network of 16 worldwide ground stations (Figure 6).

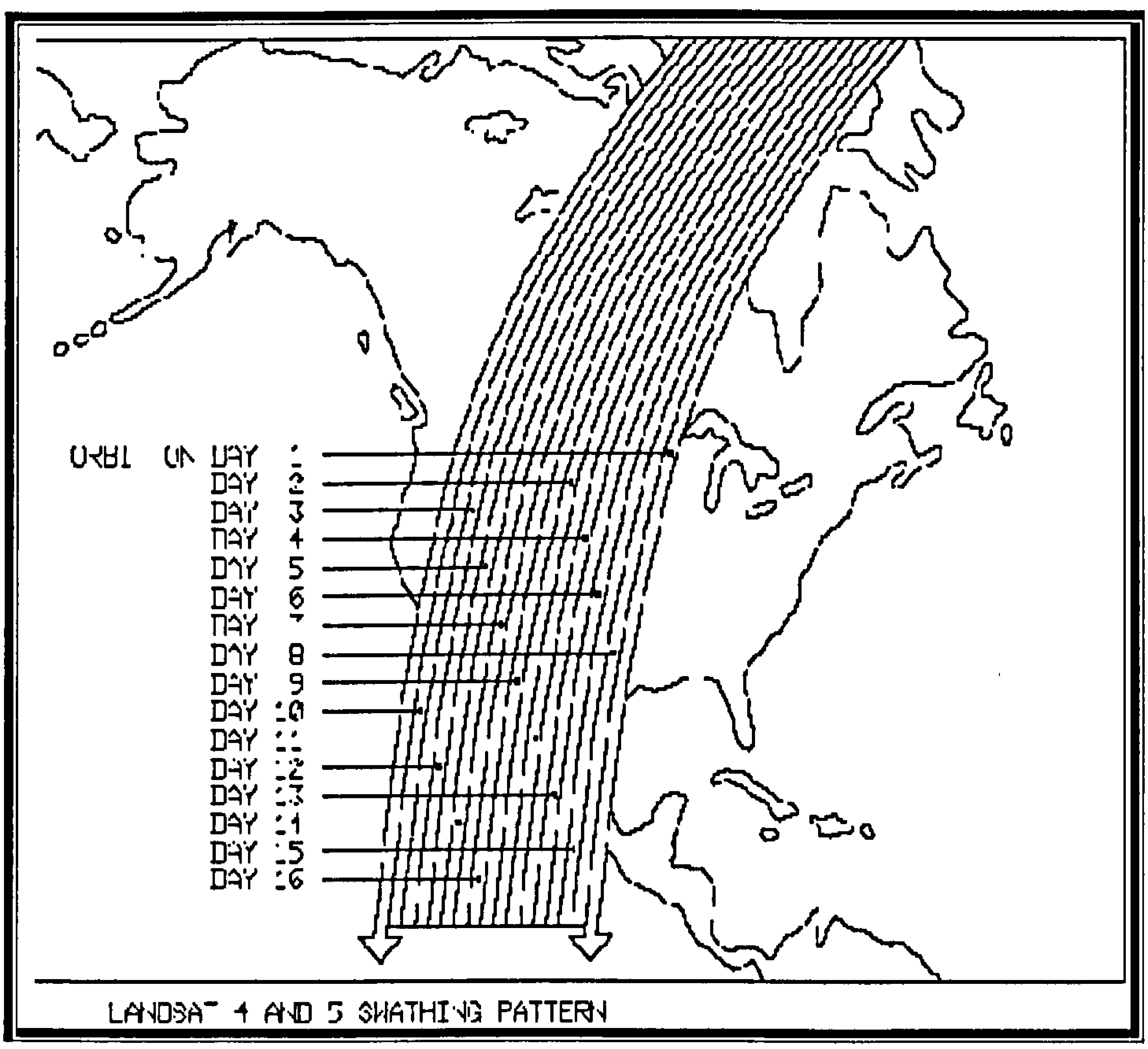


Figure 5 Landsat 4 and 5 swathing pattern (USGS 2002)

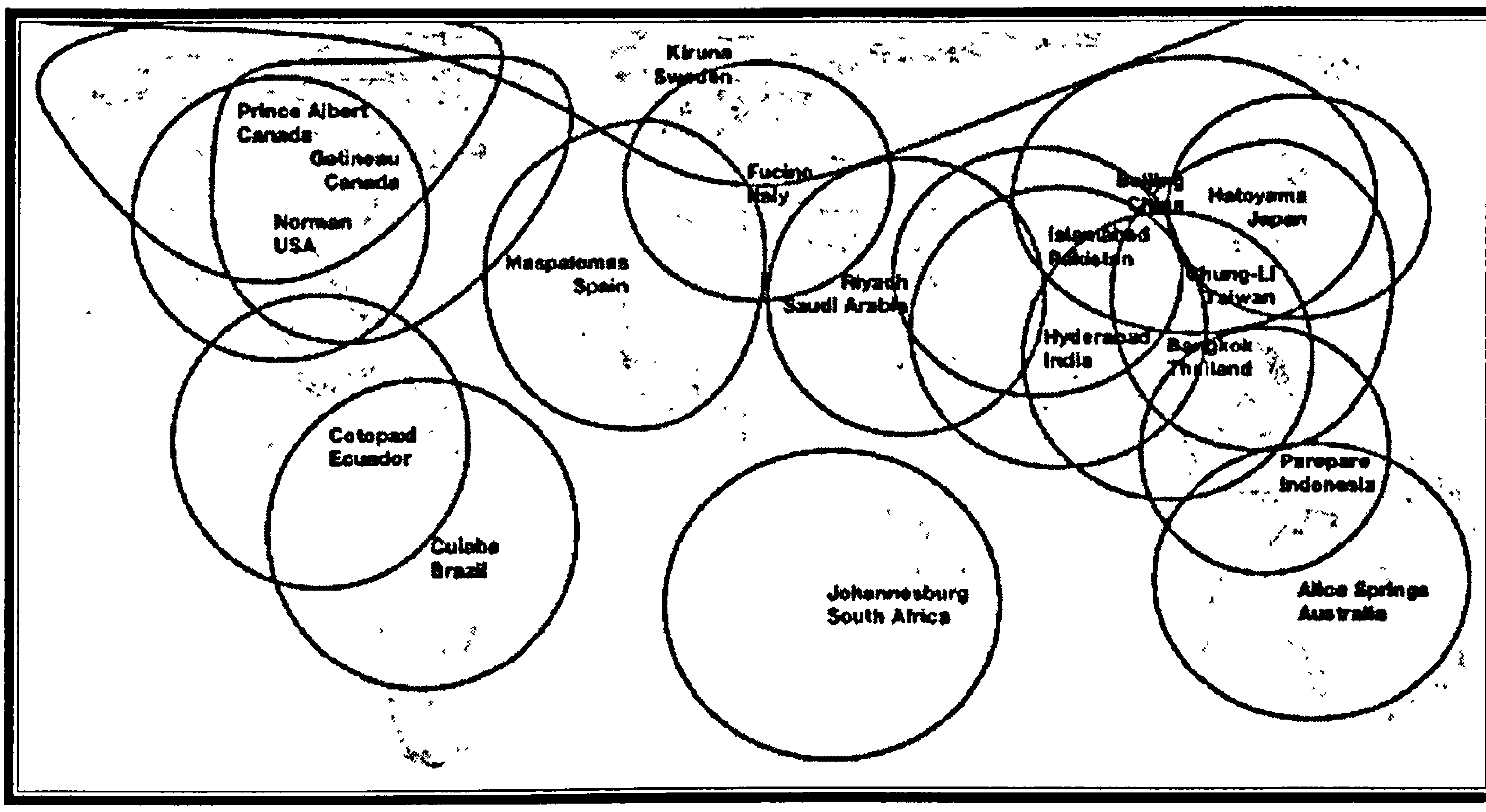


Figure 6 Current Landsat TM Ground Receiving Stations and Extent of Coverage (NASA 1999)

Governmental, commercial, industrial, civilian, and educational communities have used Landsat data worldwide. These data are being used to support a wide range of applications in such areas as global change research, agriculture, forestry, geology, resource management, geography, mapping, water quality, and oceanography. Landsat data have potential applications for monitoring the conditions of the Earth's land surface. The images can be used to map anthropogenic and natural changes on the Earth over periods of several months to several years. Examples of changes that can be identified include agricultural development, deforestation, natural disasters, urbanization, and the development and degradation of water resources (USGS 2002).

According to all the above-mentioned grounds and the nature of this study and the examples shown in chapter one, Landsat (TM) is one of the best data sources; therefore, it was decided to use Landsat (TM) images in the current study. Landsat Satellite systems are discussed in detail in the next section.

2.2.1.2 Landsat Satellite images

Landsat satellite images are available since 1972 up to date in seven successive generations, therefore, a long time series of data is potentially available for analysis. Figure 7 and Table 1 list the generations of Landsat system.

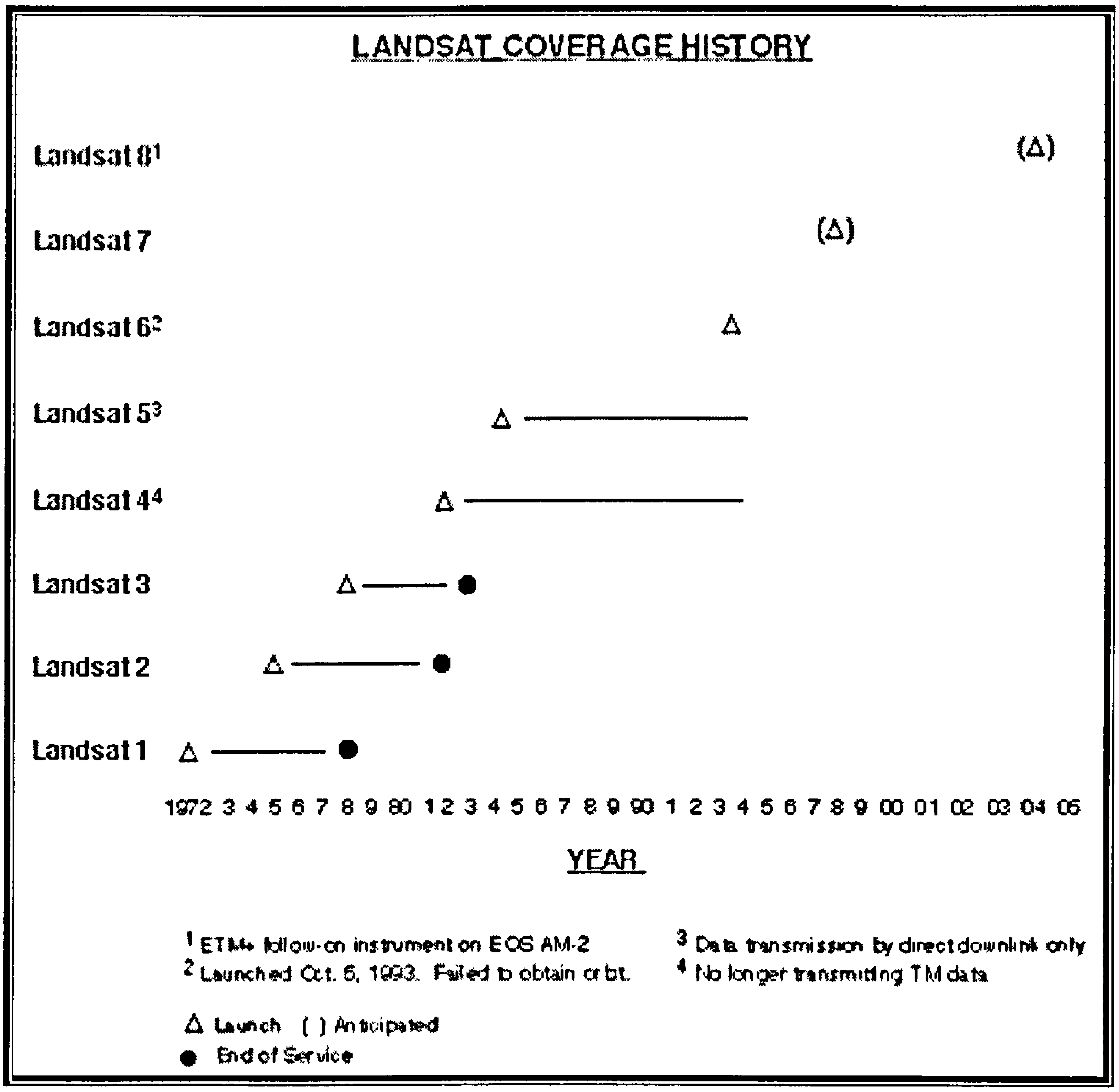


Figure 7 Landsat coverage history (NASA 1999)

Satellite	Launch date	Decommission date	Sensors
Landsat 1	23 July, 1972	6 Jan, 1978	MSS-RBV
Landsat 2	23 Jan, 1975	25 Feb., 1982	MSS-RBV
Landsat 3	5 Mar., 1978	31 Mar., 1983	MSS-RBV
Landsat 4	16 July, 1982		MSS-TM
Landsat 5	1 Mar., 1984		MSS-TM
Landsat 6	5 Oct., 1993	Failure upon launch	ETM
Landsat 7	15 April, 1999		ETM

Legend:

MSS- Multi-Spectral Scanner

RBV- Return Beam Vidicom

TM- Thematic Mapper

ETM- Enhanced Thematic Mapper

Table 1 Landsat Generations (Sanchez and Canton 1999)

2.2.1.2.1 Characteristics of Landsat TM

Landsat TM data has a 30-m ground spatial resolution cell for all bands except band 6, which has a 120m spatial resolution. Although, the Landsat TM bands are finely tuned for vegetation discrimination, other applications benefit from the enhanced characteristics of Landsat TM. Band one is the best for bathymetry investigations. Bands five and seven have proven to be extremely valuable in discrimination of rock types. Meanwhile, band five is used to differentiate between snow and cloud covered areas. In addition, band six is useful in thermal mapping (Lillesand and Kieffer 1994). Table 2 lists the spatial and spectral characteristics, and the applications of Landsat TM data.

Band	Wavelength (μm)	Spectral Location	Resolution (m per pixel)	Applications
1	0.45-0.52	Blue	30	- Water body penetration in coastal water mapping. - Soil/ vegetation discrimination. - Forest type determination. - Cultural features identification
2	0.52-0.60	Green	30	- Vegetation's green reflectance peak. - Vegetation type discrimination. - Vegetation vigour assessment. - Cultural feature identification.
3	0.63-0.69	Red	30	- Chlorophyll absorption determination. - Plant species differentiation. - Cultural feature identification.
4	0.76-0.90	Near infrared	30	- Vegetation type determination. - Vegetation vigour determination. - Biomass contents determination. - Delineating water bodies. - Soil moisture discrimination.
5	1.55-1.75	Mid-infrared	30	- Vegetation moisture determination. - Soil moisture determination. - Snow/ clouds differentiation.
7	2.08-2.35		30	- Mineral types determination. - Rock types determination. - Vegetation moisture determination.
6	10.4-12.5	Thermal	120	- Vegetation stress analysis. - Soil moisture discrimination. - Thermal mapping.

Table 2 Landsat TM characteristics and Applications (Sanchez and Canton 1999)

Although a Landsat TM satellite image consists of seven bands, only three-band combinations can be displayed on the computer system at one time (Sanchez and Canton 1999). Table 3 shows some possible band combination to enhance the Landsat TM images according to the different purposes.

Blue	Green	Red	Composite	Possible Applications
1	2	3	Normal colour	Water sediment pattern
2	3	4	Infrared	Urban features
3	4	5		
3	4	7	False colour	Vegetation enhancement
3	5	7		
4	5	7		
1	4	7		

Table 3 Some possible Landsat TM Band combination (Sanchez and Canton 1999)

2.2.1.3 Satellite images collection

Alexandria lies on the intersection area of many Landsat images. Figure 8 illustrates the images that cover the area of study. Thus, a mosaic of four images is needed if the investigated phenomenon does not require chronological comparison. However, because the main aim of this study is to monitor urban growth and detect the changes between two different dates at least, two mosaics forming eight images in total were requested for this study. Indeed, the data needed is huge from the size point of view and it will cost much. Therefore, it was decided to use two satellite images of each date, and these images should cover a major part of the area of study. The images of Path/Row 177/38 and 177/39 were selected, as they met those conditions.

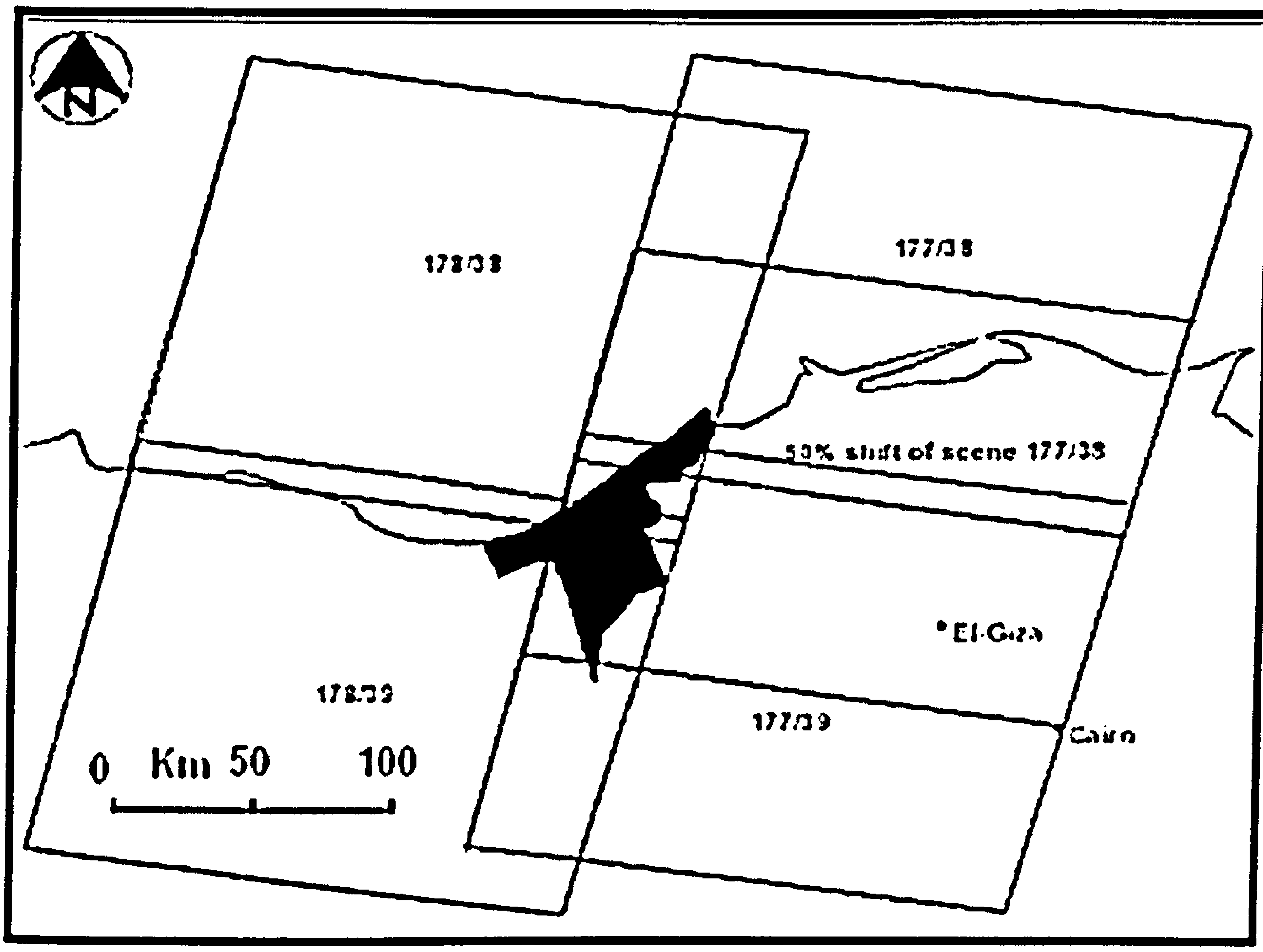


Figure 8 The satellite images that cover area of study

Two sets of data were received from two different sources. Two images (1988 and 1997) were from National Authority for Remote Sensing and Space Sciences (NARSS), Egypt. Another two mosaic images (Path/Row: 177/38 and 177/39) of years 1984 and 1993 were from the Remote Sensing Center of Boston University, USA. Both sets were investigated. NARSS data set was avoided because of incomplete coverage for the area of study; some western and southern parts are missing. Moreover, band 7 was missed from both dates (1988 and 1997). Finally, it was agreed to use the Boston data set as it is complete and covers most of the area of study. Table 4 shows the information of the used satellite images.

Path/Row information	(Year) 1984	(Year) 1993
177/38		
Start Date	1984-06-07	1993-04-29
Start Time	07:57:48	07:52:05
Stop Date	1984-06-07	1993-04-29
Stop Time	07:58:12	07:52:28
177/39		
Start Date	1984-06-07	1993-04-29
Start Time	07:58:12	07:52:28
Stop Date	1984-06-07	1993-04-29
Stop Time	07:58:36	07:52:52

Table 4 The information of used satellite images (Lenney *et al.* 1996) and (Eurimage 2003)

2.2.2 Maps

Maps with different scales were collected for this study. Egyptian series maps of scale 1:50,000 were used for rectification (geometric correction or georeferencing), land use/cover classification, and change detection analysis phases. These maps were compiled from aerial photography taken between 1990 and 1991(EGSA 1997). Table 5 shows the main characteristics of these maps.

Projection	Transverse Mercator
Ellipsoid	Helmert 1907
Horizontal Datum	National Geodetic Net, Venus 1874
Vertical Datum	Mean Sea Level, Alexandria 1906

First edition 1997, Map produced by the Irrigation Management Systems Project- Surveying and Mapping Component in cooperation with the Egyptian General Survey Authority (EGSA).

Table 5 The main characteristics of Egyptian Map Series scale 1:50,000

Topographic maps of scale 1:25,000, Alexandria tourist maps with a scale of 1:15,000, and cadastral maps with a scale of 1:5,000 were collected for use in both the land use classification and change detection analysis as well.

2.2.3 Ancillary data

The ancillary data includes reports, statistical data, and all other documents that can be used along with image and map data to give it a significant explanation. The final results of 1986 (CAPMAS 1989) and 1996 census (CAPMAS 1998), were used in this study for demographic data. Different issues of the Statistical Yearbook of the Central Agency for Public Mobilization and Statistics (CAPMAS) were used as well for other different types of data. The final report of the "Alexandria Comprehensive Master Plan Project" (Alexandria 1984) was used to investigate the different conditions of the city before 1984. Moreover, the report contains the suggested plan of the city until 2005. This plan will be reviewed and discussed. The reports of the "General Plan of Alexandria City till 2017"(Ministry of Housing 1997) will be discussed as well.

2.3 Data Entry

Image data were received "compressed" in separated bands and files. To obtain appropriate and ordinary image files, the data files needed to be "uncompressed", then grouped to form image(s). The data files were uncompressed and grouped in a UNIX environment. The image files were imported into ERDAS IMAGINE. Table 6 displays the main characteristics of the imported images.

Type	Generic Binary
Media	File
Data Format	BSQ
No. of Bands	7
Output Data Compression	ESRI Run-length-encoding
Output Data Type	Unsigned 8 bit
Block size	64

Table 6 The main charactertistics of imported Landsat images

2.4 Data Pre-processing

The image data were ready to use at that stage. The images were investigated and it was found that the data set does not cover Alexandria area only, but also it covers a great part of the Delta. Figures 9 and 10 illustrate the crude images for 1984 and 1993. It is suitable for the area of study, but a small part of the western fringe is missing.

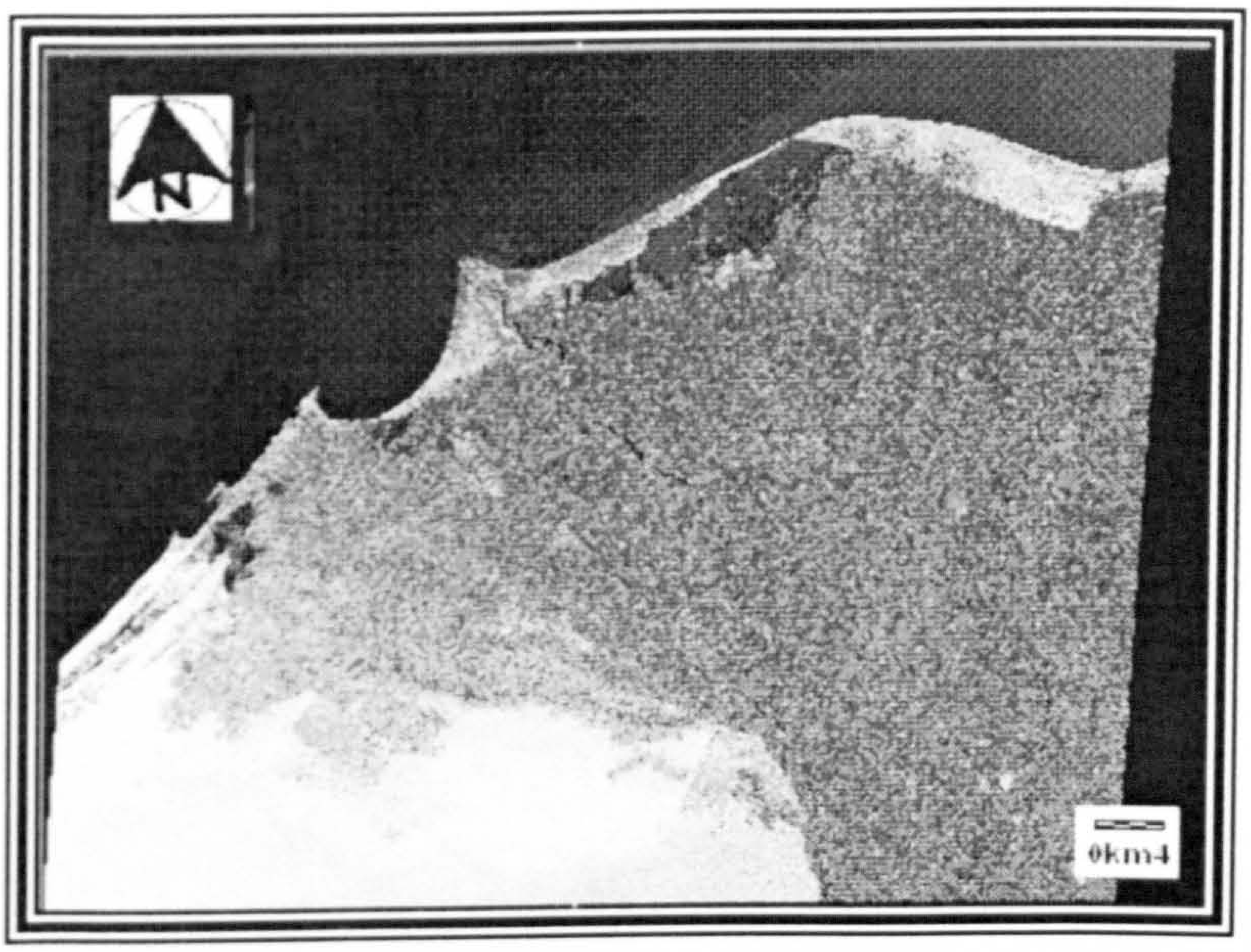


Figure 9 1984 Landsat (TM)

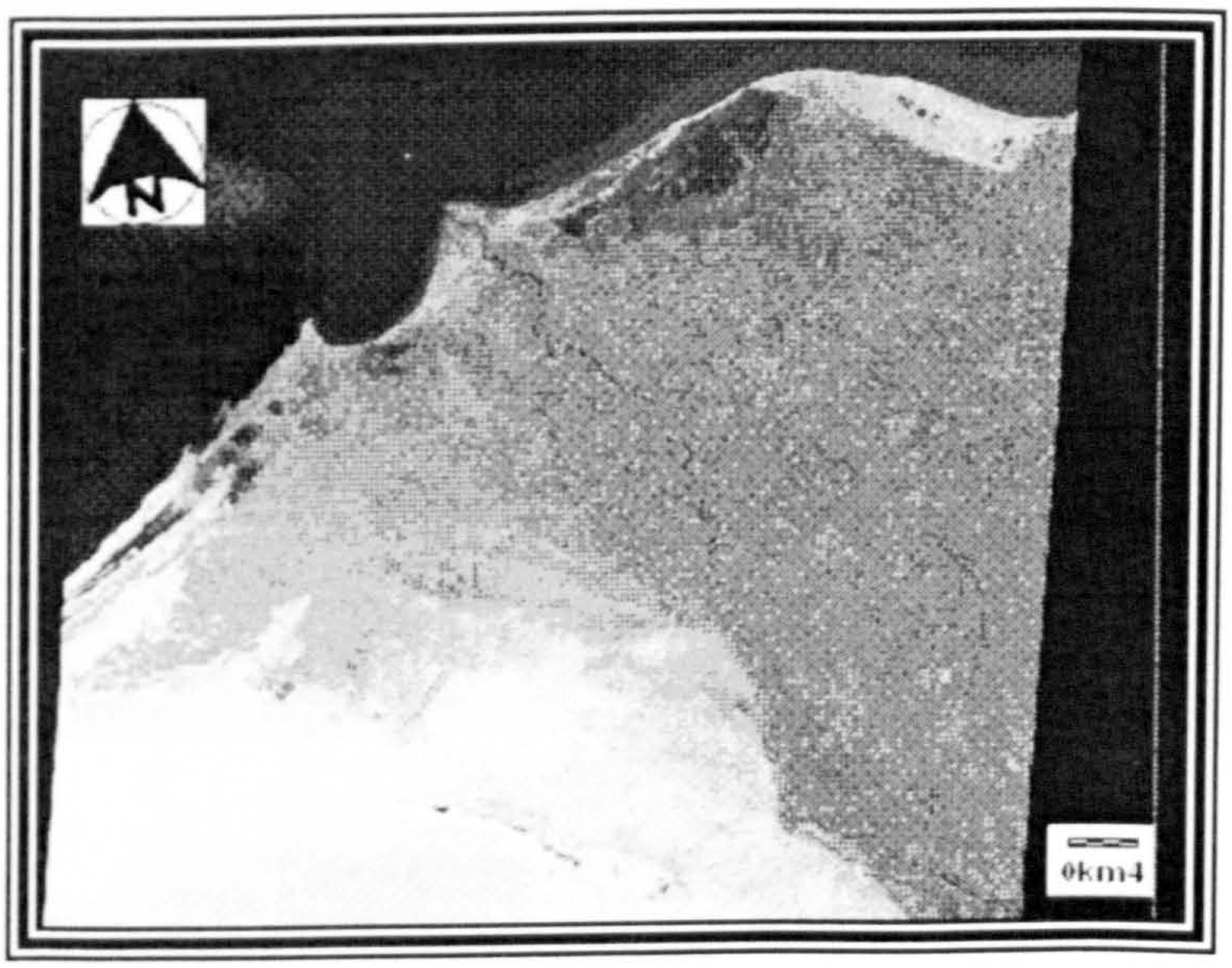


Figure 10 1993 Landsat (TM)

2.4.1 Images partition

Because of the huge size of the satellite images and the computer resources needed for image processing and analysis, only the part that covers the area of study was taken from both dates (1984 and 1993). This process was done using the Image ***Subset*** command inside ERDAS IMAGINE. Figures 11 and 12 demonstrate 1984 and 1993 after application of ***Subset.***

Figure 11 Area of study image (1984)

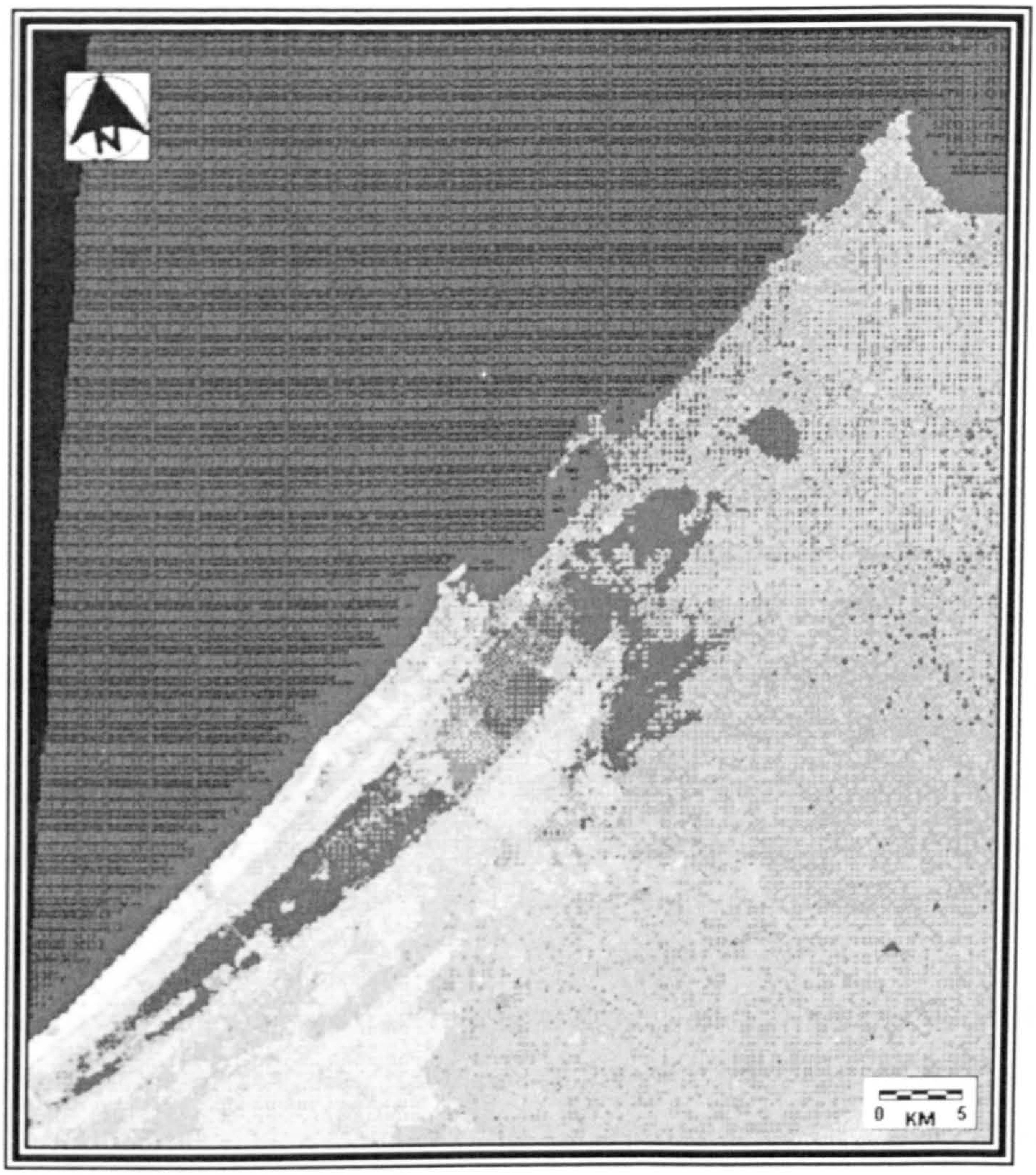


Figure 12 Area of study (1993)

2.4.2 Geometric correction

Representation of the surface of the Earth is one of the critical challenges that face earth scientists. The early attempts were when cartographers tried to prepare charts to illustrate features of the earth. They tried to develop methods to avoid distortion that is generated from the curvature of the earth. They developed map projections to solve that defect and achieve an accurate representation for this curved surface. Remotely sensed data is one of the modern ways to represent the entire globe. Satellite images usually contain geometric distortions so that they cannot be used as maps. The satellite images are distorted by different sources such as the curvature of the earth, the sensor being used, atmospheric effects, relief displacement and many other factors. (Lillesand and Kiefer 1994).

The remotely sensed images should be geometrically corrected so that they can be represented on a planar surface, conform to other images, and have the integrity of a map (ERDAS 1997). Two approaches are commonly used for correcting image distortions (Wilkie and Finn 1996). The first approach is to model the nature and magnitude of all sources of distortion and generate correction formula. If the sources of distortion are well understood and consistent, this approach will work well. Because of the unknown and unsystematic variations in satellite altitude and attitude, this method cannot remove all distortions (Wilkie and Finn 1996). In the second approach, a set of ground control points with known geographic coordinates are used to generate statistical functions to transform pixel locations within the uncorrected image into their corresponding coordinates within a standard projection system (Wilkie and Finn 1996)

The process of transformation of the data from one grid system to another is called ***Rectification.*** Because the pixels of the new grid may not align with the pixels of the original grid, the pixels must be ***resampled.*** Estimation of the data values of the pixels on the new grid from the values of the reference pixel is called ***Resampling*** (Verbyla 1997). Geometric corrections for satellite images can be done using one of the following methods (Jensen 1996):

1- Image-to-map transformation (Rectification).
2- Image-to-image registration.

In this study, both methods will be used in the following sections.

2.4.2.1 Rectification of 1984 image

Rectification involves the following general steps regardless of the application:

- *Identifying and locating a set of ground control points in both reference map and raw image.* The reference map should be in an appropriate scale according to the type of application and the image resolution. Many variables should be considered when selecting ground control points (GCPs); GCPs should be well distributed spatially over the image; GCPs that follow linear features such as rivers should be avoided as they may provide only one-dimensional information and the coordinate systems need two-dimensional information (Wilkie and Finn 1996). Road intersections, edges of bridges or dams, and corners of buildings are amongst the best control points (Wilkie and Finn 1996).

The number of GCPs affects the accuracy of rectification. The number of GCPs depends on the order of transformation being used. Polynomial equations are used to convert source file coordinates (raw image) to rectified map coordinates. The degree of complexity of the polynomial is expressed as the Order of the polynomial. The order is simply the highest exponent used in the polynomial. The higher order of transformation, the more GCPs needed. For instance, three points define a plane. Therefore, to perform a 1st-order transformation, which is expressed by the equation of a plane, at least three GCPs are needed. 1st-order transformation is commonly used to rectify a small area of an image to a geographic frame of reference (Jensen 1996). Table 7 shows the minimum number of GCPs required to perform a transformation.

Order of Transformation	Minimum GCPs Required
1	3
2	6
3	10
4	15

Table 7 The minimum number of Ground Control Points (GCPs) required to perform a transformation (ERDAS 1997)

In this study, the first order transformation polynomial was applied due to the type of application. Despite the used order, 43 GCPs of 1984 image were identified over the reference maps of Alexandria scale 1:50,000. The selected GCPs met all the above criteria and were distributed evenly over the maps. Before locating the GCPs over the 1984 raw image, projection parameters needed to be defined, and the projection of the maps was not in the projections list of ERDAS

IMAGINE. The new projection with its parameters was customized and added to ERDAS IMAGINE projections list. Table 8 shows the parameters of the added projection.

Projection type	Transverse Mercator
Spheroid Name	Helmert
Datum Name	Old Egyptian 1907
Scale factor at central meridian	0.9996
Longitude of central meridian	31:00:0.00E
Latitude of origin of projection	30:00:0.00N
False easting	615.0000 meters
False northing	810.0000 meters

Table 8 The parameters of Transverse Mercator projection for the area of study

- *Computing and testing the transformation matrix* is the second stage of rectification process.

The transformation matrix consists of coefficients, which are used, in polynomial equations to convert the coordinates. The size of the matrix depends upon the order of transformation. The least squares regression method is used to calculate the transformation matrix from the GCPs (Jensen 1996)

The difference between the desired output coordinate for a GCP and the actual output coordinate for the same point is called Root Mean Square Error (RMSE) (Campbell 1996). RMSE is computed with the following distance equation:

$$RMSE = \sqrt{(\chi_r - \chi_i)^2 + (\gamma_r - \gamma_i)^2}$$

Where:

χ_i And γ_i are the input x and y source coordinates

χ_r And γ_r are the retransformed x and y coordinates

RMSE is expressed in terms of the source coordinate system. Usually, the data file coordinates are used, therefore, the value of RMSE is expressed as a distance in pixels unit for both north/south and east/west directions (Campbell

1996). Therefore, a RMSE of 2 means the reference GCP is 2 pixels away from the retransformed pixel (ERDAS 1997).

Using ERDAS IMAGINE GCP Tool, the reference GCPs can be entered using different ways namely; keyboard, digitizer; and on-screen. In addition to the input (raw) and reference coordinates columns, GCP tool has columns for RMSE and Residuals. Residuals are the distances between the source and retransformed coordinates in one axis (direction) (Campbell 1996).

From the different residuals of the GCPs, the Total RMSE, the (X) RMSE, and the (Y) RMSE are calculated.

In this study, the transformation matrix of 1984 image was computed and tested many times until an acceptable RMSE was achieved. The average RMSE for X direction for all 43 GCPs was 0.0347, the average RMSE for Y direction was 0.25, and the total RMSE was less than 0.3 pixel (0.26) (Abdou-Azaz 1997).This means that an average position of any reference pixel is estimated by the 1st order transformation to be 0.26 a pixel in error.

There are many variables that control the size of RMSE; the objectives of the project, the type of data used, and the accuracy of locating GCPs in raw image (Jensen 1996). The reference maps used in rectification in this study were produced from aerial photographs (EGSA 1997). Aerial photographs are part of remote sensing data. These photographs are consistent with satellite images data as both are acquired from a distance but by different platforms. This might explain this small RMSE. In addition, computing and testing the transformation matrix many times, which involves reviewing the individual RMSE for each GCP and changing its position, may help along with the accuracy of the maps being used.

- Resampling the pixels. After calculating and testing the transformation matrix, the next stage was to create the output image file. The pixels grid of the raw image may not match the pixels grid of the reference image, therefore, the pixels should be resampled so that the new data file values for the output image can be calculated (ERDAS 1997).

There are three methods for resampling; Nearest-neighbour, bilinear interpolation, and cubic convolution (Mather 1999). The Nearest-neighbour method uses the closest pixel value of the input image to the computed coordinates. It is the fastest way and the pixel values in the output image are "real" as they are taken directly from the input image and not "fabricated" by an interpolation algorithm as in the other two methods (Mather 1999). Bilinear interpolation uses the data file values of four pixels in a 2 X 2 window to calculate an output value with a bilinear function while cubic convolution method uses the data file values of sixteen pixels in a 4 x 4 window to calculate an output values with a cubic function (ERDAS 1997).

In this study, 1984 image was resampled using the nearest neighbor method. Table 9 displays the image information of 1984 image before rectification. Table 10 illustrates the image information of 1984 after rectification, and Figure 13 shows the final output rectified 1984 image.

File info	**Layer name**	Layer_1				
	Last modified	Sun Mar 11 15:09:19 2001	**Number of layers**	7		
Layer info	**Width**	1809	**Height**	4352	**Type**	Continuous
	Block Width	64	**Block Height**	64	**Data Type**	Unsigned 8-bit
	Compression	None	**Pyramid Layers**		Present	
Statistics Info	**Min**	2	**Max**	255	**Mean**	148.408
	Median	170	**Mode**	83	**Std. Dev.**	49.578
	Skip Factor X	28	**Skip Factor Y**	28		
	Last Modified	Sun Mar 11 15.09:58 2001				
Map Info: (File)	**Upper Left X**	0.0	**Upper Left Y**	0.0		
	Lower Right X	1808.0	**Lower Right Y**	-4351.0		
	Pixel Size X	N/A	**Pixel Size Y**	N/A		
	Unit	Other				
Projection Info:						

Table 9 1984 image information before rectification

File info	Layer name	Layer_1				
	Last modified	Tue Jun 18 18:33:33 2002	Number of layers	7		
Layer info	Width	2529	Height	4605	Type	Continuous
	Block Width	64	Block Height	64	Data Type	Unsigned 8-bit
	Compression	None	Pyramid Layers		2x2	
Statistics Info	Min	63	Max	255	Mean	149.009
	Median	172	Mode	83	Std. Dev.	48.969
	Skip Factor X		28	Skip Factor Y	28	
	Last Modified		Thu Mar 11 12:27:57 2004			
Map Info: (File)	Upper Left X		460112.0	Upper Left Y	981031.0	
	Lower Right X		535952.0	Lower Right Y	842911.0	
	Pixel Size X		30.0	Pixel Size Y	30.0	
	Unit	Meters	**Geo. Model:** Map Info			
Projection Info:		**Projection:** Transverse Mercator **Spheroid:** Helmert **Datum:** Old Egyptian 1907				

Table 10 1984 image information after rectification

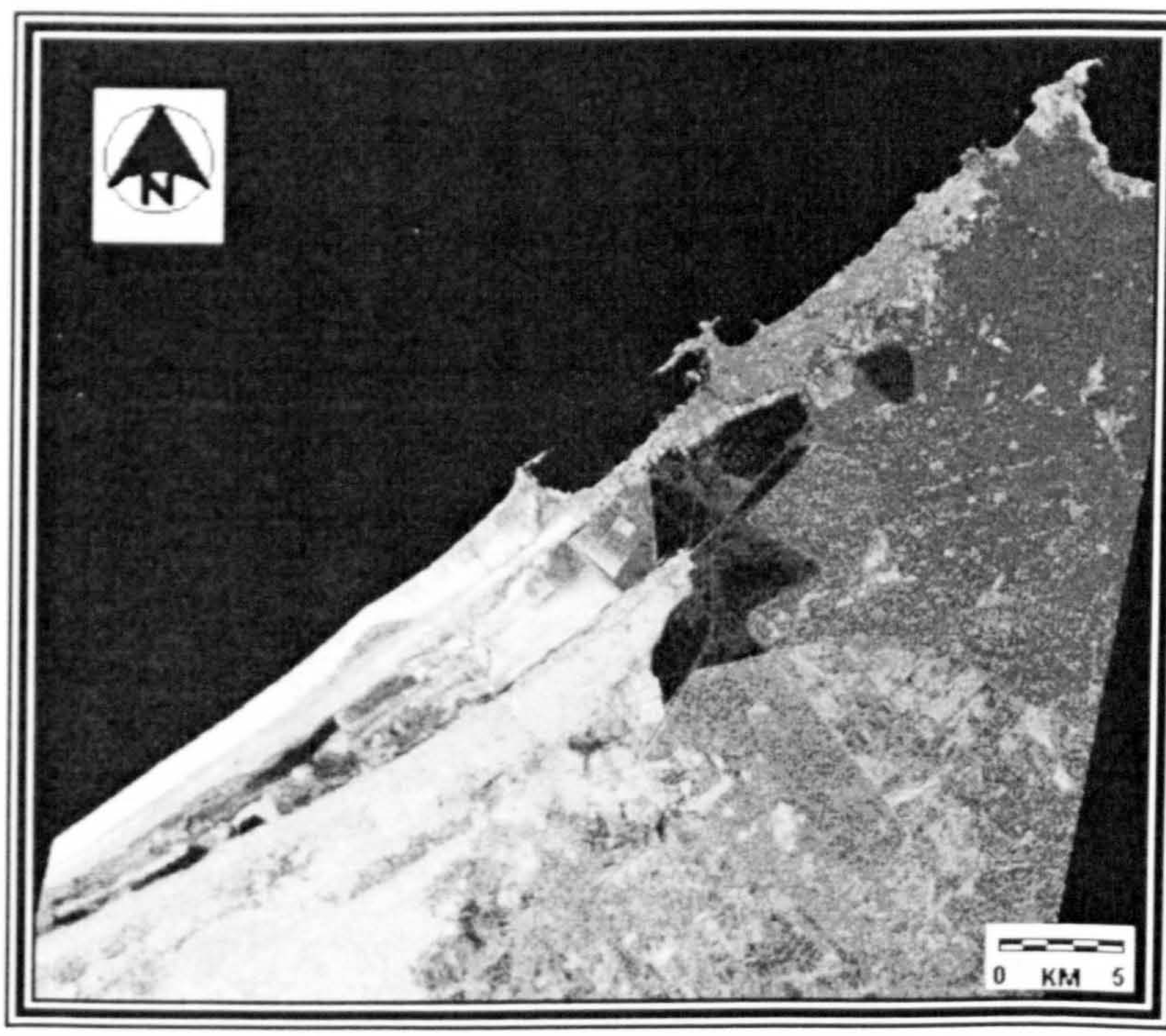


Figure 13 1984 image after rectification

2.4.2.2 Registration of 1993 image

One of the main applications of remote sensing in this study is to compare two satellite images pixel by pixel to detect the changes of land use in a certain period. As such, the pixel grids of the two images must conform to each other geographically; this process is called registration (ERDAS 1997). The 1984 image has been rectified using a Transverse Mercator Projection, therefore, the 1993 image must be registered to the 1984 image. Image-to-Image registration method was used, where the 1993 image is registered to the 1984 image. The first order transformation polynomial was applied using 39 GCPs from the reference image. The transformation matrix of 1993's image was calculated and tested. The total RMSE was less than 0.3 pixel (0.25). 1993 image was resampled using the nearest neighbour method. Table 11 displays the image information of the 1993 image before rectification and Table 12 illustrates the image information of the 1993 after rectification. Figure 14 shows the final output rectified 1993 image.

File Info	**Layer name**	Layer_1				
	Last modified	Sun Mar 11 14.07:05 2001	Number of layers	7		
Layer Info	Width	1886	Height	4169	Type	Continuous
	Block Width	64	Block Height	64	Data Type	Unsigned 8-bit
	Compression	None	Pyramid Layers		Present	
Statistics Info	Min	1	Max	255	Mean	123.928
	Median	128	Mode	86	Std. Dev.	32.552
	Skip Factor X	28	Skip Factor Y		28	
	Last Modified	Sun Mar 11 14.07:33 2001				
Map Info: (File)	Upper Left X	0.0	Upper Left Y		0.0	
	Lower Right X	1885.0	Lower Right Y		-4168.0	
	Pixel Size X	N/A	Pixel Size Y		N/A	
	Unit	Other				
Projection Info:						

Table 11 1993 image information before registeration

File info	Layer name	Layer_1				
	Last modified	Tue Jun 18 19:05:41 2002	Number of layers	7		
Layer info	Width	2574	Height	4432	Type	Continuous
	Block Width	64	Block Height	64	Data Type	Unsigned 8-bit
	Compression	None	Pyramid Layers		2x2	
Statistics Info	Min	1	Max	255	Mean	124.356
	Median	131	Mode	83	Std. Dev.	32.450
	Skip Factor X	28	Skip Factor Y	28		
	Last Modified	Thu Mar 11 12:10:39 2004				
Map Info: (File)	Upper Left X	456766.0	Upper Left Y	974015.0		
	Lower Right X	533956.0	Lower Right Y	841085.0		
	Pixel Size X	30.0	Pixel Size Y	30.0		
	Unit	Meters	Geo. Model: Map Info			
Projection Info:	Projection: Transverse Mercator Spheroid: Helmert Datum: Old Egyptian 1907					

Table 12 1993 image information after registration

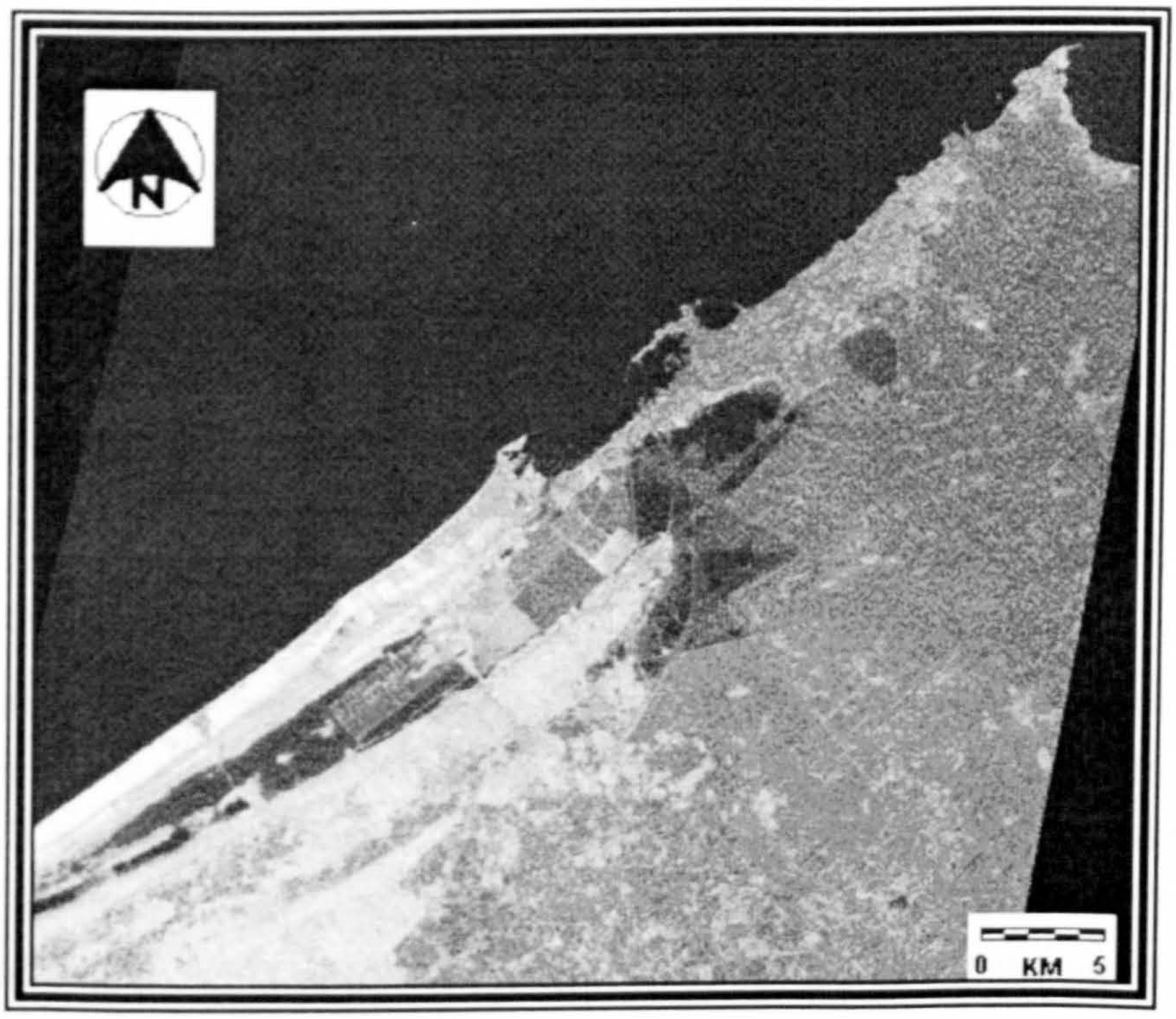


Figure 14 1993 image after registration

2.5 Data Analysis

As we have different types of data sources e.g. digital satellite images, hardcopy maps, census data, and plans, the data analysis phase is divided into two main themes; a) GIS and remote sensing analysis and, b) ancillary data analysis. The detailed explanation of these elements is introduced in the next sub-sections.

2.5.1 GIS and Remote sensing analysis

GIS and remote sensing analysis involves satellite images classification, change detection analysis, and modelling. The following sections provide an explanation of each phase.

2.5.1.1 Satellite images classification

There are some steps to classify land use/cover using satellite images:

- Selection of land use/cover classification scheme

The selection of the land use/ cover scheme for this study was not an easy task as there is a wide range of classification schemes that are being used and applied in the field of remote sensing and the associated fields. Most of the available land use/cover schemes are reviewed in detail in chapter five "Land use/cover classification in Alexandria". Despite the wide availability of classification schemes, there is no single system that can be adopted in this study for reasons that are detailed in chapter five. Thus, a user-defined classification scheme was developed for this study to be consistent with the nature of both area of study and used data. The detailed presentation of this developed scheme can be found in Chapter five.

- Selection and application of classification method

There are two types of satellite image classification; supervised and unsupervised classification. Adopting a classification method relies on different factors. In this study, a supervised classification approach was applied initially relating to the analyst's experience of the study area, but this produced inadequate separation between the target classes because of the small spectral variation between the major classes (Abdou-Azaz 2001). Therefore, unsupervised classification was applied using the ISODATA clustering method with a small number of classes (5). Unfortunately, the results were imperfect as well because of the overlap between some main classes in some parts of the area of study (Abdou-Azaz 2001). Because of this, another unsupervised classification was performed using a larger number of classes (16). Topographic maps of the study area helped in combining and recoding the classes to reduce the number of classes from 16 to 5. The overall accuracy of this classification was 88% (Abdou-Azaz 2001). Because achieving a high accuracy of land use classification is one of the most important objectives of this study to establish a good base for change detection analysis, another unsupervised classification using a larger number of classes (30) was carried out, and then the classes were merged and recoded to the pre-defined 5 classes in the customised classification scheme. The overall accuracy of the last test is 93.82% and 95.27% for 1984 and 1993 images respectively. The detailed analysis of the accuracy assessment and the final land use/cover classified satellite images can be found in Chapter five.

2.5.1.2 Change detection

As satellite images provide a repetitive coverage of the land, change detection techniques are able to record and analyse any change that might occur. The first step to detect change is to select the appropriate method, as the selected algorithm will have different impacts. Many methods have been developed to detect land use/cover change. An extensive review of the available methods is presented in chapter six. This review recommended the use of a "Post-classification comparison" method to detect land use/cover change in the area of study. This method consists of three stages; geometric correction, image classification, and finally image comparison. The method was applied in the area of study and the main changes between the two images are presented in detail in Chapter six. Moreover, quantitative analysis of the land use/cover categories was employed. The full application of change detection analysis can be found in Chapter six.

2.5.1.3 Modelling urban growth

Because of increased land use/cover change, especially in urban areas, there are many endeavours to predict potential change using modelling techniques. There are many methods to model urban growth. Some of these models were reviewed and assessed in chapter seven to select the appropriate model(s) to simulate urban growth in Alexandria. Finally, the SLEUTH model has been chosen for its ability to apply in other sites, and its compatibility with the available data. Chapter seven explains how the SLEUTH model was chosen. The SLEUTH model is an advanced product of the Clarke urban growth model that uses cellular automata (CA). The detailed information of the model can be checked in chapter seven. Model implementation involves:

- Data set preparation.
- Files transformation.
- Downloading and verifying model functions.
- Application phases.

The full details of the model application and results can be reviewed in chapter seven.

2.5.2 Ancillary data analysis

To understand the characteristics of urban growth in Alexandria, an approach based on both demographic development and physical expansion of the city itself was adopted.

2.5.2.1 Demographic development analysis

Population development in Egypt, with a focus on the urban population between 1897 and 1996, was tracked using statistical analysis. More concentrated analysis of Alexandria's population from 200 B.C. to 1996, with reference to the future projection of 2015, was applied. Demographic measures, namely population development, annual growth rate, internal migration, natural increase, population density, age-sex structure, reproductive age groups for women, family size, and crowding rate, were employed to draw the complete demographic profile of the city, which is the main controlling factor of urban growth. The detailed results of the demographic analysis are presented in chapter three.

2.5.2.2 Physical expansion analysis

Stages of urban physical expansion of the city were investigated from the establishment era up to the contemporary city. Directions and boundaries of urban growth were highlighted with reference to the development of the total built-up area. Urban growth stages were modelled using some of traditional geographical urban growth models. Chapter four provides a full explanation of the physical expansion analysis of the city.

2.5.2.3 City plans and urban growth management analysis

Countries deal with urban growth problem with different approaches. Chapter eight will commence with reviewing the previous experience in managing urban growth mainly in the developing countries. The main principles of managing urban growth are discussed in reference to the current situation in Egypt as a country –national level- and Alexandria as a city –local level-. Alexandria urban plans are reviewed as well.

2.5.3 Software used

Different computer programs were used in this study. ERDAS IMAGINE was the principal software for image processing and GIS analysis. Arc/Info and Arc View were used partly in GIS analysis. MS Excel was used for statistical analysis. Adobe Photoshop, MS Photo Editor, Imaging, and Paint were used to edit and produce pictures and figures. MS Word and EndNote were used for word processing.

3. CHAPTER THREE: DEMOGRAPHIC CHARACTERISTICS OF URBAN GROWTH IN ALEXANDRIA

3.1 Introduction

The global population has grown dramatically during the last century. Meanwhile, we have witnessed an unprecedented concentration of population into urban places around the world (Masek *et al.* 2000). Urban growth became a global phenomenon as can be witnessed in both developed and developing countries. For this reason, some authors claimed that

> "... *the global change that most of Earth's inhabitants will experience during the next decades may well be dominated by the changing demographic, economic, and environmental conditions of the world's cities, rather than by comparatively subtle shifts in climate*" (Masek *et al.* 2000:3474).

Urban growth is just one of many ways in which humans are altering the land cover of the globe. Human activities in land cover transformations are estimated to have significantly altered more than 80% of the Earth's land area over the last several centuries (Masek *et al.* 2000).

Masek et al (2000) argue that the critical importance of linking the observed land cover changes to the driving socio-economic or environmental factors. They declared that;

> "The *geography of urban growth offers a graphic depiction of the interplay between economics, political systems, and the environment*" as the growth of the cities reflects " *a multitude of conscious choices made by individuals and institutions reconciling these competing factors for their own 'best interests'*"(Masek *et al.* 2000:3474).

To understand the characteristics of urban growth in Alexandria, an approach based on both demographic development and physical expansion of the city itself will be adopted. Hence, it is suggested that the urban growth in any given city can be monitored using demographic data as an indicator for population characteristics, and city expansion to support the hypothesis of urban growth as the growing population leads to both vertical and horizontal developments in the built up areas. In this chapter, demographic characteristics will be discussed starting with a brief introduction on population growth generally, and urban population specifically in Egypt. The following sections will focus on urban population in Alexandria. Population development in Alexandria will be examined from 200 B.C. up to 2015 with much detailed study of demographic indicators. The chosen indicators are; annual growth rate, internal migration, natural increase, population density, age-sex structure, reproductive age groups for women, family size, and crowding rate. These demographic indicators may provide a clear idea of population growth as a motive for city expansion.

3.2 Population growth

3.2.1 Population growth in Egypt

Egypt is the most populous Arab country with a population of 59.3 million in 1996. Its population was 9.7 million in 1897. It doubled within fifty years to more than 18 million by 1947. It multiplied by two for the second time within thirty years to 36.6 million between 1947 and 1976. Also, the population increased from 36.6 millions to 59.3 millions between 1976 and 1996 (CAPMAS 1999). In general, the Egyptian population increased by almost six times since the beginning of the 20th century and by almost three times from 1947 to 1996.

The population grew slowly at an average rate of 1.3 percent per annum from 1897 to 1947, but this rate was accelerated greatly after World War II. The annual growth rate was around 2.3 percent between 1947 and 1976 when it dropped to 2.2 percent due, in part, to postponement of marriage, reductions in marital fertility (because of the 1973 War), and to some changes in age structure echoing the effects of World War II. Once these temporary effects passed, the rate of population growth rebounded to 2.75 percent between 1976 and 1986. Since that period, it has begun to fall as decreases in birth rates have exceeded continuing decreases in the crude death rate (Cochrane *et al.* 1995). The current population growth rate of about 2.1 percent per annum is one of the lowest in the region, (Table 13).

Census periods	National Annual growth rate (%)
1897-1907	1.46
1907-1917	1.28
1917-1927	1.09
1927-1937	1.16
1937-1947	1.75
1947-1960	2.34
1960-1976	2.22
1976-1986	2.75
1986-1996	2.08

Table 13 Population annual growth rates in Egypt between 1897 and 1996 (CAPMAS 1993)

3.2.2 Urban population development in Egypt

It is worth examining the situation of urban population in Egypt as a whole to provide a better understanding for the urban growth phenomenon in the area of study. Egypt has 26 governorates, of which four are totally urban. The urban governorates are Cairo, Alexandria, Port Said, and Suez. All these governorates are located in the north of Egypt, (Figure 15).

In spite of the continuous increase of the population of urban governorates, the percentage of urban governorates population is declining. This percentage represented about 21.84 % of total population in Egypt in 1966 and started to fall in the following census to 21.43% in 1976, 20.15% in 1986, and 18.68% in 1996, table 14. In addition, this is not only for urban governorates but also for the whole urban population in Egypt where the percentage was 44% in 1986 and 43% in 1996, (Table 15). These figures are totally in contrast to the projected trends of urban population in Egypt that are produced by UN (UNCHS 2001), (Table 16).

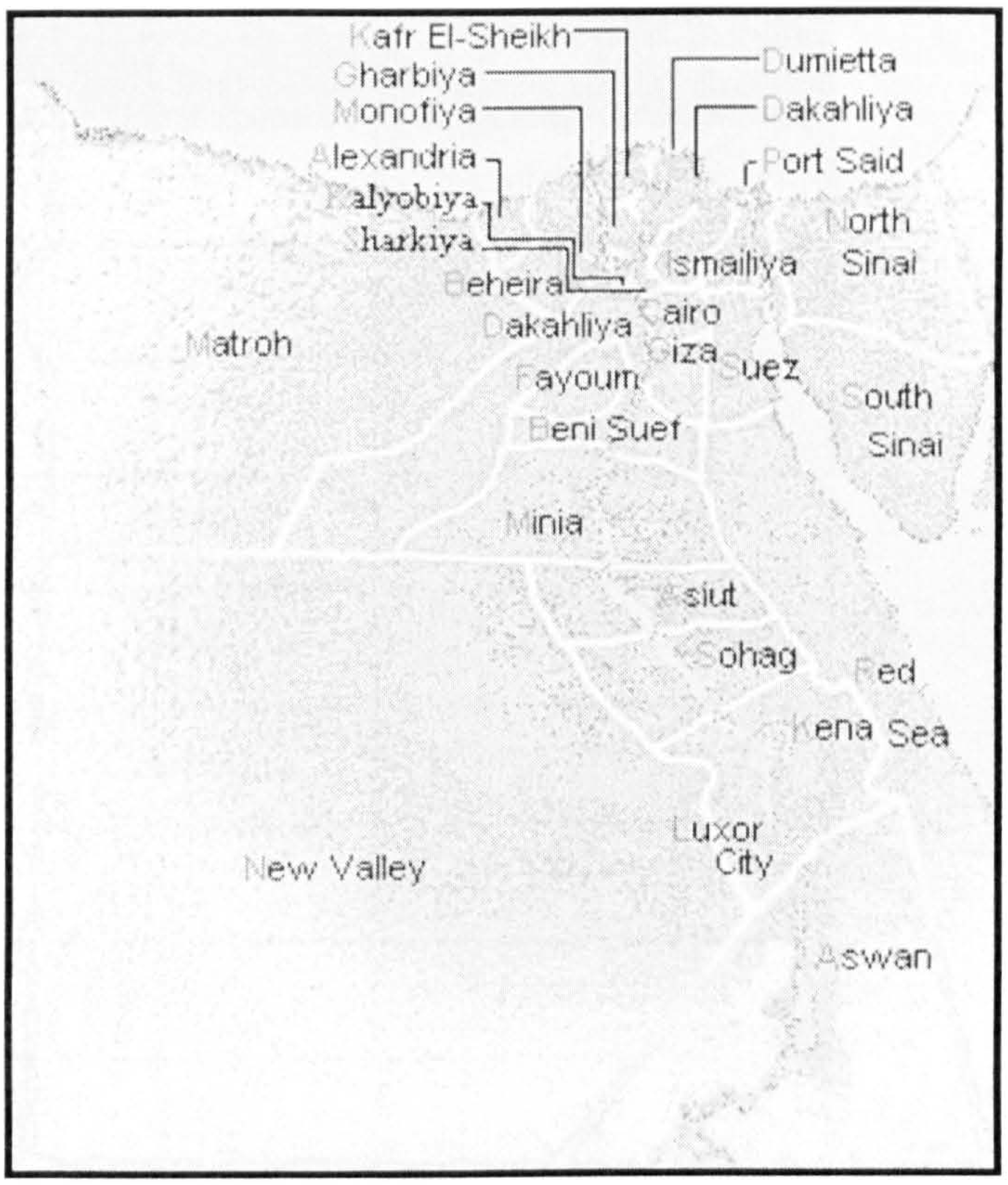


Figure 15 Egypt governorates (IDSC 2004)

	1966	1976	1986	1996
Cairo	14.03	13.85	12.58	11.5
Alexandria	5.99	6.33	6.06	5.6
Port-said	0.94	0.72	0.83	0.9
Suez	0.88	0.53	0.68	0.68
Total	21.84	21.43	20.15	18.68

Table 14 Percentage of urban governorates population in Egypt between 1966 and 1996 (CAPMAS 1999)

This is an interesting and important finding; Egypt has started to witness an *urban decline era* instead of the long history of urban growth regardless of the continuous increase in total population. Indeed, this phenomenon needs more investigations to understand its driving forces.

Year	% of urban population
1907	17.2
1927	26.9
1937	28.2
1947	33.5
1960	38.2
1966	40
1976	43.8
1986	44
1996	43

Table 15 Percentage of Population Residing in Urban Areas in Egypt (CAPMAS 1999)

Year	% of urban population
2000	45.2
2005	46.6
2010	48.7
2015	51.2
2020	54.2
2025	57.1
2030	59.9

Table 16 Projections of population residing in urban areas in Egypt (Habitat) 2002)

The total population of urban governorates was approximately 11 million in 1996, and this represents about 43.7% of urban population in Egypt, (Table 15). Cairo is the first and the largest governorate and city in Egypt with a population of 6.8 million in 1996. This size makes Cairo 11.5%, 26.9%, and 61.7% of total population, urban population, and urban governorates population respectively, (Table 17).

Governorate	Population	% of total population	% of urban population	% of urban governorates
Cairo	6800992	11.5	26.9	61.7
Alexandria	3339076	5.6	13.2	30.3
Port-said	472335	0.9	1.9	4.2
Suez	417527	0.68	1.7	3.8
Total	11029930	18.68	43.7	100

Table 17 Urban governorates population and its percentages from total, and urban population, and urabn governorates in Egypt 1996 (CAPMAS 1998)

3.3 Urban population in Alexandria

3.3.1 Population development

Alexandria had experienced fluctuating population growth for about twenty centuries during its long history from 200 B.C. up to 1897 A.D, (Table 18). Alexandria started the first" *population peak"* during the Greek era, when the city was similar to most Greek ancient cities so that a large number of Greek people migrated to the city increasing the population to 325,000 in 60 B.C. (Abdel-hakeem 1958), (Table 18). Later, the city saw fluctuating demographic development according to different political conditions such as foreign invasions, occupations and conquests. But, Alexandria started to develop a continuous "population growth" from the middle of the ninetieth century during the Mohamed Ali era with his development projects especially "El-Mahmoudya Canal" in 1821. As the population figures before 1897 were "estimations" from different sources rather than accurate statistics by official census, they will not be considered to investigate urban growth in the city. This brief review of population development in Alexandria since its establishment is important as it proves that the city experienced variable population growth during about 19 centuries and the city started to witness continuous urban growth recently in the last 150 years only.

Year	Population	Year	Population
200 B.C	300,000	***1250***	55,000
60 B.C.	325,000	***1300***	65,000
100 A.D. ROME	250,000	***1350***	60,000
250 A.D. SHARP DECLINE 250-350	150,000	***1384***	50,000
361/ ROME	125,000	***1400***	40,000
500 SOME DESTRUCTIVE RIOTS, BYZANTIUM	100,000	***1500***	35,000
622 PERSIA	94,000	***1693*** **TUREKY**	15,000
730	90,000	***1798***	4,000
800 ARABIA	95,000	***1828***	12,528
860	100,000	***1848***	134,000
881	160,000	***1850***	138,000
900	175,000	***1862***	164,400
1175	45,000	***1875***	212,000
1200	50,000	***1897***	315,844

Table 18 Alexandria's population from 200 B.C. until 1897 A.D. (Chandler 1987)

The population of Alexandria was 315,844 according to 1897 census. It was nearly doubled for the first time within about thirty years in 1927 to become 573,063. It was increased twofold again between 1917 and 1947 from 444,617 to 919,024 in 1947. Alexandria started its membership in "million-city club" in the beginning of 1950s. The population of Alexandria became 1,516,234 in 1960 and it almost doubled again in about 26 years in 1986 to be 2,896,459, (Table 19).

Year	Population	Year	Population
1897	315,844	**1960**	1,516,234
1907	353,807	**1976**	2,303,539
1917	444,617	**1986**	2,896,459
1927	573,063	**1996**	3,339,076
1937	685,736	**2015**	5,400,000
1947	919,024		

- *Data up to 1986 from (Abdou-Azaz 1997)*

  Data of 1996 from (CAPMAS 1999)and projected data of 2015 from (UN 1997)

Table 19 Urban growth in Alexandria from 1897 to 2015

The current population in the city according to the final results of 1996 census is 3.3 million, which means the city population increased by ten times in about 100 years, and the city is projected to have population of 5.4 million by 2015 (Table 19).

Alexandria, with this population size, was ranked 62 at the international level in 1996 and it is expected to be 54 in 2015 (UN 1997). Its rank is the fifth in Africa (UN 1997), and is the third largest city in the Arab world (UNCHS 2001) .

At the national level, Alexandria is the seventh governorate in Egypt. The rank of Alexandria nationally was the sixth in all census up to 1986 but it became seventh loseing its place to the Al-Gharbya governorate according to the final results of 1996 census (CAPMAS 1999). It consists of 5.6%, 13.2%, and 30.3% of total population, urban population, and urban governorates population of Egypt in 1996, table 17.

Between urban governorates, Alexandria is the second largest urban governorate after Cairo and it seems that it will keep its position permanently as there is a great distance between Alexandria and the other two urban governorates (Port-Said and Suez). The population of Alexandria represented 5.6% of Egypt's total population in 1996, while, the share of Port-said and Suez is only 0.9% and 0.68% in the same period (CAPMAS 1999), (Figure 16).

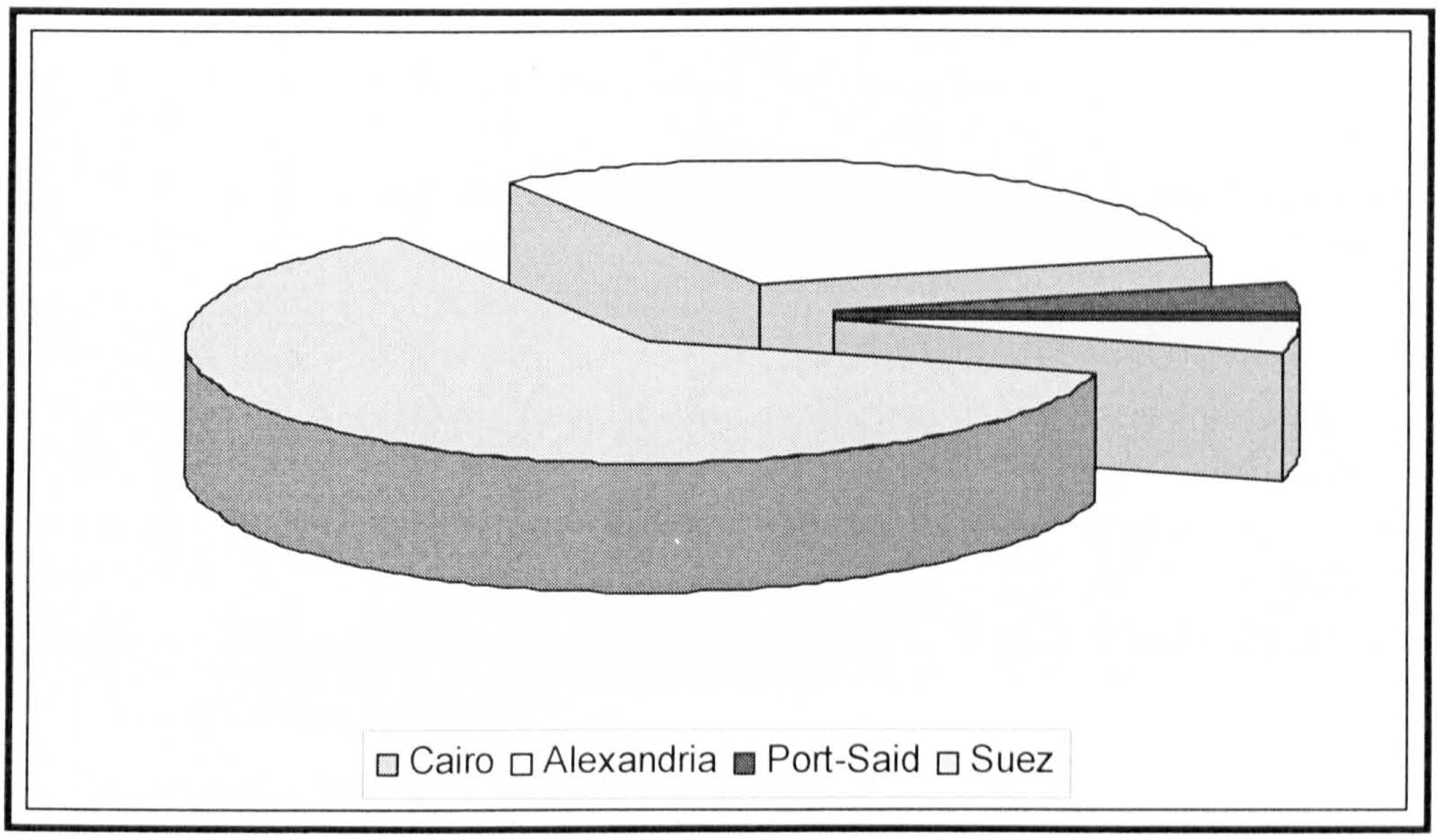


Figure 16 Urban Governorates Shares in population in 1996

3.3.2 Annual growth rate

High growth rates in Alexandria between 1897 and 1976 have fuelled the growth of the city and contributed to its distinguishing demographic structure, Table 20. Alexandria growth rates were higher than the national rates for seventy years within the period of (1907-1976). Alexandria growth rates were almost double the national rates until 1960, Table 20.

The annual growth rates of Egyptian cities are higher than the growth rates of rural areas because of rural migration to urban centers. The growth rates of Alexandria between 1927 and1937 dropped to just 2% because of the effects of

"The Great Depression" in Egypt at that time. This decrease also happened in Cairo as well (Abdel-hakeem 1958).

Census periods	Alexandria Annual growth rate (%) (A)	National Annual growth rate (%)(B)	Index of trend (A) / (B)
1897-1907	1.2	1.46	0.82
1907-1917	2.6	1.28	2.03
1917-1927	2.9	1.09	2.66
1927-1937	2	1.16	1.72
1937-1947	3.4	1.75	1.94
1947-1960	5	2.34	2.14
1960-1976	3.3	2.22	1.49
1976-1986	2.6	2.75	0.95
1986-1996	1.5	2.08	0.72

- *Alexandria annual growth rate up to 1986 from (Abdou-Azaz 1997), and the rate of the last period was calculated by the author.*
- ***National annual growth rate from** (CAPMAS 1999)*

Table 20 Urban annual growth rate in Alexandria and Egypt

The growth rate begun to increase again in the following census up to 1976, and started to decline for the second time from 1976 up to the last census (1996), Table 20. The trend of annual growth rates confirms the fact of *Urban decline Era* in Egypt. The high success of the family planning programmes in Egypt generally, and in the urban areas especially may explain the growth rate' lessening.

Likewise, the percentage of Alexandria population from the total population in Egypt has increased regularly from 1907 to 1976, and it doubled within seventy years from 3.16% to 6.33 %, Table 21. It started to decrease to 6.06% from 1986 and it became 5.6% in 1996. This means Alexandria's share of Egypt's population dropped by 11.5% in twenty years.

Census Years	*% from total population*	*% from urban population*
1897	3.27	*
1907	3.16	18.33
1917	3.50	*
1927	4.04	15.04
1937	4.31	15.27
1947	4.85	14.44
1960	5.80	15.22
1976	6.33	14.36
1986	6.06	13.65
1996	5.60	13.21

- *The percentages from total population up to 1947 were calculated by the author, and the rest from (CAPMAS 1999).*
- *The percentages from urban population were calculated by the author.*
- ** Data not available.*

Table 21 Development of population percentage in Alexandria (National/ urban levels) between 1897 and 1996

From total Egyptian urban population , Alexandria population formed about 15% - as an average- between 1927 and 1960, table 21. However, this percentage went down slightly in 1947 and this can be understood because of World War II. In 1976, this value started falling to 14.36% and it has 13.21% in 1996. This also means Alexandria's share of the urban population declined by 27.9% between 1907 and 1996, Table 21. In spite of this remarkable decline in the percentage of population residing in Alexandria, Habitat (2002) expected an increase in the percentage of Egypt, table 22.

1980	1985	1990	1995	2000	2005	2010	2015
5.8	5.7	5.7	5.9	6	6.2	6.3	6.5

Table 22 Percentage of total population residing in Alexandria, 1980-2015 with five - year intervals (UNCHS 2002)

3.3.3 Internal migration

The role of internal migration as a *feeding branch* was very important in the structure of the population growth in Alexandria up until the middle of the twentieth century. Sufficient job opportunities in the new industrial projects and Alexandria port attracted a sizable number of migrants from the adjacent governorate "Al-buhyra" and even from the distant governorates in Upper Egypt such as "Souhag" and "Assyout". Internal migration to Alexandria formed more than half - as an average - of the total increase from 1907 to 1947, Table 23. There is a dramatic decline in this percentage between 1927 and 1937 because of the economic difficulties in Egypt at this time.

Census periods	Total increase	Natural increase	Internal migration	% Natural increase	% Internal migration
1907-1917	90,810	40,564	50,236	44.7	55.3
1917-1927	128,446	51,053	77,393	39.8	60.2
1927-1937	112,673	108,159	4,514	96	4
1937-1947	233,288	121,146	112,152	51.9	48.1
1947-1960	566,521	452,024	113,317	80	20
1960-1976	787,145	672,965	114,180	85.5	14.5
1976-1986	609,154	586,791	22,363	96.3	3.7
1986-1996	442,617	581,000 (1995)	-138,383	131.26	-31.26

- *Data up to 1986 from (Abdou-Azaz 1997)*
- *Data of 1986-1996 total increase was calculated by the author, and the natural increase of the same period from (GACP 1997)*

Table 23 Elements of total increase in Alexandria

In the second half of the twentieth century, the contribution of this factor started to collapse from 48.1% in 1947 to 20% in 1960 and to 14.5% in 1976. It shrank to 3.7% in 1986, the input of internal migration in demographic structure in

Alexandria stopped completely in the 1990s and the city lost about a third of its total increase (32.3%) in 1996, (Table 23). This change in the role of internal migration is due to the difficulties in getting jobs in the city and other urban centres in the country, which directed a major part of the past internal migration to the Gulf States.

To understand the role of internal migration in total population increase in Alexandria, the internal migration rates will be investigated at micro level inside Alexandria. The level will be "Al-Qism". Alexandria has six "Ahyaa" or districts, Each "Haiey" or district has a number of "Qisms". "Al-Qism" is the area that is served by a certain police station. Alexandria consisted of 13 Qisms in 1986.

"Qisms" of Alexandria can be categorized into two according to the role of internal migration rates:

- **Sender (exporter) Qisms;** these qisms are characterised by negative migration. This means that the population in these parts are decreasing regardless of the misleading population increase figures because of the population movements. This group includes more than half of qisms of the city. These qisms are Bab Sharky, Moharrm Bey, El-Attareen, El-Manshia, Karmous, El-Laban, and El-Gomrok, (Table 24). All these qisms are located in the old core of Alexandria city, (Figure 17). These parts are believed to have reached a demographic *saturation point* and started to loose part of its population. The new families face many difficulties in finding new homes with affordable prices in the old city, so, they move to where many alternatives are available in the "capturing qisms" at the city fringe. Some of that population is believed to have moved to other governorates in Egypt such as Cairo to work and live. Another three qisms; namely El-Ramel, Sidi-Gaber, and Mena Elbassal are expected to join this group in the next decades.

- **Receiver (capturing) Qisms;** these qisms have positive migration rates. These qisms are; El-Montazah, El-Ramel, and Sidi-Gaber in the east, and Mena-Elbassal, El-Dekhyla, and Elamrya in the west, (Figure 17). These qisms receive migration from both "Sender Qisms" in the city and from other governorates as well. El-Montazah and El-Dekhyla have the highest migration rates in this group, (Table 24). El-Montazah contains most of the agricultural lands in the city that need labour. Most of the workforce comes from the neighbouring governorate "El-Buhyra". El-Dekhyla and Elamrya are the sites of the new industrial projects that attracted population from inside and outside Alexandria.

Qism	*Total increase rate*	*Natural increase rate*	*Migration rate*
El-Montazah	6.5	2.6	3.9
El-Ramel	3.1	2.3	0.8
Sidi-Gaber	1.7	1.2	0.5
Bab Sharkey	-0.6	2.2	-2.8
Moharrm Bey	0.2	2	-1.8
El-Attareen	-1.3	1.6	-2.9
El-Manshya	-1.7	2.5	-4.2
Karmous	-0.7	2.4	-3.1
El-Laban	-1.7	2.5	-4.2
El-Gomrok	-1.5	2	-3.5
Mena Elbassal	2.7	1.9	0.8
El-Dekhyla	7.2	3.1	4.1
Elamrya	4.1	1.7	2.4

Table 24 Annual rates for total, natural, and internal migration in Alexandria (Qisms) between 1976-1986 (Abdou-Azaz 1997)

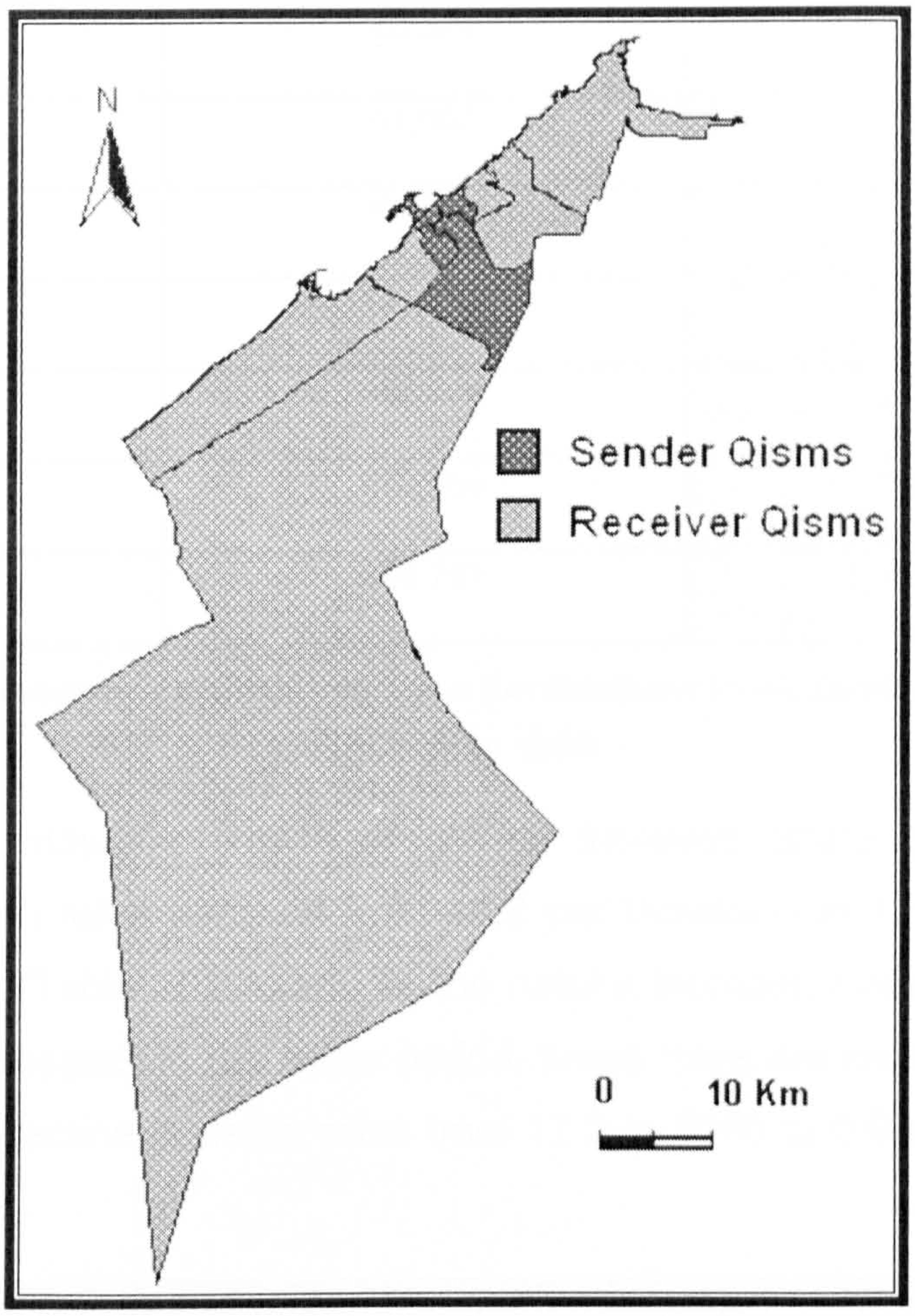


Figure 17 Receiver and Sender Qisms in Alexandria between 1976 and 1986

3.3.4 Natural increase

Population growth results from the interaction of three variables: births, deaths, and migration. The difference between births and deaths in a population produces the so-called natural increase. Natural increase usually accounts for the greatest amount of growth in a population, especially within a short period (Bureau 2004).

The function of natural increase in Alexandria's population structure started to take a lead in the second half of the twentieth century when it formed 80% of total increase between 1947 and 1960, and reached a peak (96.3%) between 1976 and 1986, (Table 25).

Census Periods	Natural Increase	Internal migration
1907-1917	40,564	50,236
1917-1927	51,053	77,393
1927-1937	108,159	4,514
1937-1947	121,146	112,152
1947-1960	452,024	113,317
1960-1976	672,965	114,180
1976-1986	586,791	22,363

Table 25 Natural increase and internal migration development in Alexandria between 1907-1986 (El-mahdy 1993)

Despite of the continuous growth of natural increase share in Alexandria's population, the birth rates declined from 44.2 per thousand in 1960 to 27.5 per thousand in 1989, (Table 26). Although, the natural increase rates reduced from 27 to 20.6 (per thousand) in the same period, these rates are kept high because of the continuous decline in death rates from 17.2 in 1960 to 6.9 in 1989, (Table 26).

Years	*Crude birth rate (per thousand)*	*Crude death rate (per thousand)*	*Natural increase rate (per thousand)*
1960	44.2	17.2	27
1965	36.5	12.9	23.6
1970	30.6	12	18.6
1975	29.1	9.5	19.6
1980	30	7.8	22.2
1985	32.7	7.3	25.4
1989	27.5	6.9	20.6

Table 26 Birth, death, and natural increase rates in Alexandria between 1960-1989 (El-mahdy 1993)

3.3.5 Population density

Density gives a better understanding about how population concentrates and distributes over the built-up area. Furthermore, density development figures can help in explaining *demographic mobilisation* within and in to the city. Table 27 illustrates the population density (capita / Km²) in Alexandria qisms between 1976 and 1996.

The population density general trends are high in all sender qisms. All the sender qisms suffer from demographic pressure in all censuses as between 1976 and 1996. El-Gomrok has the highest density in Alexandria in this period, table 27.

Qism	1976	1986	1996
El-Montazah	1,666	3,333	7,927
El-Ramel / Sidi-Gaber	50,228	68,320	66,948
Bab Sharkey	23,805	22,377	11,434
Mohrram Bey	87,602	89,268	79,250
El-Attareen	37,136	32,375	24,326
El-Manshya	78,556	65,939	47,164
Karmous	64,511	59,512	44,779
El-Laban	43,563	36,897	39,010
El-Gomrok	133,307	114,263	92,063
Mena Elbassal	13,569	17,854	17,487
El-Dekhyla	1,666	3,333	6,745
Elamrya	19	45	90

- *Data of 1976 and 1986 from (Abdou-Azaz 1997)*
- *Data of 1996 from (CAPMAS 1998)*

Table 27 Population density in Alexandria's Qisms (km²)

However, there is a clear declining trend in density in this qisms and this can be explained by the same factors of decreasing migration rates in the (internal migration) section. In contrast, most of the capturing qisms at the city fringe, specifically, El-Montazah, El-Dekhyla, and Elamrya, witnessed an increasing tendency in population density. These qisms doubled in density - as an average - every ten years (between the censuses).

This trend is expected to continue, especially in the Elamrya qism with the large amount of available land for urban development which represents 80.9% of the Alexandria governorate in 1996 (GACP 1997). The large area of this qism makes the population density very small (i.e. 90/km² in 1996), but the share of this qism in Alexandria's population is 6.8 % in 1996 which is higher than the share of the most populous qism (El-Gomrok) which is 2.95% in the same year (CAPMAS 1998).

Moreover, the average population density in informal housing areas in the city is more than the most dense qisms, with a density of 100,694 inhabitants per km² (Abdou-Azaz 1997), as they receive population from both other governorates and the new middle-class families from the city as well.

3.3.6 Age-sex structure

Age-sex structure is one of the helpful methods to understand the internal demographic structure of urban growth in cities. In this approach, the percentage of young population defines the potential of urban growth. Table 28 illustrates the distribution of population using broad age intervals in Alexandria (1986-1996). About the third of the population is young (under 15) in both censuses (1986, 1996). However, there is a decreasing trend in this group where the percentage was 34.4% in 1986 and became 31.6% in 1996.

Years	***(0-15)***	***%***	***(15-64)***	***%***	***(64+)***	***%***	***Total***	***%***
1986	1,001,007	34.4	1,817,722	62.4	92,934	3.2	2,911,663	100
1996	1,054,848	31.6	2,161,210	64.7	123,018	3.7	3,339,076	100

Table 28 Distribution of population using broad age intervals in Alexandria (1986-1996)

Moreover, the percentage of population (64+) is increasing slightly from 3.2 % in 1986 to 3.7 % in 1996 due to the improvements in health services. This will lead also to increase in the life expectancy.

Probabilities of migration typically peak during a person's late teenage years or in their early twenties (Guest 1994). In Table 29, the growth of the population aged 15-24 is shown for the period between 1986 and 1996. As the majority of migrants are males, we can easily notice the slightly higher percentage of males in these age intervals in both censuses (1986, 1996). As a general trend, the percentage of females is approaching the normal size in 1996 as the role of internal migration starts to weaken as shown before.

Age groups	1986			1996		
	Male	Female	Total	Male	Female	Total
15-	51.3	48.7	100	51.2	48.8	100
20-	51.2	48.8	100	50.4	49.6	100
Total	51.3	48.7	100	50.8	49.2	100

Table 29 Distribution of population according to migration age (15-24) in Alexandria (1986-1996)

3.3.7 Reproductive age groups for women (15-49)

Guest (1994) claims the distinctive demographic structure of mega-cities is characterized by a young population, with a high proportion of females in the reproductive age groups (Guest 1994). The reproductive age for women is between 15 and 49. This group represented 26% of the total population in 1986 and increased to 27.1% in 1996. This means that there is a great chance for future population growth in the city especially when we know that the natural increase became the only branch that fed the total population as the role of internal migration started to vanish. Nevertheless, this potential growth may be hindered by socioeconomic factors that lead to delay in marriage in Egypt generally.

3.3.8 Household size and crowding rate

As an expected result of the falling rates and percentages of annual growth of the population in the city, there is a decline trend in the percentage of Alexandria population from the total and urban population, internal migration, and population density in the old core of the city. In addition, the household size is declining in the city, (Table 30).

Qism	Household Size		Crowding Rate	
	1986	1996	1986	1996
El-Montazah	4.42	4.3	1.39	1.3
El-Ramel	4.57	4.1	1.53	1.3
Sidi-Gaber	4.07	3.9	1.17	1.2
Bab Sharkey	4.28	3.7	1.28	1.1
Mohrram Bey	4.59	4	1.57	1.3
El-Attareen	4.44	3.8	1.37	1.1
El-Manshya	4.46	3.4	1.45	1.3
Karmous	4.63	3.9	2.03	1.7
El-Laban	4.6	3.7	1.8	1.5
El-Gomrok	4.28	3.6	1.49	1.3
Mena Elbassal	4.74	4.2	1.84	1.7
El-Dekhyla	4.39	3.6	1.53	0.8
Elamrya	5.09	4.1	1.66	1.4
Total	4.51	4.1	1.51	1.3

Table 30 Household size and crowding rate in Alexandria's Qisms between 1986/1996 (CAPMAS 1989) and (CAPMAS 1998)

The average household size is 4.1 in 1996, compared with 4.51 in 1986, which means a decrease of 9.1%. The parts of the old city saw a larger fall in the rate, in El-Manshya (23.8%), El-Laban (19.6%), and El-Gomrok (15.9%). This can be interpreted by the moving of new households, leading to a lessening in the size of their original households. Indeed, there is a strong and obvious relationship between household size and crowding rate per room. The higher, the household size, the higher is the crowding rate, and vice versa.

In table 30, it is easy to notice that the crowding rate follows the household size, when the household size is large; the crowding rate is large as well. When the household size falls, the crowding rate falls as well. These declining crowding rates can be explained by the same factors, which affect household size. In spite of these declining rates in all city areas, the districts in the city edges keep relatively high values of crowding rates and household sizes.

3.4 Summary and conclusions

This chapter revealed one of the most important findings. There is an emerging decline in urban population in Egypt. These findings are totally in contrast to the UN projections of urban population in Egypt. Egypt seems to have started to witness an *urban decline era.* Indeed, this astounding phenomenon needs more investigations to understand its driving forces.

At city level, Alexandria began to experience a continuous population growth from the middle of 19th century during Mohamed Ali era up until the end of 20th century. City population increased by ten times in about 100 years from 315,844 in 1897 to 3.3 million in 1996. However, the rank of Alexandria nationally was the sixth in all censuses up until 1986 but it became seventh leaving its place to Al-Gharbya governorate according to the results of 1996 census.

Alexandria growth rates were higher than the national rates for seventy years within the period of 1907-1976. During the 20th century, growth rates dropped off twice; the first between 1927 and 1937 because of the effects of the Great Depression. The second was between 1976 and 1996, and it is due to the high success of the family planning programs in Egypt generally, and in the urban areas especially. The decrease in growth rates led to a drop in Alexandria's share of Egypt population by 11.5% between 1976 and 1996. In addition, Alexandria's share in Egyptian urban population was declined by 27.9% between 1907 and 1996.

Another finding, the role of internal migration in Alexandria, changed from a *feeding branch* of the total population up to 1986 to a *loss source* from the total population by the end of the 20th century. This change in the role of internal migration is due to the difficulties in getting jobs in the city. Qisms of Alexandria can be categorized into two parts according to the role of internal migration rates: sender and receiver qisms. The sender qisms are characterised by negative migration rates. All these qisms are located in the old core of Alexandria city that are believed to have reached a demographic *saturation point* and started to lose part of their population to the capturing qisms at the city fringe and to the other governorates in Egypt. On the other hand, the receiver qisms have positive migration rates. These qisms receive migration from both Sender Qisms in the city and from the other governorates as well. In the same context, all the sender qisms suffer from demographic pressure in all censuses between 1976 and 1996. However, there is a clear decline trend in density in these qisms and this can be explained by the same factors of negative migration rates. On contrast, most of the capturing qisms at the city fringe witnessed a boosted tendency in density.

The function of natural increase in Alexandria population structure started to take the lead from the second half of the twentieth century when it formed 80% of total increase and reached its peak (96.3%) in 1986.

Females in the reproductive age groups (15-49) represented 26% of the total population in 1986 and increased to 27.1% in 1996. This means that there is a chance for future population growth in the city especially when we know that the natural increase became the only branch that feeds the total population as the role of internal migration starts to vanish.

In addition, the family size is declining in the city; the average family size is 4.1 in 1996 when it was 4.51 in 1986, which means a decrease by 9.1%. The parts of the old city saw a higher rate of fall; this is because of the moving of new smaller families that leads to lessening in the size of their original extended families.

However, there is a drop also in the family size in the edges of the city, which may be explained by the high availability of flats, which is higher than the demand in these parts.

Urban growth can be monitored using a two-dimensional approach: demographic and physical growth of the city. This chapter has dealt with the demographic dimension. Chapter four will deal with physical expansion.

4. CHAPTER FOUR: PHYSICAL EXPANSION OF ALEXANDRIA

4.1 Introduction

In the current chapter, the physical expansion of the city will be investigated since its establishment. Reviewing urban expansion in Alexandria from its establishment is very important for many factors. First, as physical expansion of any city follows population growth, and population growth was discussed as early as establishment stage in the previous chapter. Therefore, it is important to synchronise physical expansion analysis with previous demographic analysis to link between the cause (population growth) and effect (physical expansion). Second, reviewing previous growth stages will be used as a base for predicting future urban expansion (chapter seven). Moreover, such review will help in modelling urban growth stages at the end of this chapter. Within this historical review, the directions and the boundaries of urban growth will be highlighted. The development of the total built-up area will be discussed as well.

4.2 City growth stages

4.2.1 Establishment and first boom era (331 BC- 641 AD)

Alexander The Great founded Alexandria 331 BC. Alexander established several Alexandrias, the most famous being in Egypt (Hilberseimer 1955). Forster (1986:8) claimed, *"Few cities have made so magnificent an entry into history as Alexandria."*

On the road to the Mediterranean coast, an isthmus - separating the sea from Maryout lake - fascinated Alexander the Great. He found this site was suitable to build a great city because of many advantages such as: *a)* Superfluity of water supply from the Nile through its Canopian branch, *b)* The possibility of connecting a small island (Pharos) to this site and this island can be considered as a front line defiance for the potential city, *c)* Maryout lake also can offer another defense line in the south (Mahgoub et al. 2000).The

Macedonian ruler's overall purpose was to bring Egypt closer to the Greek world, and he wanted to found a new port that would not be affected by the Nile floods (Empereur 2002). Alexander commissioned his architect Dinocrates of Rhodes to prepare new city plans. Dinocrates designed its layout on a gigantic scale that was to impress the ancient world. Applying Aristotle's principles for planning the ideal city, a rectangle grid of streets was patterned, orientated in such a way as to profit from the sea breezes, or conversely to provide shelter from the wind (Empereur 2002), (Figure 18).

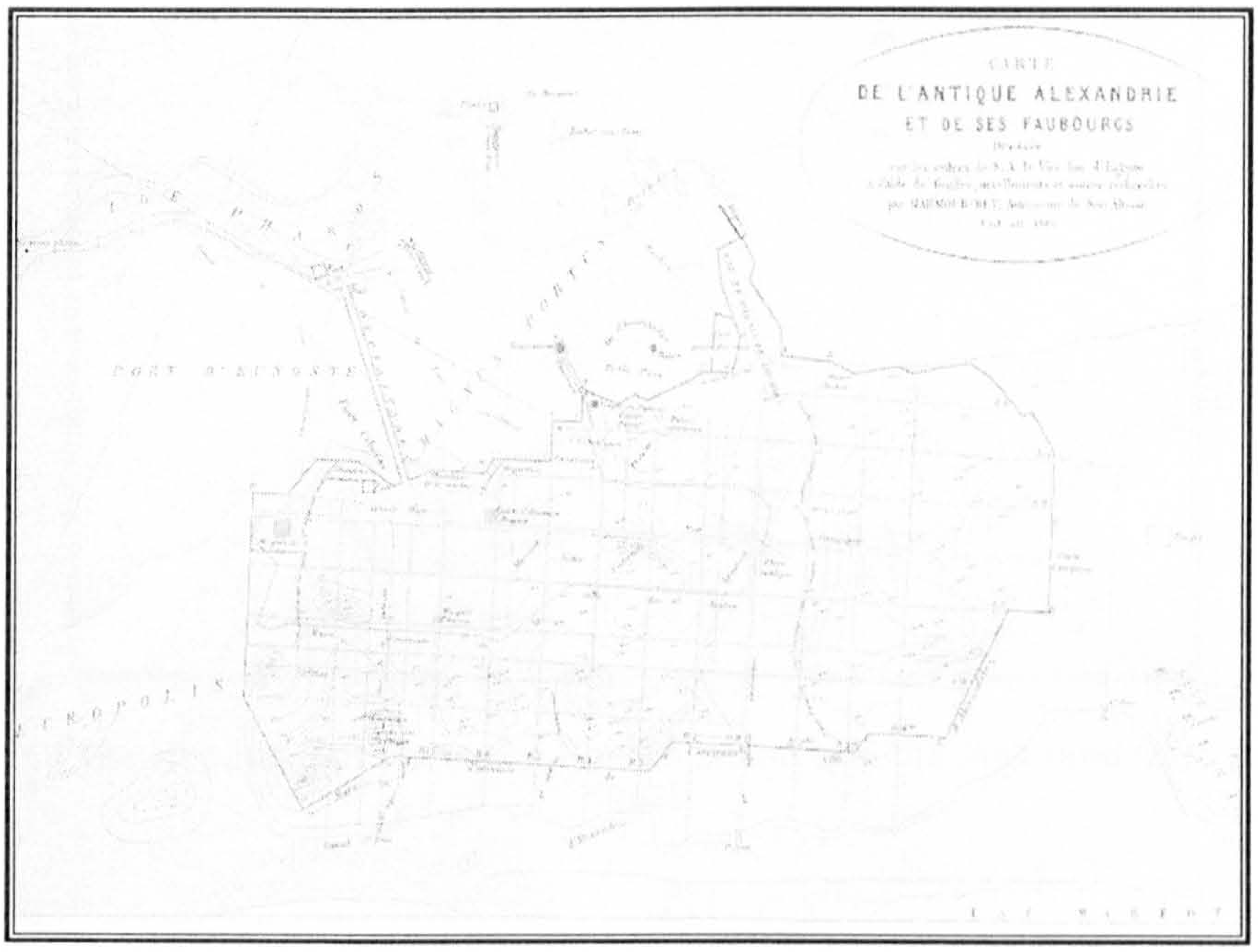


Figure 18 Map of ancient Alexandria by Mahmoud El-Falaki (1866) published in 1872 (Fattah 1998)

This "grid pattern" was very common to many of the ancient cities since the 5th century BC (Mahgoub et al. 2000). The Hepastadium (causeway) of 7 *stadia* (1169 m) in length was the bridge that connected the Pharos Island to the mainland of the city, (Figure 19). The eastern port *"Megas Limen"* or "great port" and western port *"Eunostos"* or "port of good return" were the results of this new bridge (Empereur 2002). The western port was more important than the eastern one during Ptolemaic and Roman periods (Mahgoub et al. 2000). The city was divided into five districts, named after the first five letters of the Greek alphabet. Alexander wanted his city to be a "Megalopolis"[1], with walls stretching endlessly into the distance (over 15 km in circumference) and streets of exceptional width - 30 m in the case of two main streets and 15 m for the rest - exceeding anything that had previously been seen (Empereur 2002).

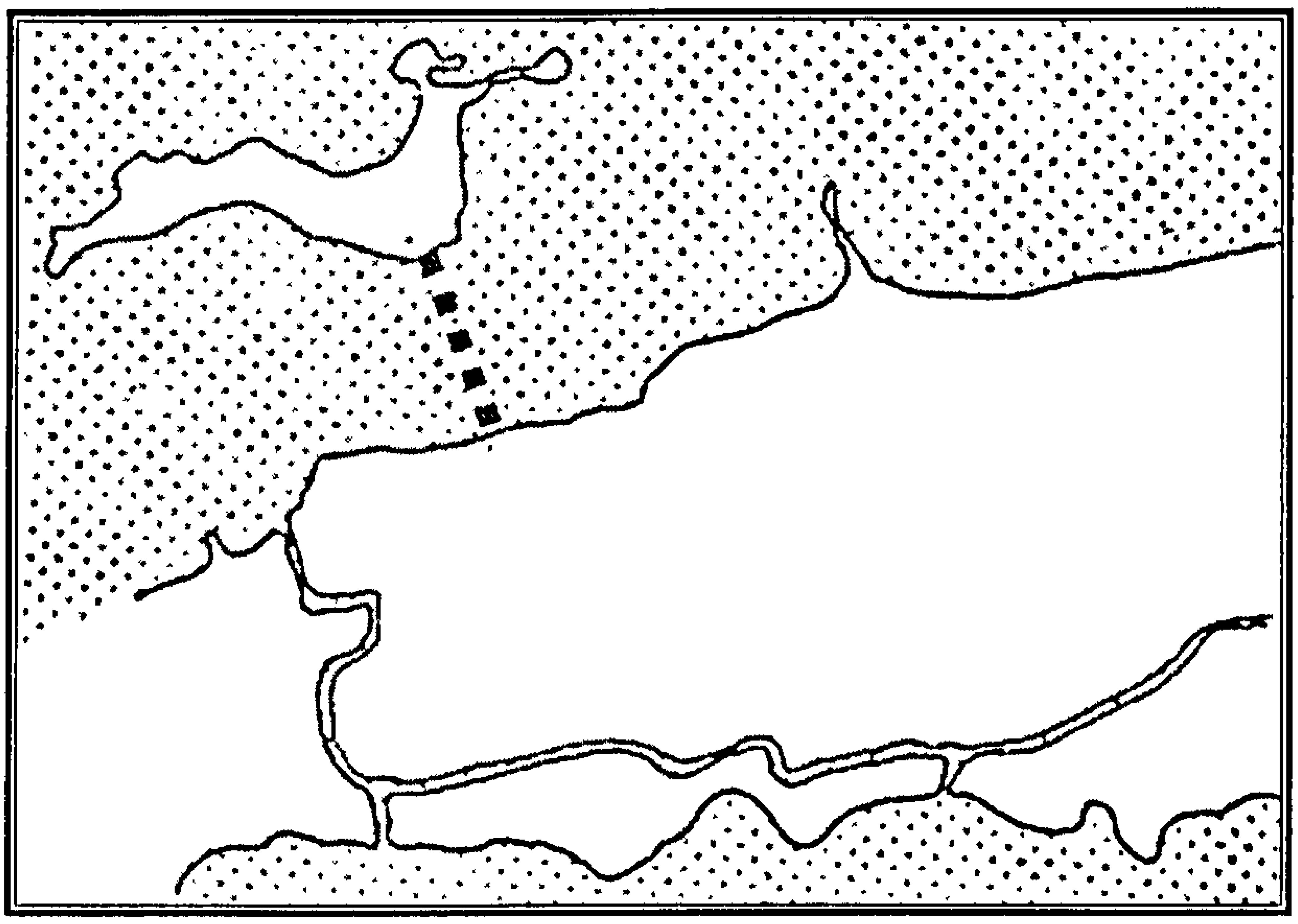


Figure 19 The Hepastadium between Pharos island and the mainland (Adriani et al. 1983)

El-Falaki identified 18 main streets of which 7 were south to north and 11 were east to west. The main streets such as Canope Street represented the major axis. Most of these streets were paved (Mahgoub et al. 2000).

Alexandria became the link between the rich Nile valley and the Mediterranean world, the most important maritime and commercial city of the Hellenistic age. Moreover, Alexandria became a seat of learning, famous for

[1] Megalopolis: a large, densely-populated urban area (Brown 1997)

its library, a great metropolis with mixed population (Hilberseimer 1955). All of these factors made the city thrive and grow in this era.

After Alexander's sudden death, the Ptolemies made the city their capital. Alexandria remained the seat of government for a thousand years until its conquest by the Arabs of AD 640 (Empereur 2002). The choice of the city as a capital of the Ptolemaic realm increased its role as a world emporium and cultural centre of the two worlds; eastern world and western world. Moreover, as the city overlooks the sea, it became also the principal Egyptian port up until present day. Thus, Alexandria became the first international trade centre in Egypt for imports and exports with the different parts of the world; The eastern ports of the Mediterranean, the Aegean sea, the Arab peninsula, India, and the African ports on the Red Sea (Mahgoub et al. 2000).

Egypt experienced recurrent periods of unrest from 180 BC onwards because of the weakness of the Ptolemies. Roman rule in Egypt began in 30 BC. Alexandria ceased to be a capital and became the chief city of the province of the Roman Empire. However, the city kept its position as an international trade centre and as the knowledge beacon of the ancient world with its outstanding scholars such as the engineer Heron, the Jewish philosopher Philo of Alexandria, and the geographer Claudius Ptolemy. Moreover, Alexandria made a distinctive contribution to the development of Christian theology long before Christianity reached the city (Empereur 2002). The walls of the city had not stop its growth during the Roman Era as the emperor Augustus established a new suburb called "Nicopolis" or "City of Victory" (between Mustafa Kamel and Gleem beaches area now in the east of the city), to mark its first expansion (Abdel-hakeem 1958) after his triumph over Cleopatra in the battle of Actium in 31 B.C., figure 20.

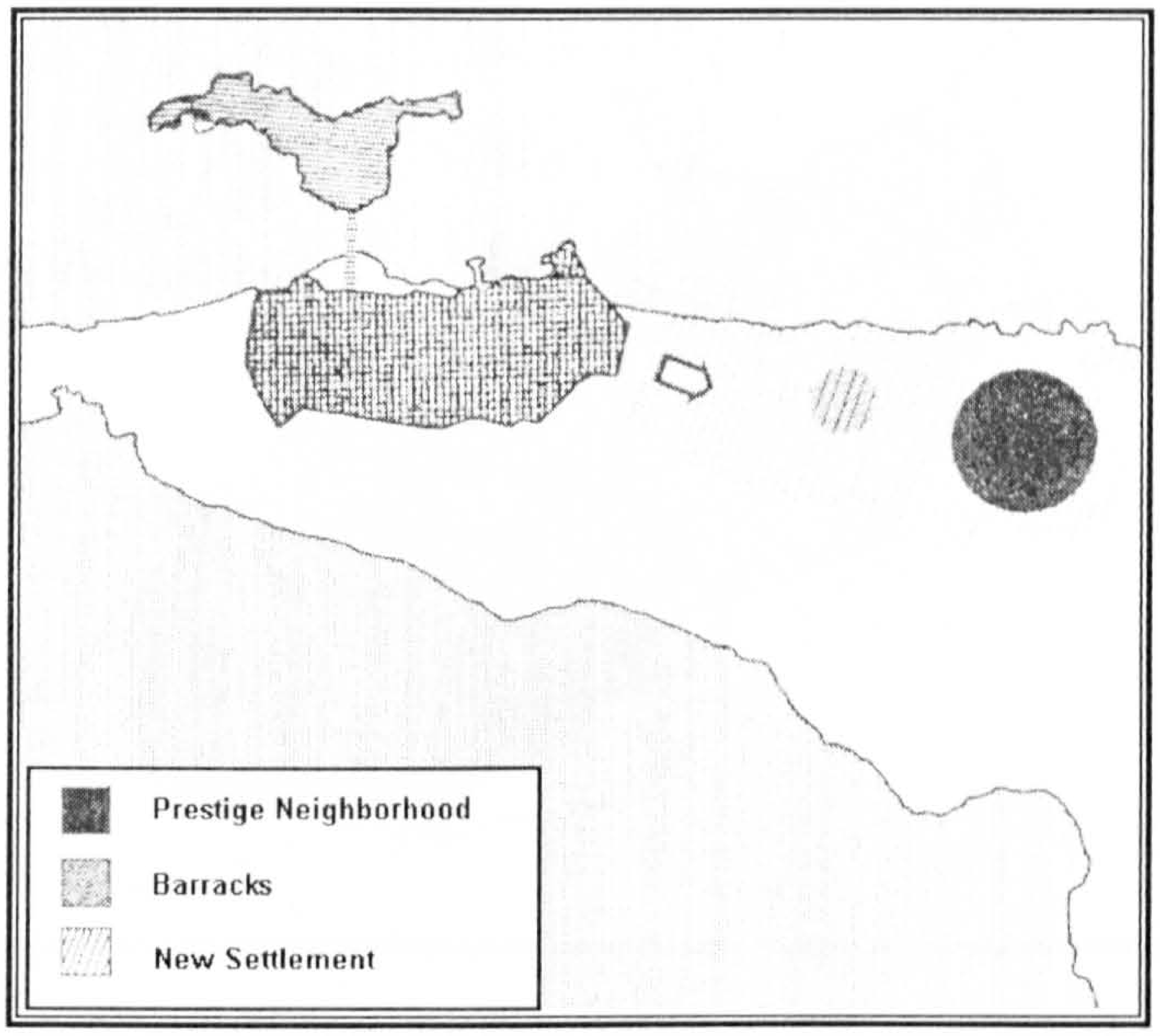


Figure 20 Expansion of Alexandria during the Roman rule (Elkholy 1968)

4.2.2 Deterioration and decline era (641- 1820) (Medieval Alexandria)

Alexandria experienced a long history of deterioration from the end of the Roman era until the French expedition departure in the beginning of the 19th century. When the Arabs conquered Alexandria in 641, the city was not in its ancient boom because of the repeated political conflict that led to the destruction of some of the most important symbols such as its library and royal palaces (Abdel-hakeem 1958).

The built-up area of the city within the Greco-Roman times extended to its walls, El-Falaki defined the length of the old city as 5.09 km; the width was 1.15 km to the west and 1.4 km to the east. The widest part (the centre) reached 1.7 km. This definition complies with that of Strabon, the Greek geographer (Mahgoub et al. 2000). Figure 21 illustrates the boundaries of the city during Greco-Roman Era.

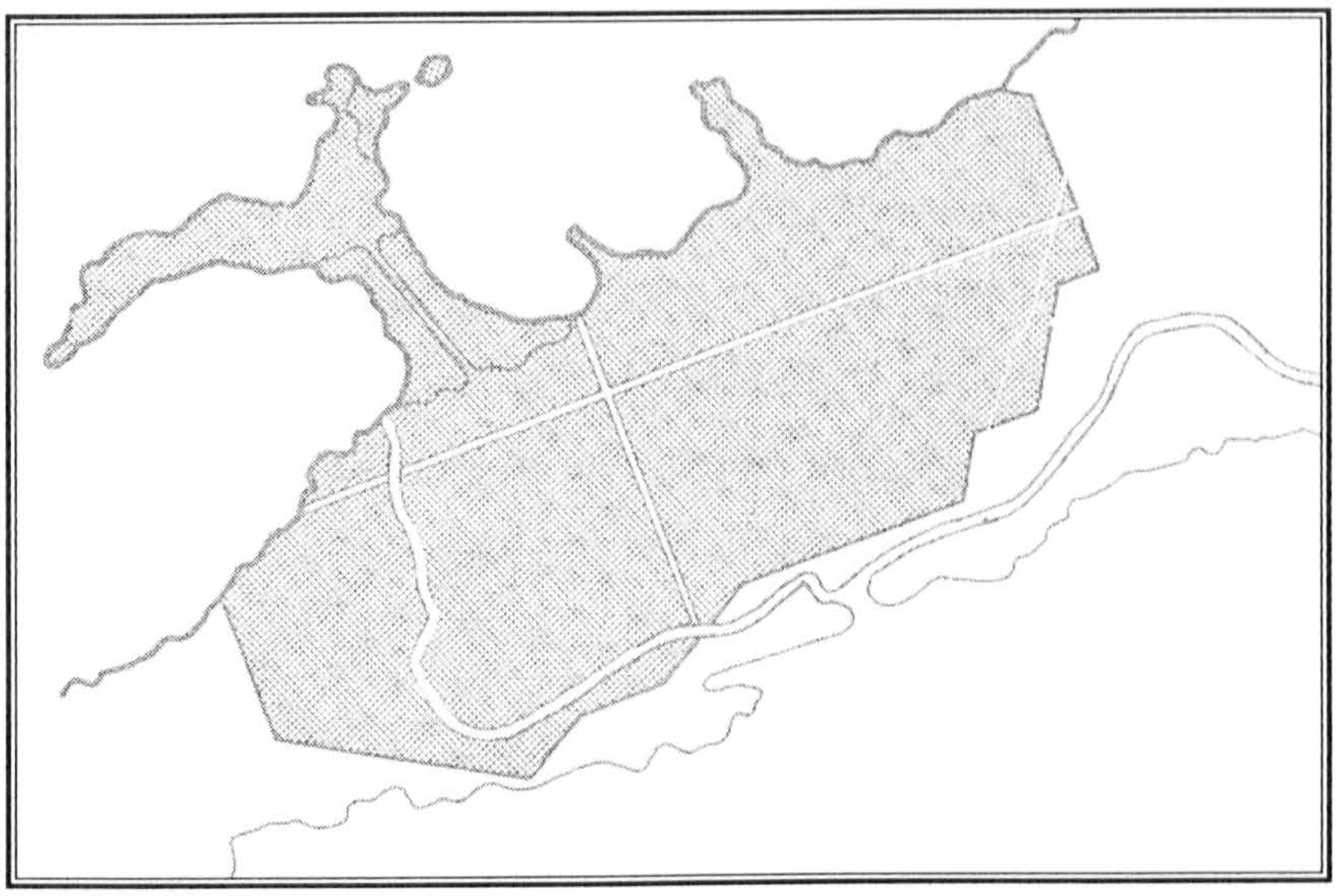


Figure 21 Alexandria during the Greco-Roman Era, after (Alexandria 1983)

Within the Arab era, the city contracted from the western and southern parts, (Figure 22).

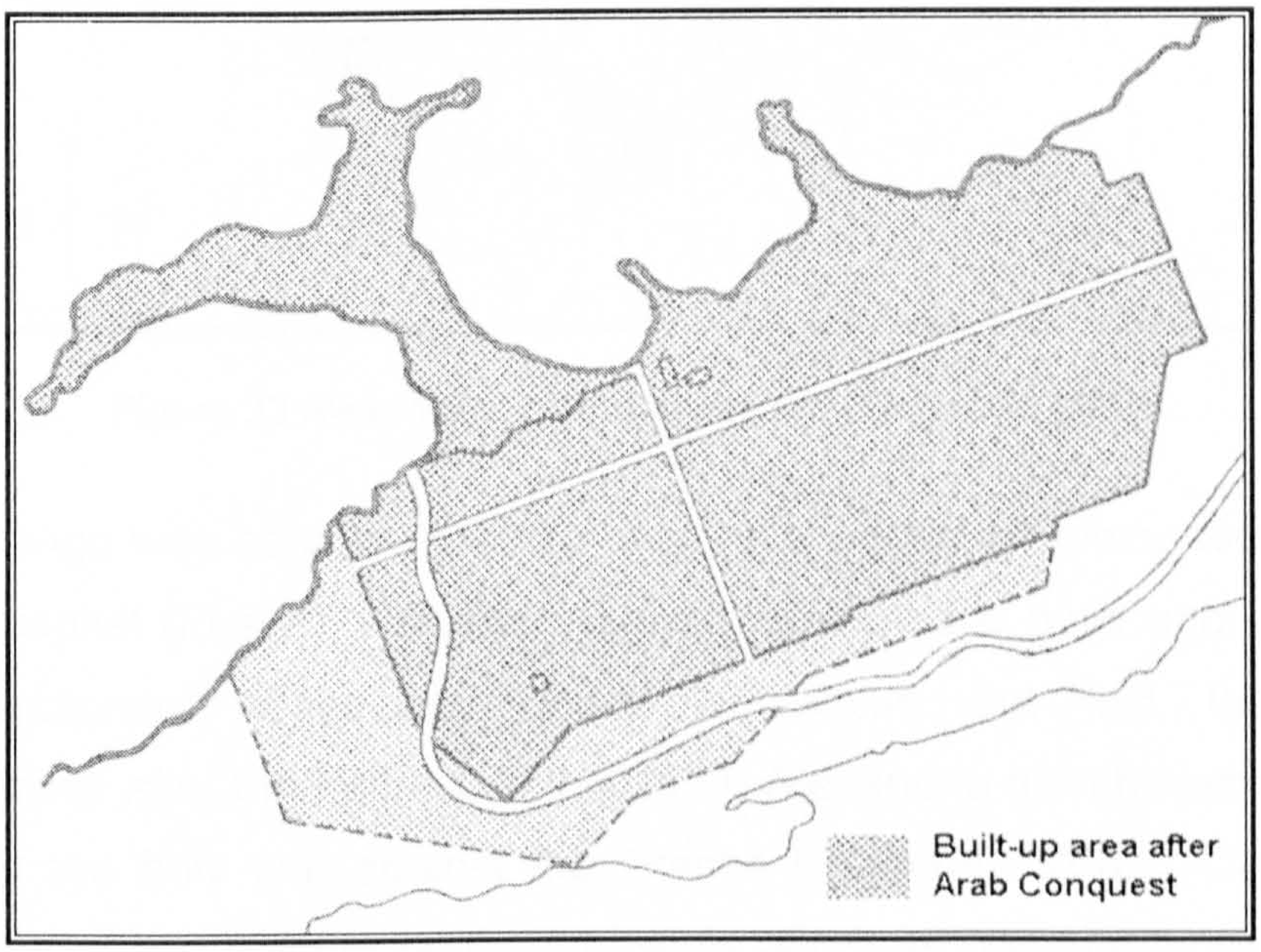


Figure 22 Alexandria after the Arab Conquest, after (Alexandria 1983)

The length of the city from the east to the west became about 3 km (about 41.1% decrease from its length in the Greco-Roman era), its width to the west was about one kilometer (13% decrease), and the width to the east was about half kilometer (64.3% decrease). The built up area within the Arab era covered the area of El-Attareen, El-Manshya, and El-Laban qisms now (Abdel-hakeem 1958). Some sources claims that the new city walls during the Ibn Tulun era (9th century) reduced the urban area by half (Empereur 2002), (Figure 23).

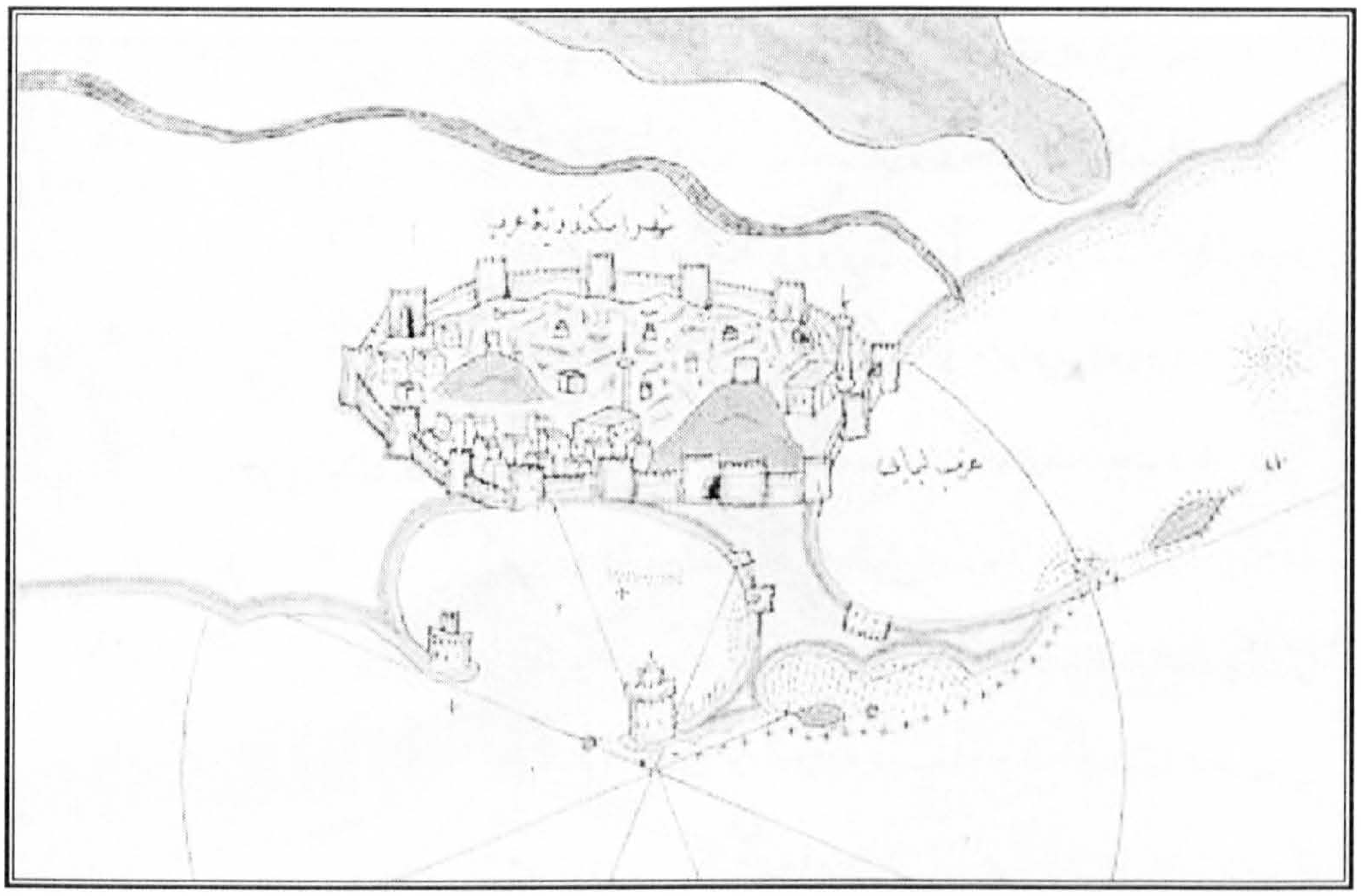


Figure 23 Alexandria during Arabs era (Empereur 2002)

The shrinkage was because the city became a provincial town, secondary to the new capital (Fustat). However, the city remained a polis and enjoyed a relative autonomy especially under Ibn Tulun but lost that virtual independence after the Fatimids fell in 1171. Alexandria then became a *taghr*, or fort for the holy war against the Franks (Empereur 2002). During both Greco-Roman and Arab eras, the city walls acted as boundaries of the built-up area. The city kept these boundaries until the 15th century (Abdel-hakeem 1958).

In the first years of the 16th century, the Mamluks started to weaken and the city started to deteriorate. The Ottoman secured Alexandria in 1517 and the shape of the city changed. The Turks did not prefer the areas that were inside the 9th century walls. Instead, they moved north to the area which had been formed by silting-up on either side of the Hepastadium (the ancient bridge) (Empereur 2002) and built the "new city" as it was named after the French expedition or the so-called "Turkish city" in other sources. Figure 24 shows the boundaries of the Turkish city.

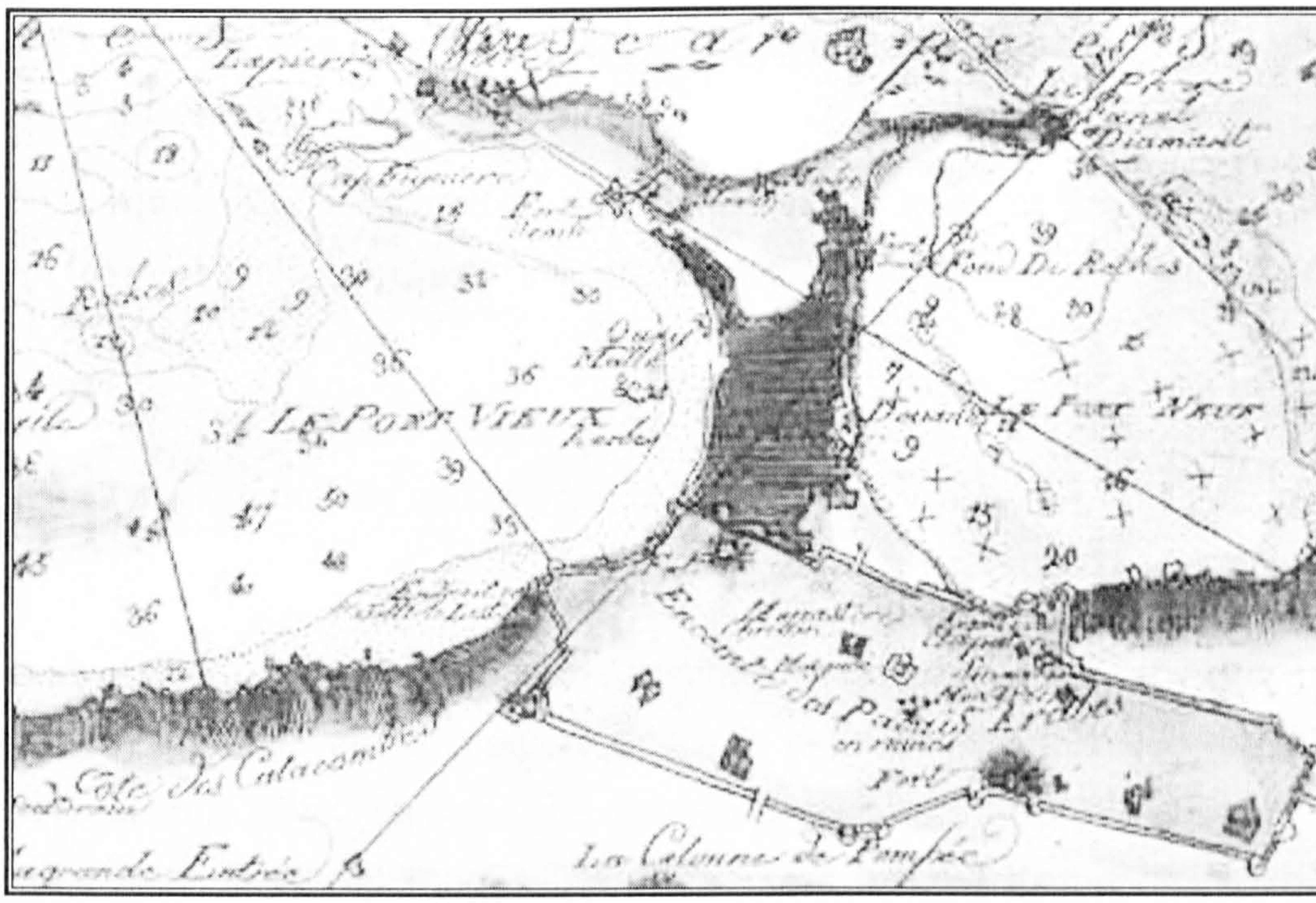


Figure 24 Alexandria (Turkish city) (Empereur 2002)

The original city inside the 9th century walls was called the "Arabian city". This city was abandoned during the Ottoman era. The length of the Turkish city from the north to the south was no more than one kilometre, and the width from east to the west was about half a kilometre (Abdel-hakeem 1958). Accordingly, the population of Alexandria shrank significantly. The estimations are between 3,000 and 15,000 inhabitants, and the plague was the main cause of depopulation (Empereur 2002).

4.2.2.1 Deterioration factors

Many factors led to city deterioration in the Middle Ages. Moving the capital of Egypt from Alexandria to El-Fustat was one of the important agents. The selection of the Egyptian capital location was related to complicated political and economical motives. The capital was first in Alexandria during Greco-Roman era as it was so close to their homeland, but the Arabs moved the capital for the following reasons (Abdel-hakeem 1958):

1 Alexandria was far away from the central administration in the Arabian Peninsula.

2 The city was very near to the enemies of the Arab state in the north of the Mediterranean.

3 Alexandria is located at the far end in the north of Egypt; that made accessibility between the city and the other parts of Egypt difficult during that time.

4 The city had also natural water barriers (old Nile branches and lakes) between the city and the rest of Egypt.

Another important factor led to the contraction of the city; the city witnessed land decline from the 6^{th} century and it is believed that this decline is still active up until now. The scientists such as Breccia, proved this decline by the disappearance of Antirrhodes island that was located in the eastern port. Breccia also claimed that the Roman Alexandria monuments are located six or seven meters under the modern city and most of the Ptolemaic monuments are located under the current sea level (Abdel-hakeem 1958). This decline of city level by six or seven metres made the northern parts of the city fade away under the sea level.

The third factor of city deterioration was the shortage of water supply from the Nile through the old Alexandria canal. This canal faced filling up by sand and clearance six times in seven centuries from 859 to 1423 (Abdel-hakeem 1958).

This made the population migrate to the other parts that were wealthy in water supply. However,

> *"Ottoman Alexandria was a diminished yet still relatively wealthy city. There was competition from Rosetta and Damietta, but no other Egyptian port could deal with as many ships as Alexandria. It comes as no surprise that Bonaparte chose it as the place from which to launch his Egyptian expedition."* (Empereur 2002:79)

In addition, under the French occupation (1798-1801), Alexandria had not seen any improvements. Empereur (2002:89) declared that; *"the streets were still dirt tracks".*

4.2.3 Revival and second boom era (1820 – 1993)

Abdel-hakeem (1958) identified three stages for city development in about a century between the first half of the 19th century and the first half of the 20th centuries, these stages were:

1 First stage, 1805-1855

2 Second stage, 1855-1905

3 Third stage, 1905-1955

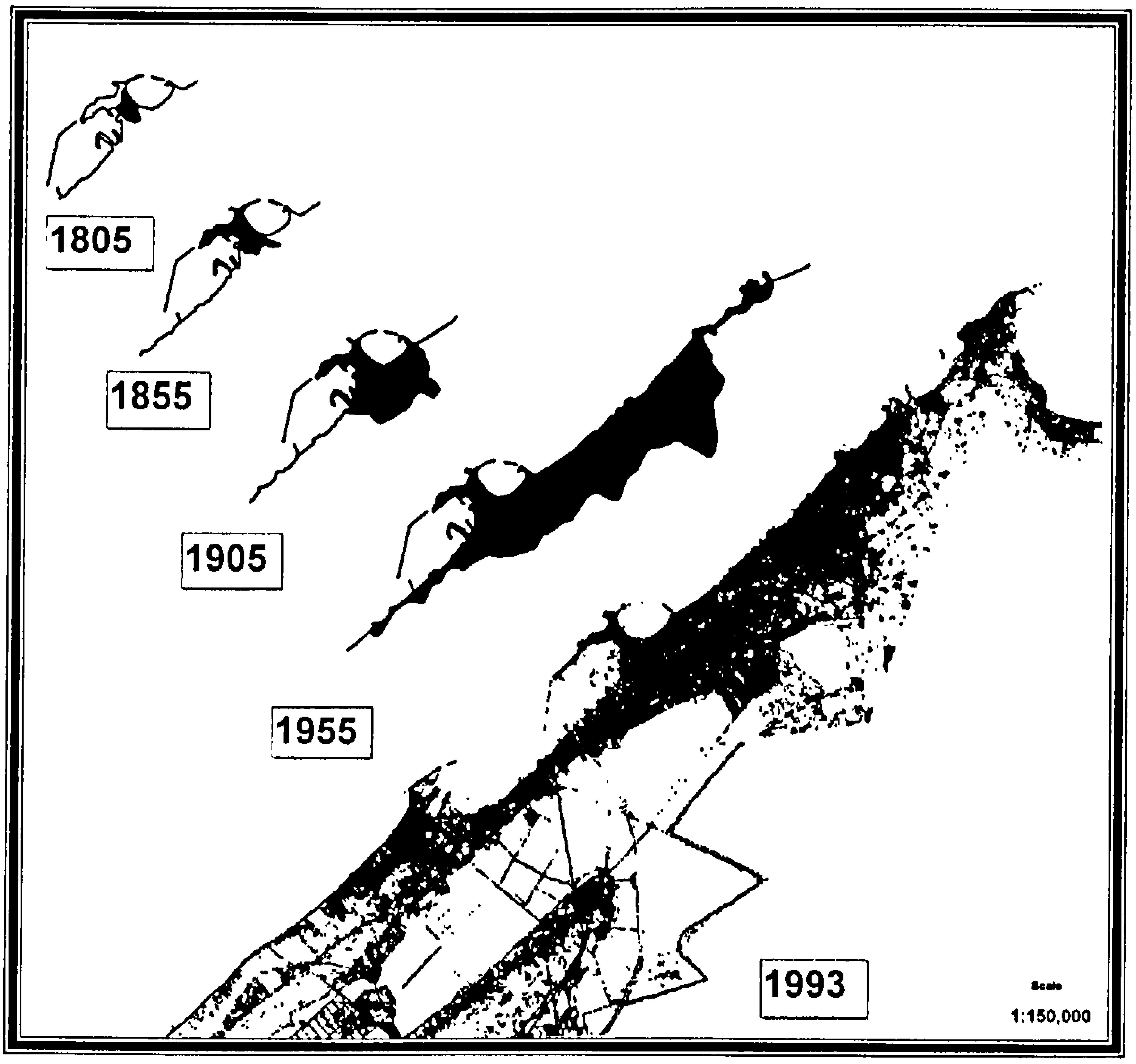
To complete the urban development story in Alexandria, another stage will be added to cover the rest of the 20th century.

4 Fourth stage, 1955-1993

In the following parts, these stages will be highlighted including the factors and characteristics of urban development in each stage.

4.2.3.1 The first stage 1805-1855

Abdel-hakeem (1958) compared Alexandria's map that was drawn by French expedition scientists in 1798 with Charles Muller's map in 1855. The built-up area during the French mission was just within the boundaries of the Turkish town over the disappeared-causeway between the two harbours, figures 24 and 25.



- *Data of urban expansion between 1805 and 1955 from (Abdel-hakeem 1958)*
- *Urban expansion of 1993 was produced from satellite image by the author*

Figure 25 Physical Expansion of Alexandria during the 19th and 20th centuries

In the middle of the 19th century or at the end of the first stage, the city expanded in two directions:

1 **To the north**, to occupy the rest of ancient Pharos Island. That means the city at this stage included Ras-elteen and El-anfoushy quarters (Abdel-hakeem 1958). In 1817, Mohammed Ali chose a site for his palace on the western tip of the island of Pharos to demonstrate his attachment to the town (Empereur 2002).

2 **To the southeast** where the central business district (C.B.D.) is located nowadays. The extension in this direction was planned if compared with the Turkish city (Abdel-hakeem 1958) so that this part was named "the European city". Francesco Mancini was the head of "Oranto", a committee set up in 1834 to oversee urban planning in the city. This committee was responsible for city cleaning, landscaping, ventilation in homes, and observing new buildings. Moving the cemeteries outside the city was one of the important achievements of this committee (Abdel-hakeem 1958). By definition, the European city was for Europeans especially and foreigners generally. This expansion was a response to the increase in the number of foreigners in the city. Mohammed Ali encouraged foreigners to settle in the city by giving them special areas inside the deserted walls such as Attarin and Mancheya. The population of these quarters was between 30 and 40% foreign (Empereur 2002).

The city had the so called suburbs at the edges of the Arabian city walls in the beginning of the 19th century. In the middle of the 19th century, these suburbs had disappeared and new ones appeared in other locations especially at the northern bank of El-Mahmoudia canal from Antonyads to the east to Karmous to the west (Abdel-hakeem 1958). "*On the banks of the Mahmoudia Canal stood the villas of rich Alexandrians and one of the royal palaces (Palace No.3). Here residents could enjoy an atmosphere of rural calm, and stroll down a famous promenade known as the 'Champs Elysees*" (Empereur 2002: 90).

Nevertheless, what were the factors of this early expansion? Mohammed Ali's development projects are the answer. Empereur (2002:89) claims, *"Under Mohammed Ali, in the 1820s, a genuine urban environment began to take shape."* Mohammed Ali had the desire to renew Egypt's links with the Mediterranean world and Alexandria played the key role in this new policy. The first development project by Mohammed Ali in Alexandria was El-

Mahmoudia canal. The new canal officially opened in 1821 provided the city for the first time in five centuries with a regular supply of drinking water. In the mean time, it became a navigable route that enabled the vessels to enter the western harbour. In addition, because of the new canal, transport links with the rest of Egypt and, in particular, the capital was improved beyond measure, and journey times reduced (Empereur 2002). This canal provided the city with drinking water as well as irrigation water that led to the increase in cultivated area about threefold from less than four thousand feddans[1] before 1820 to 11,545 feddans in 1849 (Abdel-hakeem 1958).

Beside the new canal, in 1828, the shipyard was established and this was modernised before the end of 1832 to become the arsenal to serve Mohammed Ali's grand strategic plans. Moreover, in 1829, Mohammed Ali commissioned the French engineers Cerisy and Mougel to construct a large dock in the western port. It was ready to use in 1833. The latter project increased the number of docking ships by 47% in twenty years from 1,092 in 1830 to 1,607 in 1850, and by 214% in twenty-five years from 2,137 in 1880 to 6,700 in 1905 (Empereur 2002). Cotton crops were shipped from Alexandria to England from 1822 onwards and the total value of cotton exported from Alexandria amounted to L.E. 515,000, representing 31% of the total value of exports (El-Saaty and Hirabayashi 1959). This flourishing maritime transportation led to trade thriving as well.

These booming factors made the immigrants flock to the city from all over the country to escape either from forced labour in agriculture or from payment of taxes beyond their means (El-Saaty and Hirabayashi 1959). Therefore, the population increased dramatically from 13,000 in 1821 to 60,000 in 1838, 180,000 in 1860, 232,000 in 1880, and 573,000 in 1927 (Empereur 2002). In the same period, the population of Cairo declined from 263,700 to 253,000. Alexandria did not attract only the Egyptians but also the foreigners who

[1] Feddan = 1.038 acres.

formed about 14.5% and 19% from total city population in 1897 and 1907 census respectively. The success of Egyptian cotton in Lancashire led to an increase in the number of English merchants and others settling in Alexandria (El-Saaty and Hirabayashi 1959).

4.2.3.2 The second Stage 1855-1905

The growth of the city in this stage can be monitored by comparing Muller's map (1855) with Alexandria's map of 1902. The city expanded at this stage in three different directions (Abdel-hakeem 1958), figure 25.

1 To the South, where the growth reached to Kom-Elshukafa, west Karmous, and Bab Sedra around Muslim's cemeteries. Al-Mahmoudia canal was the southern boundary of this direction.

2 To the West, where the built-up area reached to Al-Qabbary and El-Mafrouza quarters.

3 To the East, the boundaries of the growth in this direction was Al-Azaryta quarter.

The key factors in the urban expansion in this stage were transport networks especially railways networks. The construction of the railway line between Alexandria and Cairo in 1854 can be considered as the true beginning of the second urban growth stage in Alexandria (Abdel-hakeem 1958). Alexandria's growth in the first place led to the construction of the railway line which, in turn, led to the continuing growth of the city (El-Saaty and Hirabayashi 1959). This line enabled the smooth movement of both passengers and goods. The location of the final station in Alexandria represented the best site for transportation integration where it was close to both western harbour and El-Mahmoudia canal end. This new line gave the maritime transport in Alexandria port another momentum. In 1858, the Suez-Cairo railway line was opened which connected Alexandria to Suez as well. This led to a substantial increase of trade movement in Alexandria especially transit trade between

Europe and Eastern regions (Abdel-hakeem 1958). 72% of the Egyptian exports between 1853 and 1862 were transferred through Alexandria port. This ratio increased to 94% in the period of between 1863 and 1872. Moreover, the growth of El-Ramel suburb in the east was related to the construction of the railway between Alexandria and this suburb in 1863. Another railway was constructed in 1872 to link the city with Rosseta (Rashid now) that encouraged the population to move out to the eastern areas.

Owing to the continuous growth of the city, the municipal council of Alexandria was instigated in 1890. Using the revenue from local taxes, its fourteen committees ran the city, managing the water supply, drainage, street paving, and urban projects in general (Empereur 2002). Alexandria was the first city in Egypt that enjoyed this kind of local management (Abdel-hakeem 1958). Because of this, the city was the envy of every other city in the country (Empereur 2002). Planning the modern parts of the city in the first half of the 20^{th} century can be accredited to this municipal council (Abdel-hakeem 1958).

> *"A city with broad straight avenues and vast squares gradually took shape, extending progressively eastwards. This was where the rich Greek merchants chose to make their homes, in an environment of large villas set in private gardens. As expansion continued, the walls were taken down, and suburbs extended out towards Rushdy and Ramleh."* (Empereur 2002:92-93)

In the mean time, the public utilities were established. Alexandria waterworks Company was founded in 1879. For gas and electricity, Lebon and Co. was granted gasworks concession for the city and its suburbs in 1865 (El-Saaty and Hirabayashi 1959). Alexandria was among the first cities to have sewerage construction; it was established in 1878. A new sewerage project was implemented in 1893 to serve about 240,000 inhabitants (Abdel-hakeem 1958).

4.2.3.3 The Third stage, 1905-1955

Alexandria' map of 1951 was compared with the Alexandria' map of 1902 to highlight the boundaries of urban growth in this period (Abdel-hakeem 1958).

The city continued to expand along the southern, western, and eastern directions but there was a significant difference in the growth rate for each course.

For the southern trend, the built-up area extended to cover the entire gaps north of Al-Mahmoudya canal, especially the southern parts of Moharrm Bek and Karmous quarters. Furthermore, a new residential area "Ghiet-alenab" was developed between El-Mahmoudya canal in the north and the railway line in the south (Abdel-hakeem 1958). That means the growth overcame the water obstruction (the canal) towards the south. The total area of this new quarter was 1,440 km^2 and the population was 45,685 in 1947 with density of more than 30,000/km^2. The main explanation of population attraction to this area was the cheap land prices and the low rents (Abdel-hakeem 1958) that attracted the urban poor to develop this part of the city.

In the western tendency, the built-up area extended beyond Al-Qabary and El-Mafrouza quarters to Al-Werdyan, El-Max, and El-Dekhyla. Some endeavours were tried to develop Al-Agmy area (west El-Dekhyla) as a summer resort. City authorities planned the area; a new luxury hotel was founded, and transport problem was solved by bus line, however, this area with the other areas at the west of Al-Werdyan did not attract much population. Abdel-hakeem (1958) defined three factors to explain that phenomenon:

1 The existence of the wood warehouses, petroleum depots, cotton storehouse, and some small factories prevented urban growth to extend to these areas.

2 The narrow strip of land (about half kilometre) disallowed the housing spread.

3 These areas were far from El-Mahmoudya canal so that it will be difficult to provide drinking water from the canal.

In fact, the urban growth extended nowadays beyond the areas with all these named barriers. The interpretation of this phenomenon could be that the population during that time did not need any area for urban development outside the built-up area as their necessities were met inside it and when they need urgently land for development, they found no place but these areas.

The eastern direction was the most important among the other trends. Abdel-hakeem (1958) divided the growth of Alexandria towards the east into three phases; figure 26.

The first phase was urban development along the coast from Al-Ibrahemya to the west to El-Ramel palace to the east. Construction of the Corniche - coastal boulevard - (El-Saaty and Hirabayashi 1959) from 1905 to 1934 can be identified as the major motivation for urban expansion in this direction. Three different obstacles prevented urban growth in this side to take the full capacity; Alexandria Sporting club, Mustafa Kamel military district, and Al-Hadara Lake, figure 26. The first two obstacles still ban urban expansion. The lake was dried producing a new suburb called Semouha.

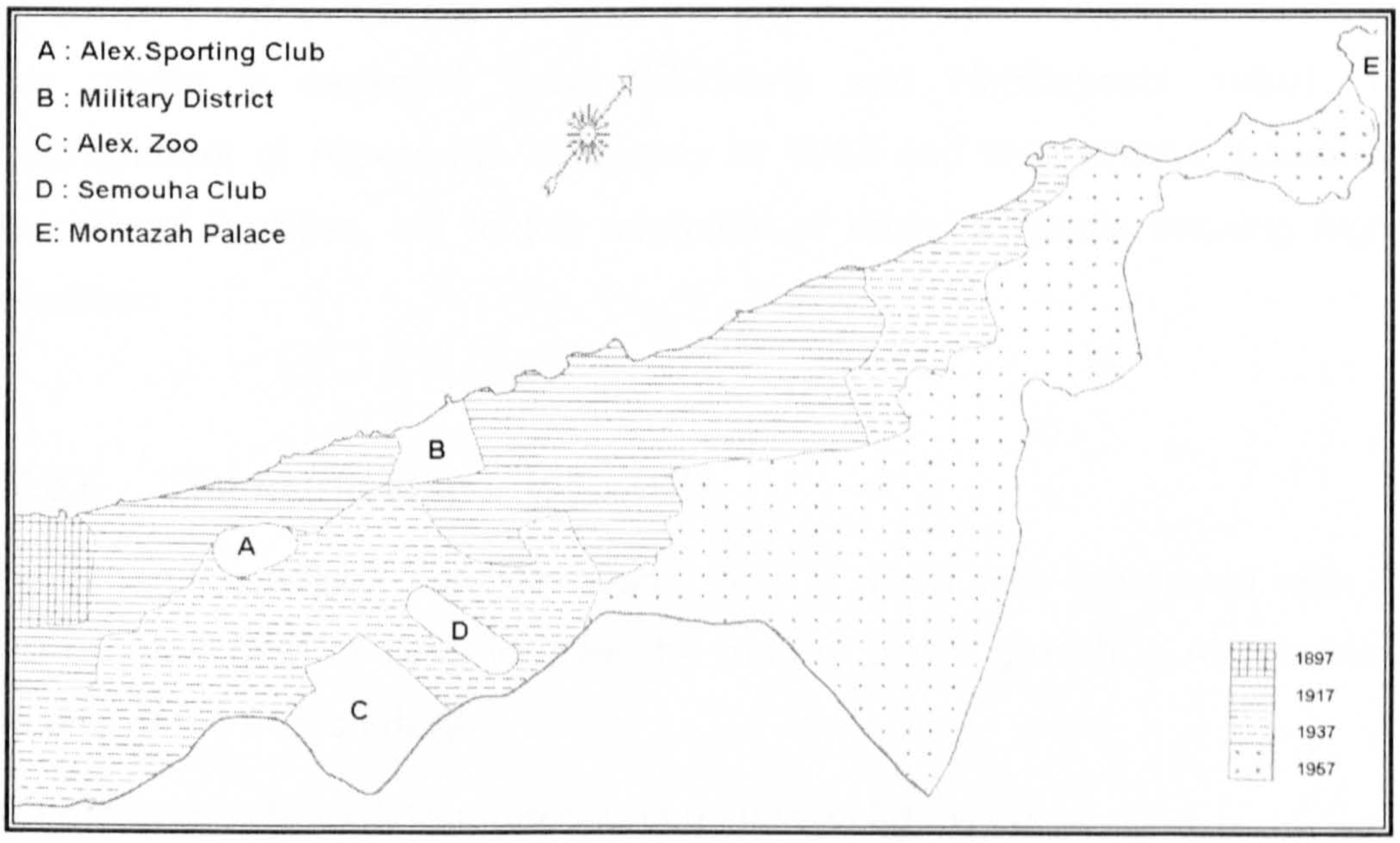


Figure 26 Development of Ramel area in the 20th century (Abdel-hakeem 1958)

In the second phase, the development continued towards the east but with less width. Meanwhile, the expansion towards the south became a major trend following the dryness of Al-Hadara Lake forming the "Semouha" suburb. The rate of development in this area was very slow because of problems such as sewage, transport shortage, swamps, and the long distance from this area and the sea (Abdel-hakeem 1958). This suburb overcame its problems and became an area of expensive and luxury homes. Moreover, it is considered as an elite district at the southern edges of Alexandria.

In the third phase, the city expanded to the east of Sidi-Bisher to Al-Mandara even beyond El-Montazah palace where El-Maamoura district is. Meanwhile, there was another trend to expand towards the southeast in Al-Seeyouf, as a response to the industrial development taking place (Abdel-hakeem 1958).

1930 marked the start of industrial development as an important factor in the growth of Alexandria. New factories were built in the city edges. As an index of recent industrial growth, 61 factories employing ten or more workers were established between 1950 and 1954. The municipal council of the city also made some improvements to make the city an attractive summer resort, and thus create a seasonal boom (El-Saaty and Hirabayashi 1959). The establishment of Alexandria University in 1942 and the general increase in educational facilities, led to the migration of many students seeking higher education.

4.2.3.4 The fourth stage, 1955-1993

The urban expansion satellite based map of 1993 was compared with the built-up area map of 1955 to draw the map of urban growth in Alexandria at the end of the 20^{th} century.

The urban growth took four directions as follow, figure 25:

- **To the east,** where the city expanded beyond El-Maamoura to cohere with Abu-Qier area. Abu-Qier area was part of El-Buhyra governorate up till 1955 but the Egyptian Cabinet decided to include this area in Alexandria governorate expecting the potential urban expansion (Abdel-hakeem 1958). New industrial sites emerged in Abu-Qier and Al-Tabya districts. Two contrasting facts developed in this part. The first, Semouha suburb became one of the best sites to settle in the city, especially for the upper middle and upper classes, with its modern plan, (Figure 27).

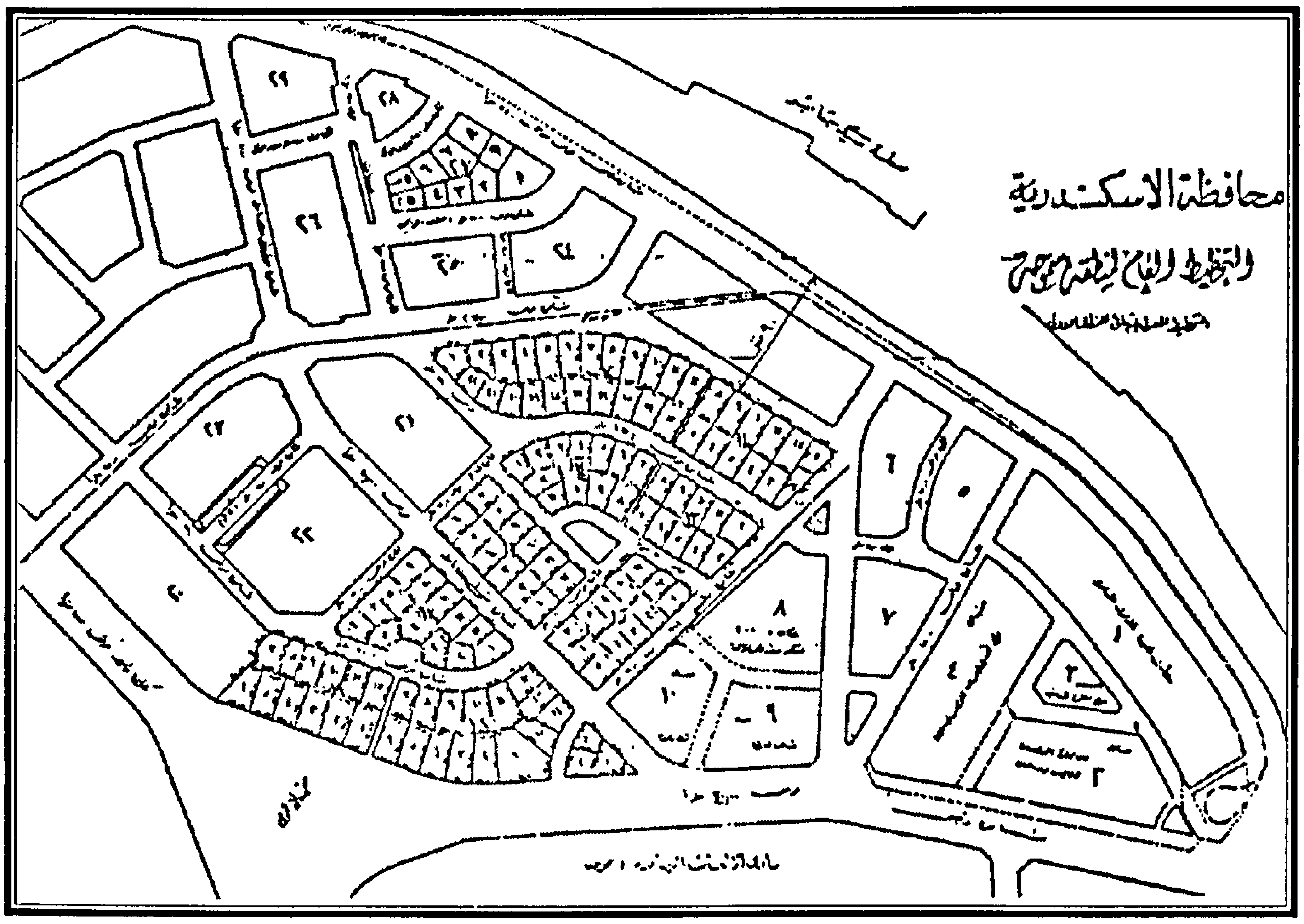


Figure 27 The general plan of Semouha area shows the level of planning

Two expensive membership sporting clubs were founded in this suburb to serve the high-income communities. On the other hand, Al-Mahmoudia canal bank villas and palaces disappeared and the area became one of the informal housing areas (Abdou-Azaz 1997). However, the local government started to develop and clean the canal along with the other projects of informal housing development, (Figure 28).

- **To the south east,** The residential area extended with the industrial sites in Al-Seeyouf and El-Ras Elsoudaa areas. A new phenomenon appeared here; a scattered pattern of residential area began to extend over the cultivated lands in this part of the city, (Figure 29).

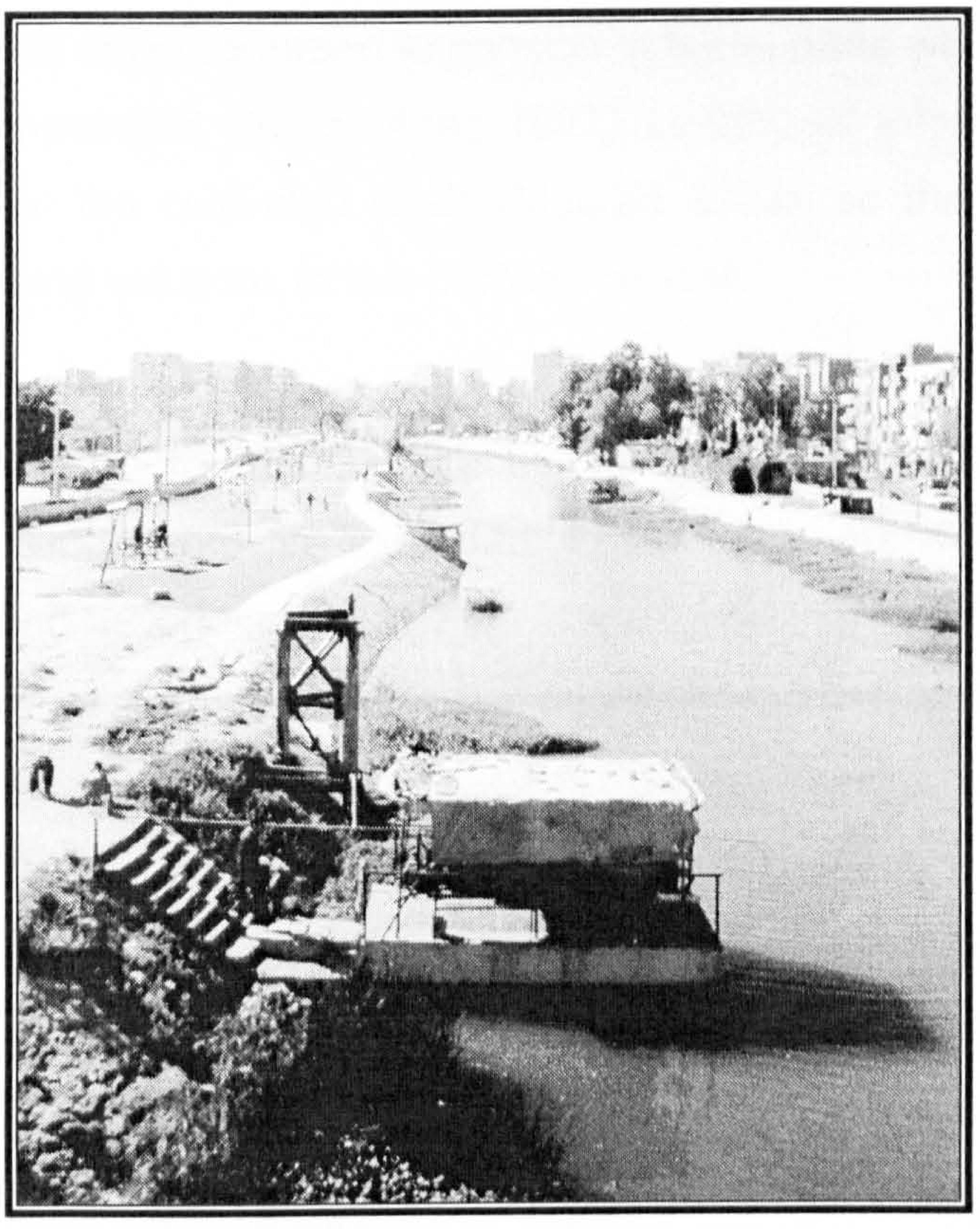


Figure 28 Al-Mahmoudia canal in 2003

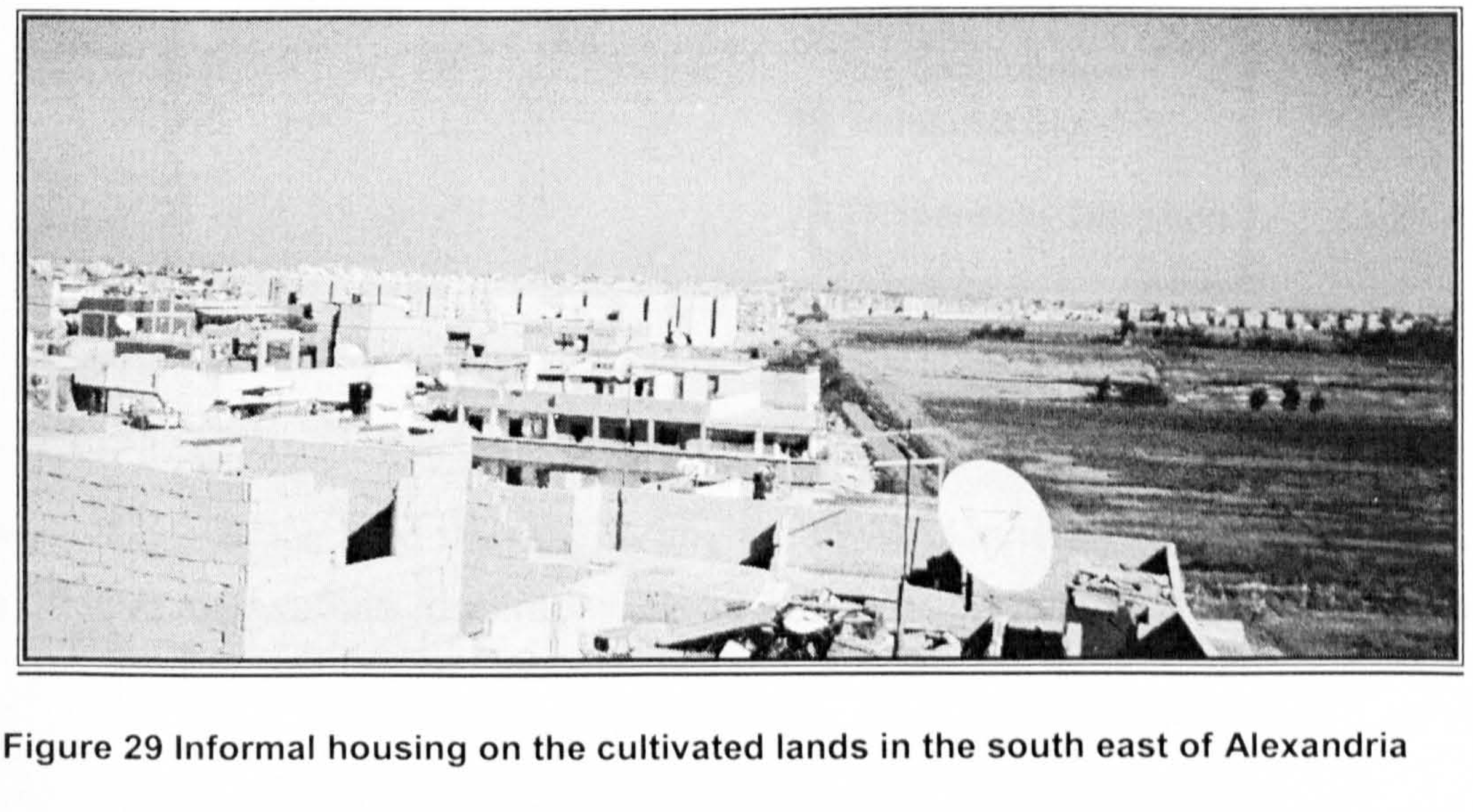


Figure 29 Informal housing on the cultivated lands in the south east of Alexandria

This is the first significant impact of urban growth in the city. Chapter seven (change detection) will present more detailed results of comparing the satellite images of 1984 and 1993 regarding land use/cover change. In the meantime, there is another side effect for urban expansion in these parts where most of the urban growth is unplanned (Abdou-Azaz 1997) as 80% of informal housing in Egypt happened on the cultivated lands (Mourad 2003), so there is a serious need also for planning solutions to this problem as well.

- <u>**To the west,**</u> where the main direction for growth in this stage is the west, figure 30. Urban growth extended to Al-Agmy areas (Beetash and Hanoville) and beyond to El-kilo 21.

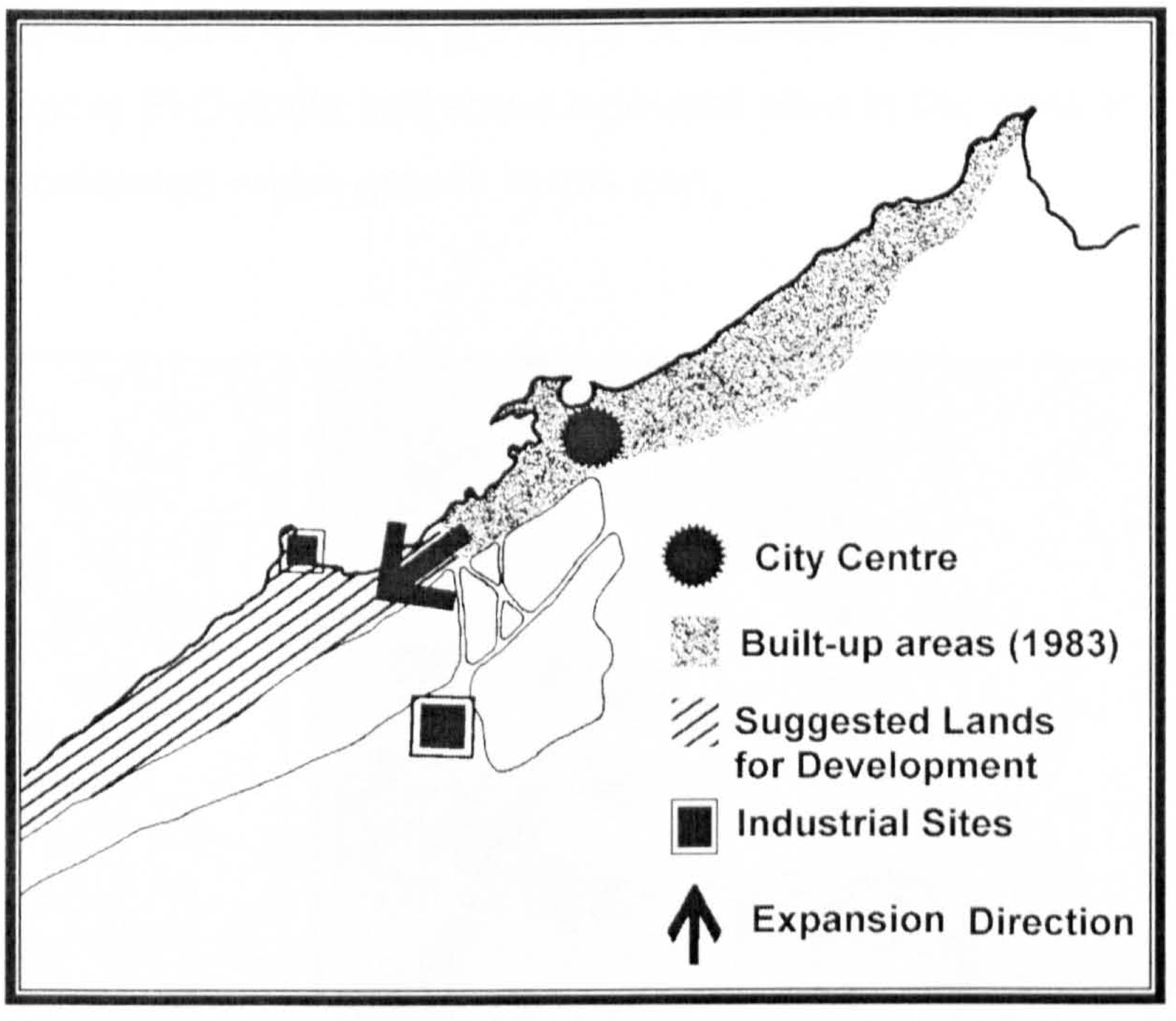


Figure 30 The situation of Built-up areas in Alexandria (1983) after (Alexandria 1983)

As mentioned in the third stage, Al-Agmy area was planned as a summer resort, but it failed at that time to attract visitors. These days, this area has become a flourishing area with mixed activities. It attracts a population for different reasons; as a summer resort for all levels, and as a permanent residence for middle and upper middle classes who work in the petroleum and chemical industries in this part of the city.

This area is served well by all utilities except sewerage, which is in progress. The governorate did not give much attention to this area from a planning view so it grew dramatically without planning regulations, (Figure 31). It became part of informal settlements in the city (Abdou-Azaz 1997), (Figure 32). From the 1990s, a national concern about informal housing began to appear in Egypt for security reasons so this area, with other parts of the city, started to enjoy national and local recognition resulting in the provision of necessary services. Establishment of the new port in El-Dekhila and some industrial sites in the west and south west of the city accelerated urban growth in this part.

Figure 31 Agmay plan

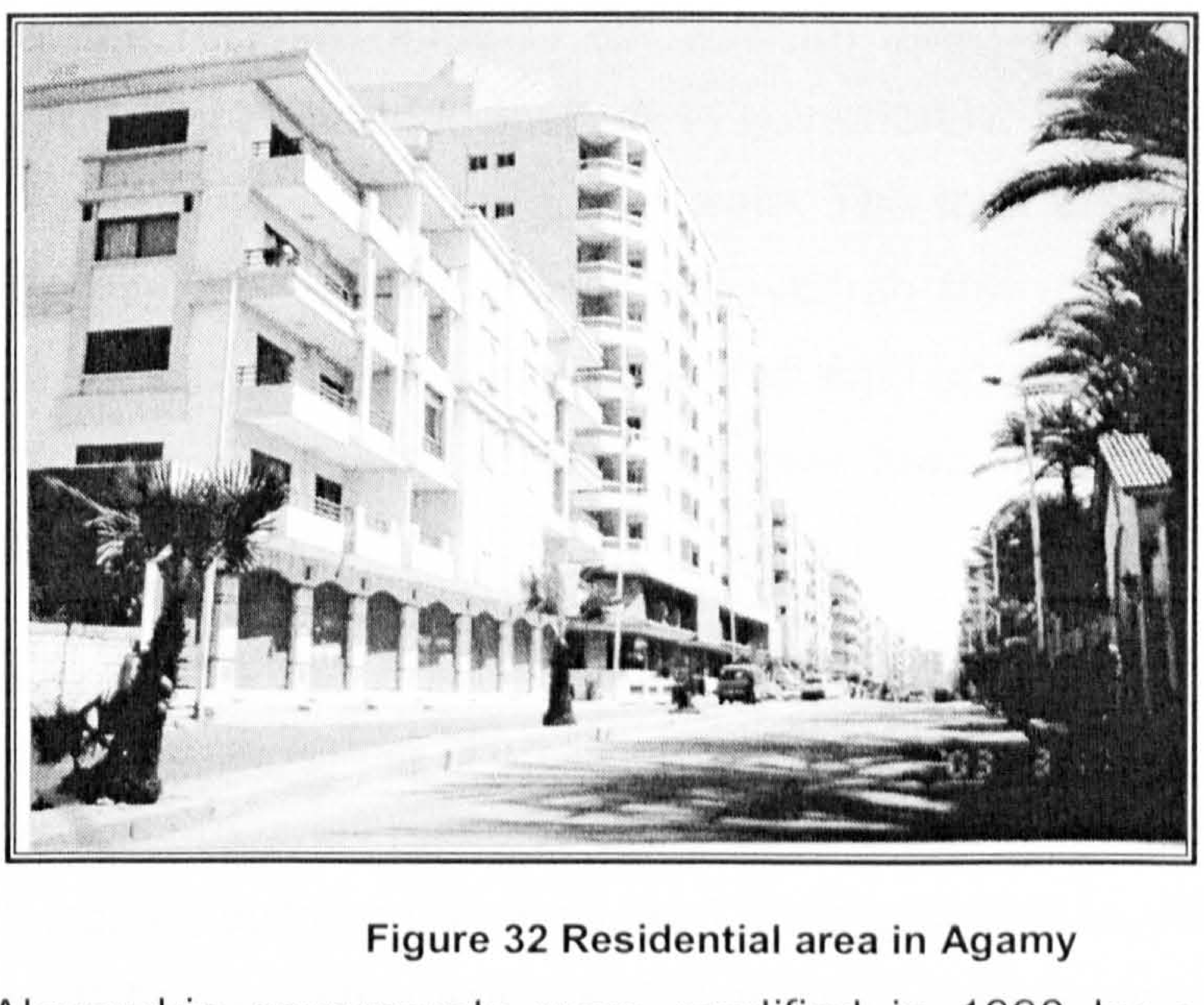


Figure 32 Residential area in Agamy

The western borders of Alexandria governorate were modified in 1990 by a presidential decree to respond to the continuous urban growth in the west, as it became the major axis for urban development. The western borders extended about 61 km along the Alexandria - Matrouh high road. This road can be considered as an urban development axis, (Figure 33).

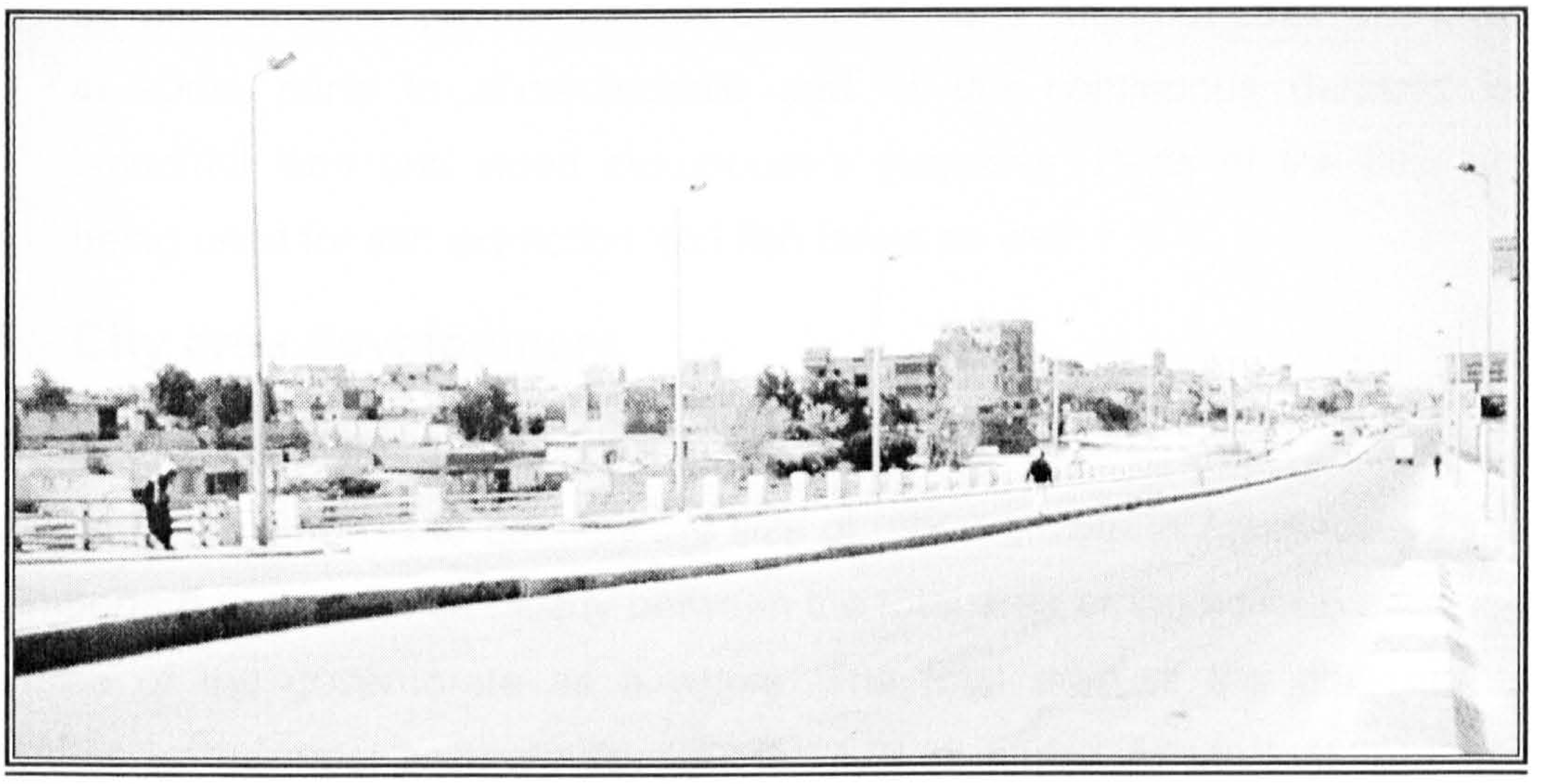


Figure 33 The urban development along Alexandria/Matrouh road

Most of the urban fabric at the northern edge of the western direction is for summer resorts. Also, as a result of these modifications in governorate' borders, another area (Burg-Alarab) was included to the governorate. The total area of Burg-Alarab is 315.48 km². This area contains New Burg-Alarab town that is planned to accommodate about half a million inhabitants. The total population is 7,055 according to the 1996 census (GACP 1997). The new town has been planned to attract industrial investments.

- **To the south west,** at the south of Maryout Lake, new suburbs Al-Amrya and King Maryout appeared. Al-Amrya is a site of mixed activities, namely residential, petroleum industries, oil refinery, chemical and petrochemical industries, cement factories, building materials, and a slaughterhouse. Al-Amrya area is part of Al-Amrya district which includes the El-Dekhyla area as well. The total area of Al-Amrya district is 2166.37 km² (GACP 1997) so that it is the biggest district in the governorate. King Maryout area can be considered as a winter resort as it contains a number of villas and motels. Permanent dwellings started to appear in this area with some educational services such as private schools and institutions. Maryout Lake was dried in some parts to accommodate part of the continuous demand for industrial land and wood storehouse's purposes. Parts of the lake are being used for salt extraction and fish farms as well.

4.3 City area development

In the last sections, the directions of urban growth of Alexandria were described qualitatively. This part is to quantify the size of urban growth in Alexandria. First, it is important to distinguish clearly between the total area of the built up area and the area of the governorate as a whole. The total area of the governorate according to the most accurate sources is 2679.36 km^2 (CAPMAS 1993) while the total built-up area is 310.02 km^2 (GACP 1997) which represents 11.57% of the total area of the governorate. The built-up area of Alexandria was about 4 km^2 in 1905 (Halim and Shouk 2000) which means that the built-up area increased by about seventy eight times in about ninety years. Moreover, comparing the area of the city through growth stages from Figure 25, and linking that with demographic data, (Tables 31 and 32), provides valuable information about urban growth in Alexandria.

Year	Density
1855	92
1905	75
1955	69
1993	51

Table 31 Development of population density in Alexandria between 1855 and 1993 [1]

[1] The density was calculated using map units of the area of the city between 1855 and 1993

Period	Annual Population growth rate (%)	Annual area growth rate (%)	Population/area (%)
1855-1905	4.65	5.71	1.23
1905-1955	7.43	7.90	1.06
1955-1993	5.19	7.24	1.40

Table 32 Annual growth of population and area in Alexandria between 1855 and 1993

The city tends to expand horizontally rather than vertically. Density development between 1855 and 1993, (Table 31), emphasises this fact where a gradual decrease in the density can be detected. Generally, the density decreased by 50% in about 150 years. In addition to that, the city experienced the largest horizontal expansion in the second half of the 20th century where every one per cent of population growth lead to 1.4 per cent of physical expansion. This rate is relatively high when compared with the previous trends, (Table 32). These figures show how great the size of urban expansion in Alexandria has been, especially in the modern and contemporary periods, and how important is to deal with this planning problem with the most effective policies to manage it and reduce its negative effects.

4.4 Modelling urban growth stages in Alexandria

This section is not a comprehensive study for all urban growth traditional models, but it introduces the most important and related models in the urban studies literature. Every urban studies student uses at least one or two of the three classic urban growth models; Concentric Zone Model, Sector Model, and Multiple Nuclei Model because they are so widely accepted by all social science disciplines (Hartshorn *et al.* 1992). Urban growth models including these classic models will be discussed in the following sections.

4.4.1 Concentric Zone Model

The earliest urban growth model (1925) was developed by Burgess in Chicago University. This model consists of five zones; specifically, Central Business District (CBD), Transition, Low-income housing, Middle-income housing, and commuting zones, (Figure 34-a). The main concept of this model is that all activities occur around one central area. The transition area or the gray zone refers to the conversion of older residential areas to commercial use as a response to the growth of the business district. This model has several deficiencies such as the failure of providing any information about the impact of transportation routes on land use (Hartshorn *et al.* 1992).

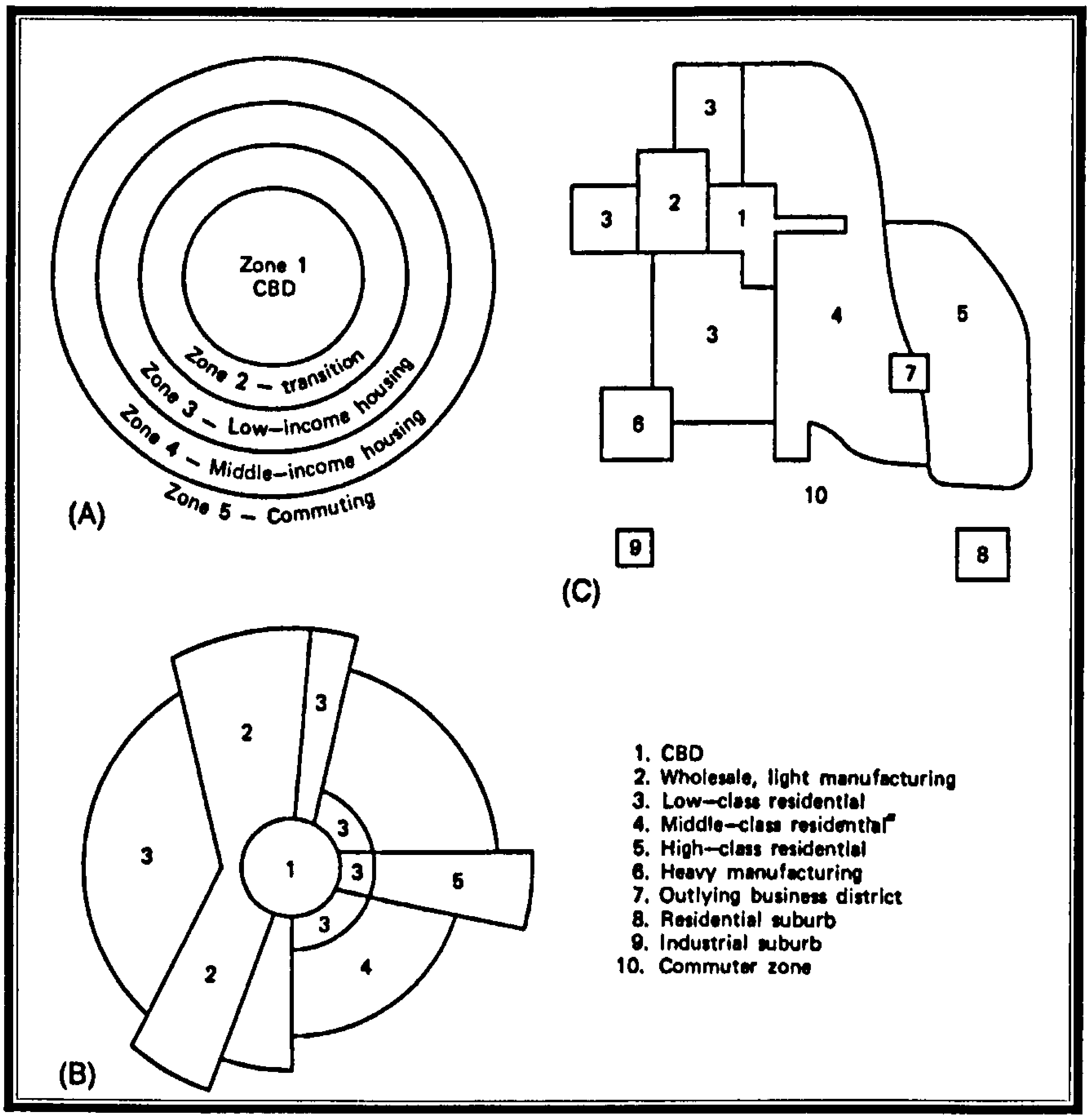


Figure 34 Classic models of urban growth (Hartshorn *et al.* 1992)

4.4.2 Sector Model

After the land economist Homer Hoyt studied more than 100 cities, he suggested in 1939 that once similar uses emerged around the CBD at the center of the city, the activities would extend over time in the same direction as the city grew (Figure 34-b). This hypothesis is accepted as similar uses grow in specific directions following road or railways. The Sector model allows new activities to be added to the periphery, rather than requiring redevelopment of existing areas as the concentric model implies (Hartshorn *et al.* 1992).

4.4.3 Multiple Nuclei Model

Harris and Ullman developed this model in 1945 to reflect that urban activities do not evolve around a single core, but at several nodes or focal points (figure 34-c). Each node could develop its own satellite residential communities (Hartshorn *et al.* 1992).

4.4.4 Urban Realms Model

James Vance introduced the urban realms model or the pepperoni pizza model in 1964 after his morphology analysis for San Francisco Bay area. This model assumes the emergence of large self-sufficient suburban sectors. Each suburban has its own downtown which is independent of the traditional downtown and the central city (Hartshorn *et al.* 1992), figure 35.

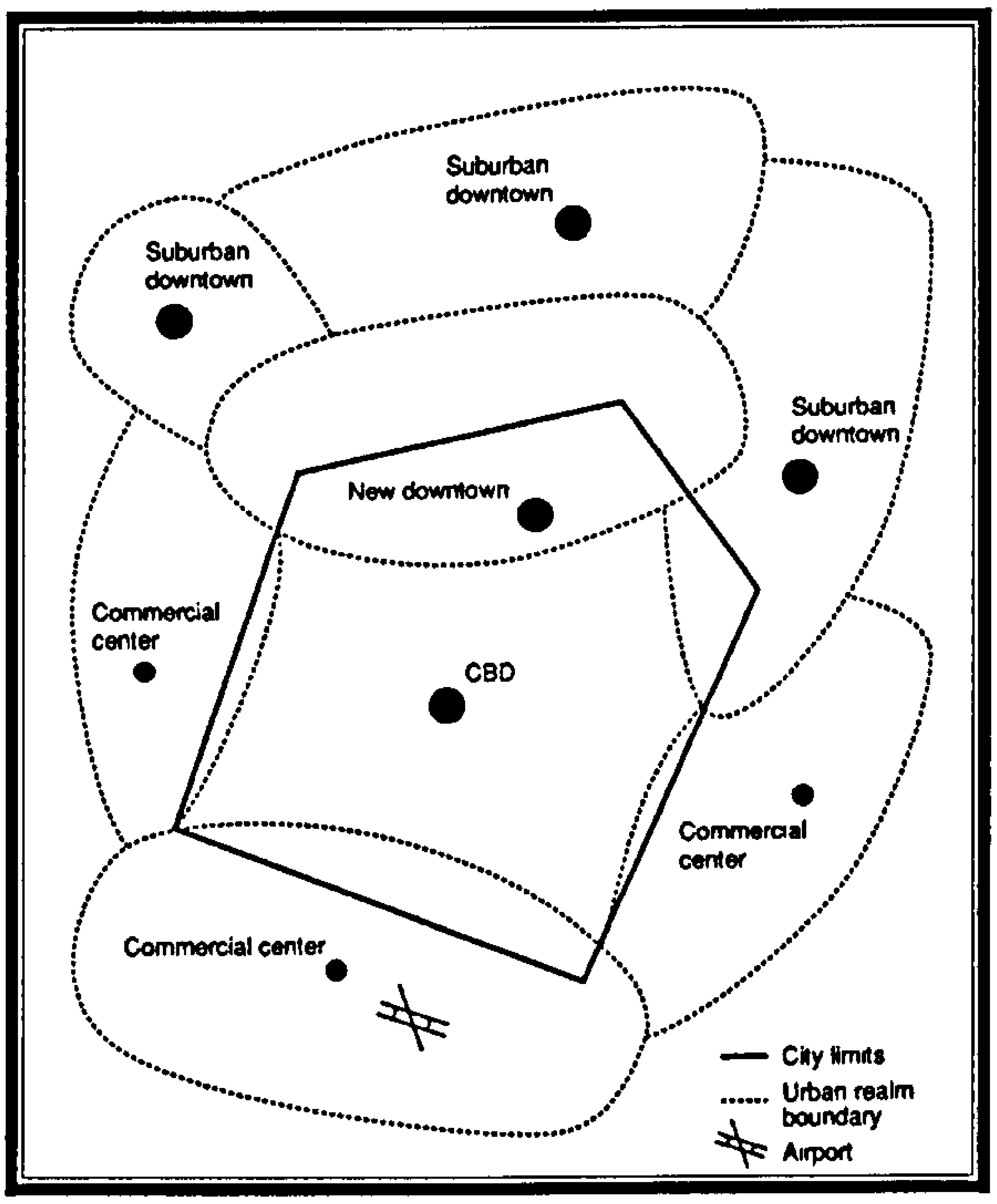


Figure 35 Urban Realms Model (Hartshorn *et al.* 1992)

4.4.5 Discussion

In spite of the many endeavors to model city expansion, these models can not be applied in most studies for two reasons; the first is that urban development usually does not follow any simple plan. Masek *et al.* (2000:3474) claimed that "*Early urban growth models based on the steady outward expansion from an intact urban core have yielded to a reality that is far more varied and complex*". The second reason is that these models have been developed to explain urban growth in the United States and Europe so that they have no intention to justify urban growth outside these regions. Moreover, the driving factors of urban growth in these regions are totally different from their counterparts in developing countries. Moreover, each city has its own character according to many complex factors such as culture, and economic situation. Lastly, Alexandria is a unique city itself by its physical limitations (e.g., Sea, Lake).

Moreover, Harris and Ullman declared that *"none of the three classic models was universally applicable and that all cities exhibited patterns identifying with aspects of one or more of the models".* (Hartshorn *et al.* 1992:233)

Monitoring urban growth is extremely difficult in both developed and developing countries. In the developed region where sophisticated government agencies maintain accurate records for taxation and development purposes, it is often possible to extract at least region-level statistics, but there is rarely specific geographical information to support such figures (Masek *et al.* 2000). On the other hand, in the developing world, access to the data is usually impossible even if it is only for research purposes. And if the data are available, in most cases, it is not accurate enough to be used in concise studies.

However, there were some endeavours to understand urban growth in Alexandria by applying some of these models; these trials will be highlighted in the following sub-sections.

4.4.6 Application of traditional urban models to Alexandria

In this study, it is found that urban growth stages of Alexandria can not be modelled using one model. Moreover, the application of urban growth models in any city should consider the temporal consequences as the city is not an inactive object and the models are static. Because of the latter, the application of urban models to Alexandria in its modern history will be divided into three chronological stages:

- **The first stage** includes the 19^{th} century as a whole. In this period, the city expanded taking a "Circular Development" shape as the city grew from the Turkish city as a central point to the north and the south east in the first half of 19^{th} century, and to the south, west, and the east in the second half of the 19^{th} century, (Figure 36).

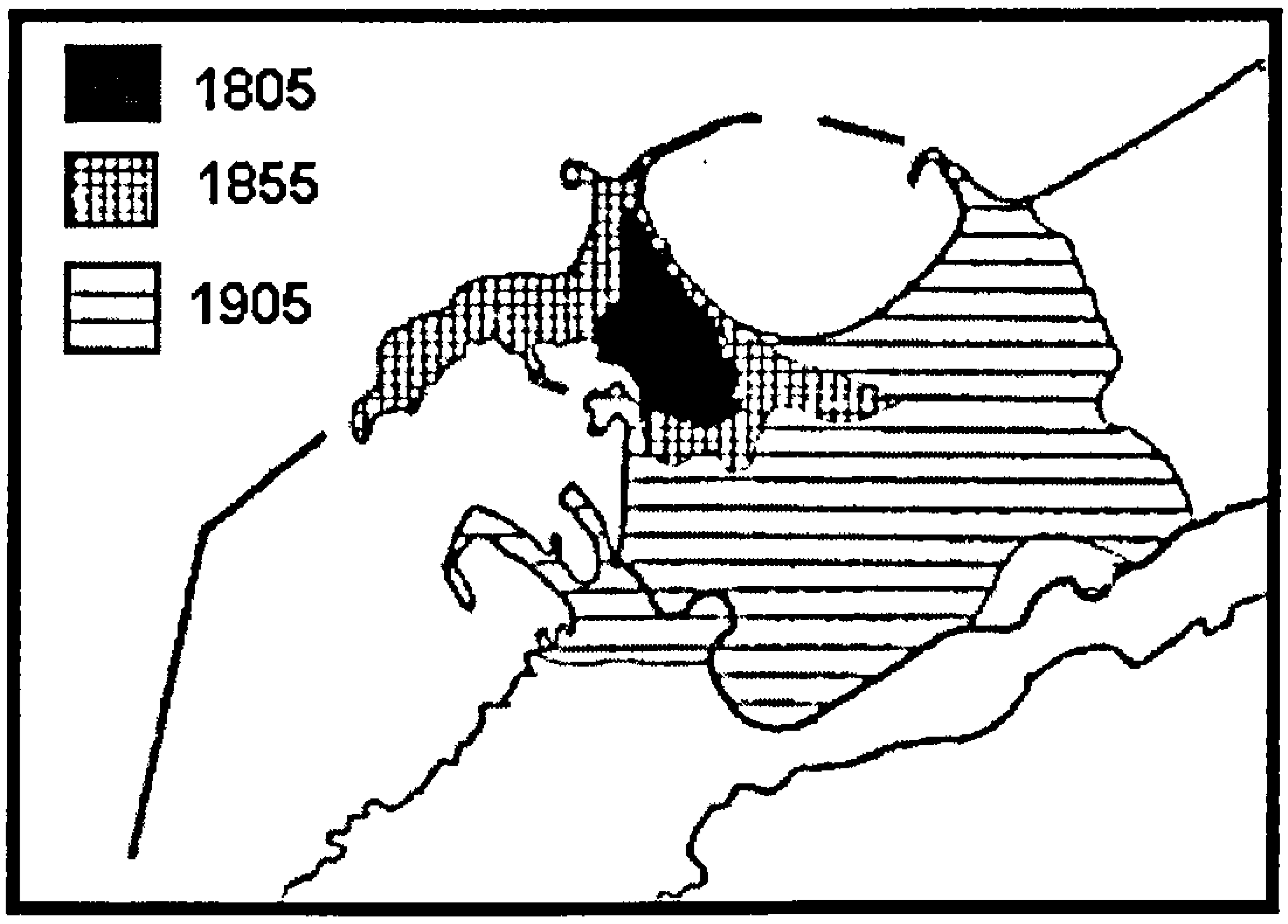


Figure 36 the Circular growth in Alexandria up to the 19th century (Abdel-hakeem 1958)

- **The second stage** covers the first half of the 20th century, where the Multiple Nuclei Model can be applied to explain the urban growth in the city as (Abdel-hakeem 1958) and (El-Saaty and Hirabayashi 1959) applied it. During Alexandria's expansion towards the east in the third stage (1905-1955), the residential area united gradually with the five villages in El-Ramel area namely, El-Hdara, El-Ramleh, El-Syeeouf, El-Mandra, and Abu-Qir. That coherence occurred between more than one nucleus so it can be considered as "Polynuclear" or "Polycentric" (Abdel-hakeem 1958).

In accordance with this explanation but with different location, El-Saaty and Hirabayashi (1959) claimed that the suburbs of Alexandria began to develop during the latter part of the 19th century and have continued through the 20th century. They defined four emerging suburban areas, (figure 37); Muharram Bek along the north bank of Mahmoudia canal in the south of the city, around El-Qabbari railroad station in the west, Al-Attarin at the central business district in the middle, and around Sidi Bisher shrine in the east (El-Saaty and Hirabayashi 1959).

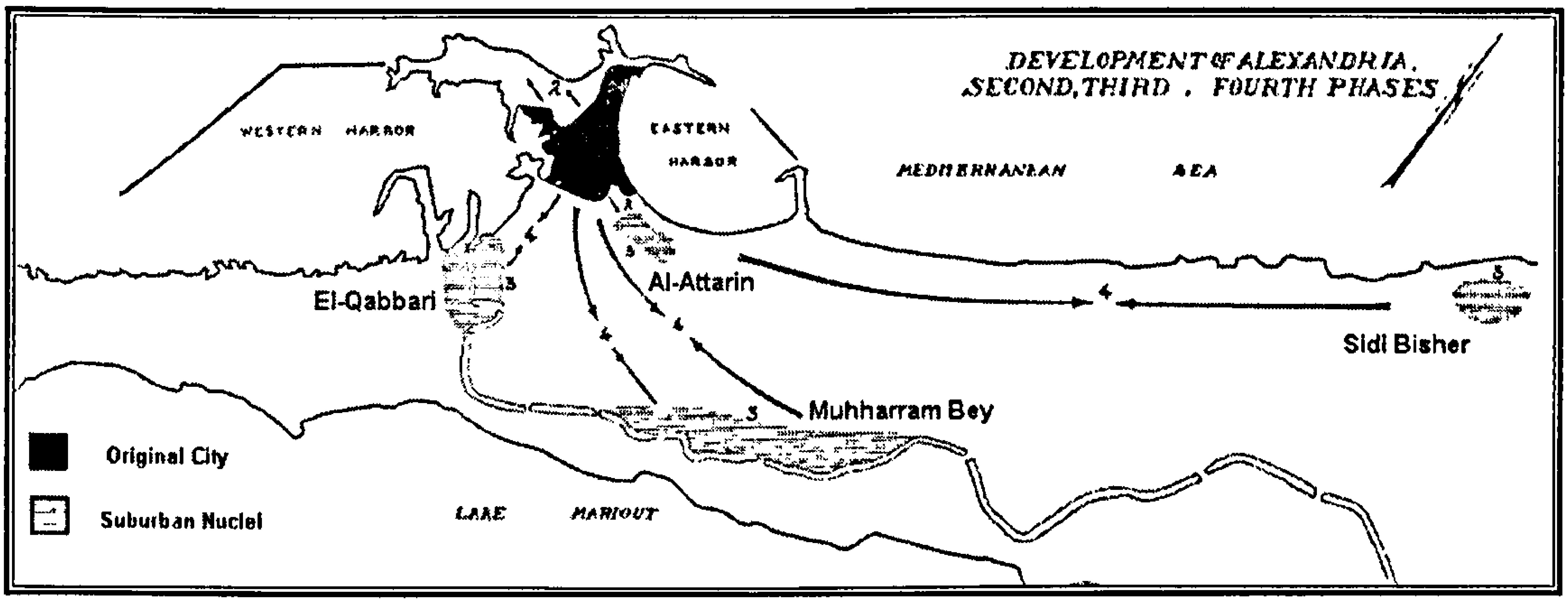


Figure 37 Growth of suburbs in Alexandria in the first half of the 20th century (El-Saaty and Hirabayashi 1959)

"These four suburbs themselves became secondary centers or nuclei of development. As the central city was expanding toward the east, southeast, south and southwest, the four suburbs were simultaneously growing toward the expanding central city. There was a reciprocal attraction between the main city and the suburbs. The undeveloped sections between these areas were gradually built up until the boundaries were merged." (El-Saaty and Hirabayashi 1959:34).

- **The third stage** begun from the second half of the 20th century up to date and it is believed it will continue as a prominent pattern in Alexandria urban growth. The urban Realms Model is the most appropriate model that can describe the contemporary situation of urban growth in the city. Alexandria took half a century to reach the stage that its suburban downtowns do not rely on the traditional city center or C.B.D. Many suburban downtowns at different levels are coexisting with the traditional centre, (Figure 38). Seven urban realms can be identified from the east to the west;

1. Montazah is located in the far east of the city. This realm consists of one major downtown (Montazah) and some medium and small centres such as Abu-Qier, El-Maamoura, Miami, and Sidi Bisher. The area is mainly residential in the north, industrial in the west, and agricultural in the south.

2. Sidi Gaber is the main centre of the East district with Glym and Rushdy as examples for the sub-levels centres. The residential function is dominant in this part.

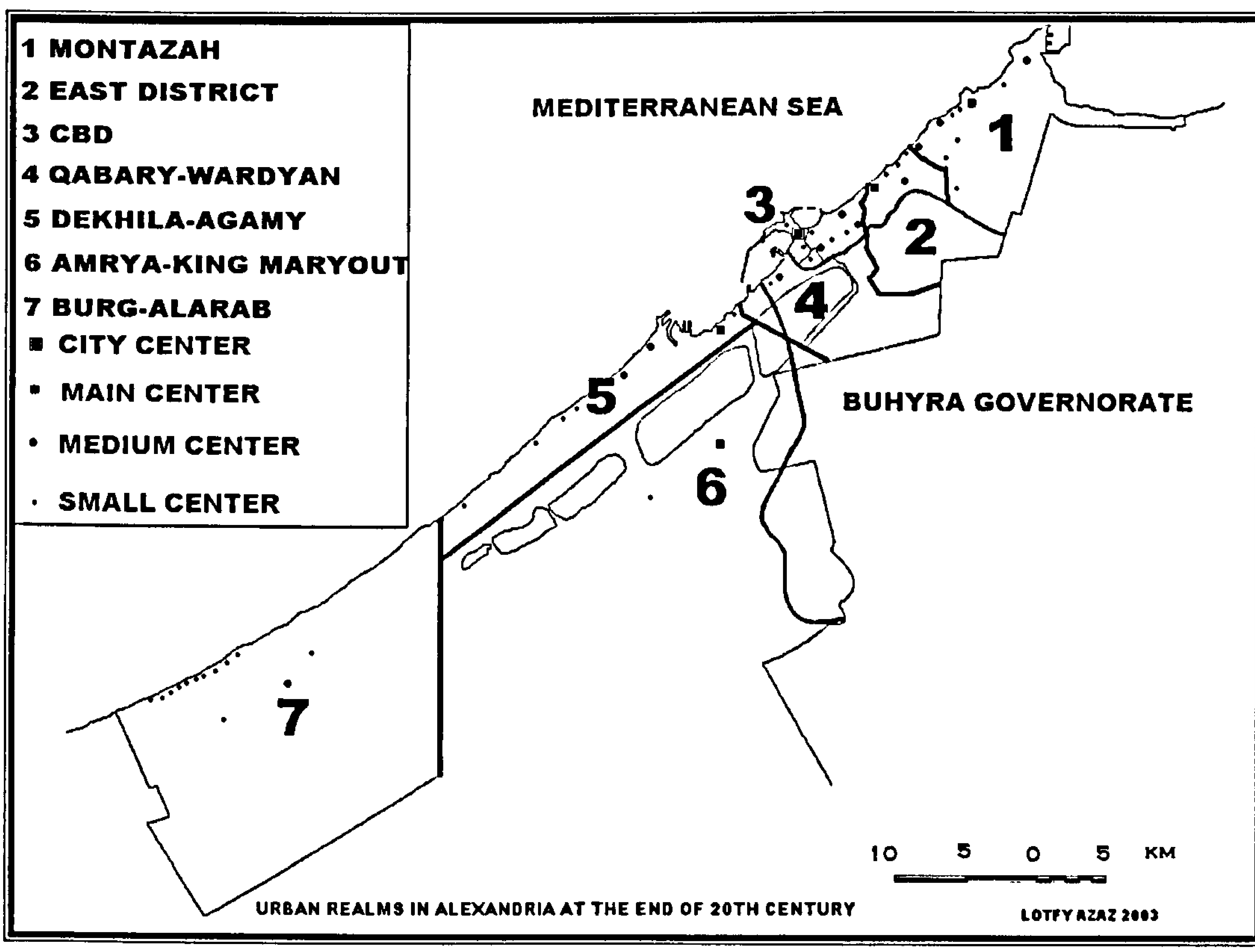


Figure 38 Urban realms in Alexandria 2003

3. Central Business District (C.B.D.) or the city centre that contains the

most important services including Alexandria University along with the other traditional services of the C.B.D. The university and other cultural sites such as cinemas and theatres are the only services that the residents of the other suburbs need from the city centre. In other words, the cultural function is the most dominant role of Alexandria city centre at the end of the 20th century.

4. Qabary-Wardyan is one of the oldest suburb centres in the city west. The activities in this area are mixed between the port, arsenal, and the residential area.

5. Dekhila- Agamy is a vast suburb in the west with many medium and small centres such as El-Max, Beetach, Hanoville, Abou-youssef, and 6th October. The main functions in this part are residential and industrial.

6. Amrya-King Maryout is the suburb that extends across the south of Maryout Lake to form a new local centre (Amrya). Amrya is backed by different activities such as industry, land development, and agriculture.

7. Burg-Alarab is the last suburb in the far west. The government included this area as part of Alexandria governorate in 1991 as a response to the continuous urban development to the west. The main activities are tourism in the north where the summer resorts are and industry in the south at New Burg-Alarab town.

4.5 Summary and conclusions

Alexandria witnessed cycles of flourishing and retrogression following the political and economical factors. The first extension of the city was towards the east during the Roman age. Alexandria experienced a long history of deterioration from the end of the Roman era up till the French expedition's departure in the beginning of the 19th century. Moving the capital of Egypt from Alexandria to El-Fustat was one of the important deterioration factors. Alexandria began to revive again in the first half of the 19^{th} century during the Mohammed Ali era as a genuine urban environment began to take shape following the development projects. Because of that, the immigrants flocked to the city so that the city expanded to the north, and to the south east in the first half of the 19^{th} century. In the second half of the 19^{th} century, the city continued to grow and extend to the south, the west, and the east. The key factor in the urban expansion in this stage was transport networks especially railways lines. In the first half of the 20^{th} century, the city continued to extend to the south of Al-Mahmoudia canal. The built-up area extended more and more to the west and the east directions but the latter was the most important among the other trends. In the second half of the 20^{th} century, the urban growth took four directions; to the east, the south east, the west, and the south west. The side effects of urban growth began to appear in some parts such as informal housing on the cultivated land in the south east. The built-up area increased about seventy eight times in the 20^{th} century as the city seems to expand horizontally rather than vertically. This significant expansion requires effective policies to manage it and reduce its damaging effects. Urban growth passed three stages. The first covered the 19^{th} century when the city expanded taking a "Circular Development" shape. The second covered the first half of the 20^{th} century, when the Multiple Nuclei Model can be applied. The third began from the second half of the 20^{th} century up to date when the Urban Realms Model is the most appropriate model that can describe the contemporary situation of urban growth in the city. This chapter investigated urban expansion of Alexandria using conventional methods (e.g., maps). Chapters 5, 6, and 7 will monitor, detect, and model urban land use/cover change using innovative methods (e.g., remote sensing and GIS).

5. CHAPTER FIVE: LAND USE/COVER CLASSIFICATION IN ALEXANDRIA

5.1 Introduction

Land use or land cover classification is the first step in satellite images analysis for this project. This chapter commences by distinguishing between *Land cover* and *Land use* terms to identify which definition will be adopted in this study. Then, land use classification will be defined as well. Classification of the satellite images of the area of study will begin with the selection of a Land use/cover classification scheme through a review of available schemes. This review generates a discussion leading to the final decision about the scheme used. The satellite images can be enhanced to improve classification outputs. Image enhancement processes will be introduced. Classification method is another important issue that will be discussed to select the most appropriate approach. Then, the classification processes of 1984 and 1993 satellite images will be presented with an accuracy assessment. Land use/cover analysis is presented at the end.

5.2 Background

There is often confusion between the terms Land use and Land cover. Therefore, it is important to distinguish between them. FAO (1998) uses the following clear definition for Land use and Land cover:

> *"**Land cover** is the observed physical cover, as seen from the ground or through remote sensing, including the vegetation (natural or planted) and human constructions (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock, or sand surfaces count as land cover.*
>
> ***Land use** is based upon function, the purpose for which the land is being used. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, piece of land and*

several land uses may occur on the same piece of land. Definition of land use in this way provides a basis for precise and quantitative economic and environmental impact analysis and permits precise distinctions between land uses, if required." (FAO 1998)

In this study, the compound term *Land use/cover* will be used instead of using one of them. This study is investigating a large city that includes both natural and artificial features. The Mediterranean Sea is the most important natural element that controls the shape of the city. Lake Maryout also is one of the factors, which confines the extension of the city. The deserts on the west and the coastal plain have a great potential for city growth. Beside all the above-mentioned natural features, the city has the urban feature - the main objective of this study - and some of the other artificial elements as well. Therefore, it is better to adopt land use/cover term rather than land use or land cover only.

5.3 Definition of land use classification

Land use/cover multispectral classification is the process that includes:

A) Organising and grouping the image pixels into a number of categories (classes) according to their data file values.

B) Assigning the pixels to a class if it meets the criteria of this class or the Land use/cover category (ERDAS 1997).

5.4 Land use/cover classification scheme

The first stage in the process of Land use/cover Classification is to select the classification scheme that will be applied in the study. The selection of the appropriate land use/cover scheme is not an easy exercise. There is a large number of classification schemes that are being used in remote sensing field and the related disciplines. Most studies try to define their own classification scheme according to the objectives of their projects. In the following part, some of Land use/cover classification schemes will be reviewed and evaluated.

5.4.1 Review of Land use/cover classification schemes

Many approaches can be applied to categorize the available Land use/cover classification schemes. Jensen (1996) divided the classification schemes into two groups:

a) ***Resource oriented (land cover) classification schemes***, The US Geological Survey Land Use/Land Cover Classification System (ANDERSON *et al.* 1976) is a good example for this group (Table 33).

Level I	Level II
1. Urban or build-up land	11. Residential. 12. Commercial and services. 13. Industrial 14. Transportation, communications, and utilities. 15. Industrial and commercial complexes. 16. Mixed urban or built-up land. 17. Other urban or built-up land.
2. Agricultural land	21. Cropland and pasture. 22. Orchards, groves, vineyards, nurseries, and ornamental horticultural areas 23. Confined feeding operations. 24. Other agricultural land
3. Rangeland	31. Herbaceous rangeland 32. Shrub and brush rangeland 33. Mixed rangeland.
4. Forest land	41. Deciduous forest land. 42. Evergreen forest land 43. Mixed forest land
5. Water	51. Streams and canals. 52. Lakes. 53. Reservoirs. 54. Bays and estuaries
6. Wetland	61. Forested and wetland. 62. Nonforested wetland.
7. Barren land	71. Dry salt flats 72. Beaches. 73. Sandy area other than beaches. 74. Bare exposed rock. 75. Strip mines, quarries, and gravel pits. 76. Transitional areas 77. Mixed barren land
8. Tundra	81. Shrub and brush tundra 82. Herbaceous tundra 83. Bare ground tundra 84. Wet tundra 85. Mixed tundra
9. Perennial snow or ice	91. Perennial snowfields 92. Glaciers.

Table 33 Anderson land-use and land-cover classification system for use with remote sensor data (ANDERSON *et al.* 1976)

b) Human activities (Land use) such as The Standard Land Use Coding (SLUC) Manual or the Michigan Land Use Classification System (Jensen 1996).

Alternatively, the classification schemes can be arranged according to the data being used :

a) Remote sensing oriented classification schemes such as, The US Geological Survey Land Use/Land Cover Classification System (USGS), US Fish and Wildlife Service Wetland Classification System (Table 34), and NOAA Coast Watch Land Cover Classification System (Jensen 1996).

System	Subsystem	Class
Marine	Sub tidal	Rock Bottom Unconsolidated Bottom Aquatic Bed Reef
Riverine	Tidal	Rock Bottom Unconsolidated Bottom Aquatic Bed Streambed Rocky Shore Unconsolidated Shore Emergent Wetland
Palustrine		Rock Bottom Unconsolidated Bottom Aquatic Bed Unconsolidated Shore Moss-Lichen Wetland Emergent Wetland Scrub/Shrub Wetland Forested Wetland

Table 34 Samples of systems, subsystems, and classes of The US Fish and Wildlife Service Classification of Wetlands and Deepwater Habitats (Jensen 1996)

b) The classification systems that do not use the remote sensing data such as The Standard Land Use Coding (SLUC) Manual or the Michigan Land Use Classification System (Jensen 1996).

In addition, the classification systems can be grouped according to the spatial level into two classes:

a) ***The Classification schemes that can be applied at the national level (country or state)*** such as all the above-mentioned US classification systems.

b) ***The systems that have been developed for International spatial scale*** such as, AFRICOVER Land Cover Classification System (LCCS) (FAO 1997) (Table 35), the International Geosphere Biosphere Programme Land Cover Classification System (IGBP) (Belward 1996) (Table 36), and CORINE land cover classification system (Bossard *et al.* 2000), (Table 37).

Level I	Level II	Level III
A. Vegetated areas	A1. Vegetated Terrestrial	A11. Cultivated Terrestrial
		A12. Natural and Semi-Natural Vegetation
	A2. Aquatic or Regularly Flooded Vegetated Land	A23. Cultivated Aquatic
		A24. Natural and Semi-Natural Aquatic Vegetation
B. Non Vegetated areas	B1. Terrestrial Non-Vegetated	B15. Built-up and Associated Areas
		B16. Bare Areas
	B2. Aquatic or Regularly Flooded Non-Vegetated Land	B27. Artificial Water Bodies:
		B28. Inland Water

Table 35 Africover Land Cover Classification System (LCCS) (FAO 1997)

Value	Description
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Water Bodies

Table 36 International Geosphere Biosphere Programme Land Cover Classification system (IGBP) (Belward 1996)

Level I	Level II	Level III
1 Artificial surfaces	1.1 Urban fabric	1.1.1 Continuous urban fabric
		1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units
		1.2.2 Road and rail networks and associated land
		1.2.3 Port areas
		1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites
		1.3.2 Dump sites
		1.3.3 Construction sites
	1.4 Artificial, non agricultural vegetated areas	1.4.1 Green urban areas
		1.4.2 Sport and leisure facilities
2 Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land
		2.1.2 Permanently irrigated land
		2.1.3 Rice fields
	2.2 Permanent crops	2.2.1 Vineyards
		2.2.2 Fruit trees and berry plantations
		2.2.3 Olive groves
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops
		2.4.2 Complex cultivation patterns
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4 Agro-forestry areas
3 Forests and semi-natural areas	3.1 Forests	3.1.1 Broad-leaved forest
		3.1.2 Coniferous forest
		3.1.3 Mixed forest
	3.2 Scrub and/or herbaceous vegetation associations	3.2.1 Natural grasslands
		3.2.2 Moors and heath land
		3.2.3 Sclerophyllous vegetation
		3.2.4 Transitional woodland scrub
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sands
		3.3.2 Bare rocks
		3.3.3 Sparsely vegetated areas
		3.3.4 Burnt areas
		3.3.5 Glaciers and perpetual snow
4 Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes
		4.1.2 Peat bogs
	4.2 Maritime wetlands	4.2.1 Salt marshes
		4.2.2 Salines
		4.2.3 Intertidal flats
5 Water bodies	5.1 Inland waters	5.1.1 Water courses
		5.1.2 Water bodies
	5.2 Marine waters	5.2.1 Coastal lagoons
		5.2.2 Estuaries
		5.2.3 Sea and ocean

Table 37 Corine land cover Classification system (Bossard *et al.* 2000)

Moreover, the classification systems can be ranked according to the level of classification; some of the classification systems apply a hierarchical system (multiple levels of classification) or the tree system for the Land use/cover classes such as USGS classification system, CORINE classification system, and AFRICOVER systems. On the other hand, the other systems use a simple classification (single level of classification) such as Seasonal land cover regions (Table 38), Global Ecosystems (Table 39), International Geosphere Biosphere Programme Land Cover Classification (Table 36), Simple Biosphere Model (1) (Table 40), Simple Biosphere Model (2) (Table 41), and Biosphere-Atmosphere Transfer Scheme (Table 42).

Value	Description
1	Fir/Cedar Forest
10	Tropical Rainforest
58	Bush/Shrubland
63	Desert/Hammadas/Shrubland
103	Savanna
146	Pasture/Cropland
154	Cropland
163	Irrigated Agriculture
192	Sahara/Sahel Sparsely Vegetated
193	Barren Or Sparsely Vegetated
196	Inland Water
197	Ocean

Table 38 Sample of Classes from Africa Seasonal Land Cover Regions Legend (USGS-NASA 2003)

Value	Description
1	Urban
8	Bare Desert
9	Upland Tundra
15	Sea Water
24	Mixed Forest
43	Savanna (Woods)
50	Sand Desert
71	Salt Playas
72	Mangrove
73	Water and Island Fringe
81	Beaches and Dunes
88	Bamboo
94	Crops, Grass, Shrubs

Table 39 Samples of classes from Global Ecosystems Classification system (USGS 2003)

Value	Description
1	Evergreen Broadleaf Trees
2	Broadleaf Deciduous Trees
3	Deciduous and Evergreen Trees
4	Evergreen Needleleaf Trees
5	Deciduous Needleleaf Trees
6	Ground Cover with Trees and Shrubs
7	Groundcover Only
8	Broadleaf Shrubs with Perennial Ground Cover
9	Broadleaf Shrubs with Bare Soil
10	Groundcover with Dwarf Trees and Shrubs
11	Bare Soil
12	Agriculture or C3 Grassland
17	Persistent Wetland
18	Dry Coastal Complexes
19	Water
20	Ice Cap and Glacier

Table 40 Simple Biosphere Model (1) (USGS 2003)

Value	Description
1	Broadleaf Evergreen Trees
2	Broadleaf Deciduous Trees
3	Broadleaf and Needleleaf Trees
4	Needleleaf Evergreen Trees
5	Needleleaf Deciduous Trees
6	Short Vegetation/C4 Grassland
7	Shrubs with Bare Soil
8	Dwarf Trees and Shrubs
9	Agriculture or C3 Grassland
10	Water, Wetlands, Ice/Snow

Table 41 Simple Biosphere Model (2) (USGS 2003)

Value	Description
1	Crops, Mixed Farming
2	Short Grass
3	Evergreen Needleleaf Trees
4	Deciduous Needleleaf Tree
5	Deciduous Broadleaf Trees
6	Evergreen Broadleaf Trees
7	Tall Grass
8	Desert
9	Tundra
10	Irrigated Crops
11	Semidesert
12	Ice Caps and Glaciers
13	Bogs and Marshes
14	Inland Water
15	Ocean
16	Evergreen Shrubs
17	Deciduous Shrubs
18	Mixed Forest
19	interrupted Forest
20	Water and Land Mixtures

Table 42 Biosphere Atmosphere Transfer Scheme (USGS 2003)

5.4.2 Discussion

Despite the number of the above-mentioned classification schemes, many other schemes are not mentioned. Although we have a large number of the classification systems, there is no single internationally accepted land cover classification system for the following reasons. Many of these systems are project-oriented systems, most of the systems are not comparable with one another (Jansen and Gregorio 1998). Because of this incompatibility among classification systems, the classification results cannot be used widely (FAO 1997). All the classification systems put hard boundaries between the classes. This is not true in the real world because there is a gradual interface at the edge of forests and rangeland for example (Jensen 1996). Therefore, the classification schemes should consider fuzzy definitions because of the fuzziness of the thematic information itself (Jensen 1996). However, Anderson et al (1976:7) admit that:

> *"There is no one ideal classification of land use and land cover, and it is unlikely that one could be ever be developed."*

In addition, Anderson et al (1976:7) confess: *"Each classification is made to suit the needs of the user."* As such, it is acceptable to develop a user-defined classification system according to the type of remotely sensed data being used and the objectives of the research project.

5.5 Image enhancement

It is recommended to enhance the image spectrally before performing classification as this can produce very specific and meaningful results. Image can be enhanced using some transformations methods such as principal components or image algebra. Image enhancement involves the process of creating a new interpretable image from the raw data. Enhancements systems can be used in preference to classification techniques for feature extraction studies. Meanwhile, enhancement tools can be used to prepare data for classification (ERDAS 1997). There are many types of image enhancement, such as, radiometric correction, geometric correction, spatial enhancement, and spectral enhancement. The principal components transformation is a standard tool in image enhancement, image compression, and classification (Singh 1989), (Richards 1986). Principal Component Analysis (PCA) or Karhunen-Loeve analysis can produce new more interpretable images and it can be used for data compression too (Jensen 1996). PCA may be used to transform the *n* wavebands into *n* new uncorrelated variables. Wilkie and Finn (1996:156) described PCA as:

> *"A decorrelation contrast stretch that often increases the visual information (features) within an image by combining the information in multiple bands for simultaneous display.*

The first principal component (PC1) is the most variable linear transform of the original data (Lark 1995). PC1 measures the highest variation between the data values (Figure 39). PC2 is orthogonal to PC1, and it expresses the second largest amount of variance in the data that is not described by PC1 (ERDAS 1997) (Figure 40).

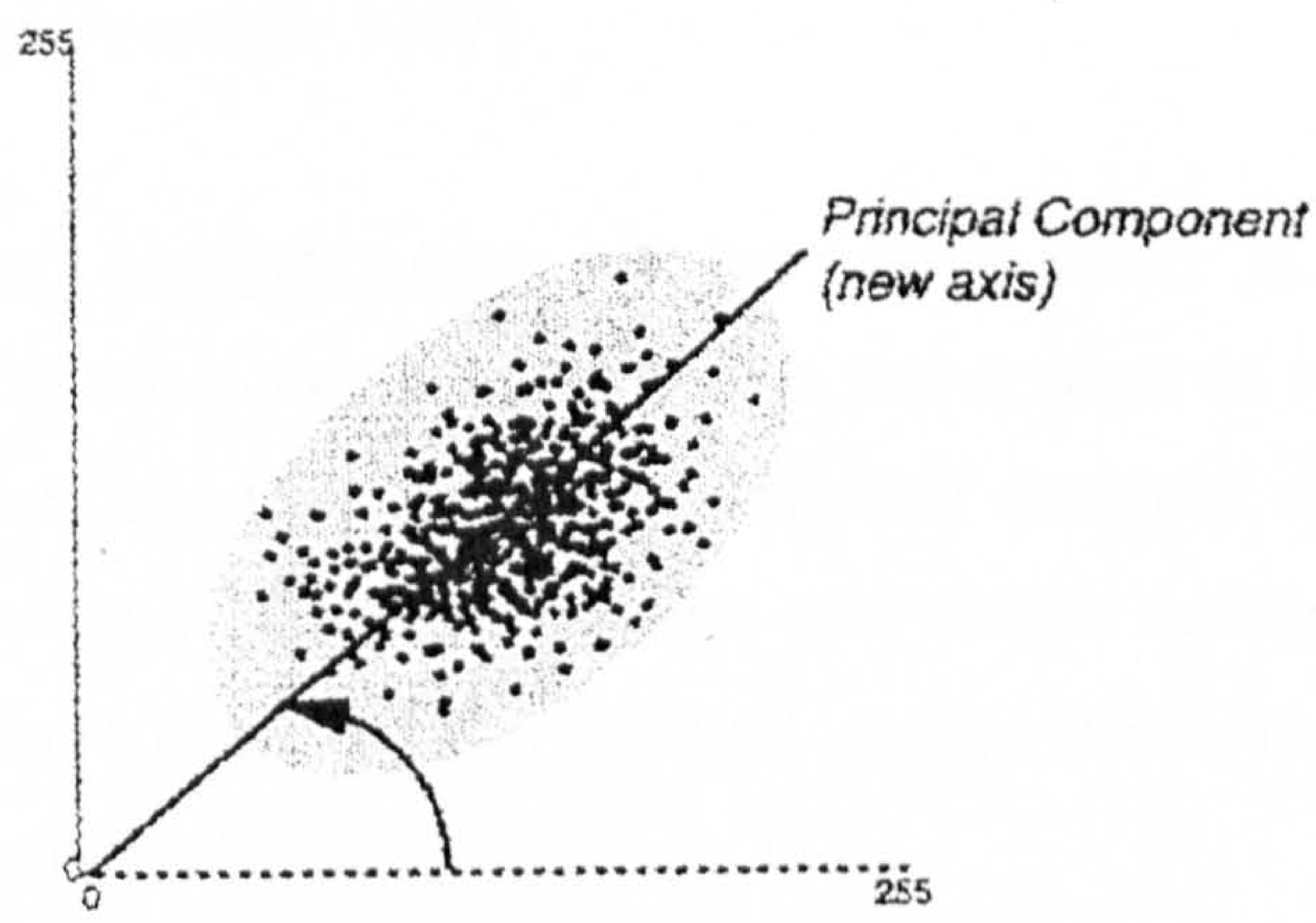


Figure 39 First Principal Component (ERDAS 1997)

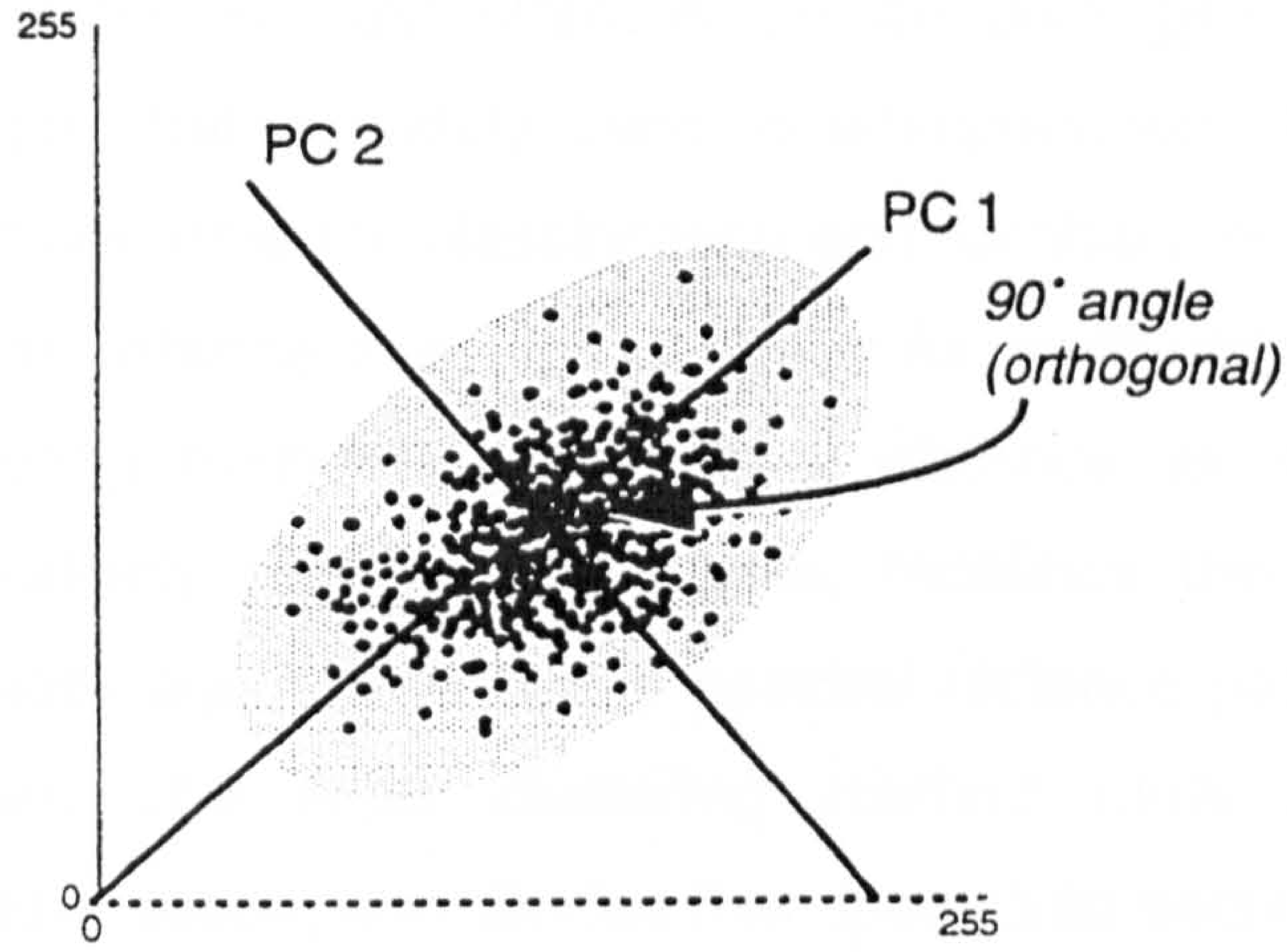


Figure 40 Second Principal Component (ERDAS 1997)

5.6 Classification technique

There are two types of satellite image classification:

a) ***Supervised classification***, which is completely controlled by the analyst and involves definition of the desired land use/cover classes that will be used in the study. The next step is to sample areas of known land use/cover classes to define their spectral values. Finally, the image can be classified based on its similarity to representative land use/cover class spectral values (Verbyla 1997).

b) ***Unsupervised classification*** on the other hand is more computer-automated; the computer system allows the analyst to identify the factors that the system employs to reveal statistical patterns of the data. These patterns are groups of pixels (clusters) with similar spectral characteristics. After classification, the analyst should assign meaning to the resultant classes (Jensen 1996).

Clustering is the other name for the unsupervised training (Lillesand and Kieffer 1994). Clusters or groups of pixels with the similar spectral characteristics are identified using a clustering algorithm. There are many kinds of clustering algorithms. ISODATA and RGB are amongst the common methods (Campbell 1996).

The ISODATA clustering algorithm is an Iterative Self-Organising Data Analysis technique that is widely used in unsupervised classification. It is iterative in that it performs the classification and recalculates statistics. It uses minimum spectral distance to assign a cluster for each candidate pixel. The ISODATA clustering method uses spectral distance as in the sequential method, but iteratively classifies the pixels, redefines the criteria for each class, and classifies again, so that the spectral distance patterns in the data gradually appear. The RGB clustering method plots pixels in three-dimensional feature space, and divides that space into sections that are used to define clusters (ERDAS 1997).

The ISODATA method is iterative so it has no bias in relation to the order in which the data is presented. Furthermore, it can find successfully the spectral clusters that are inherent in the data. Meanwhile, the disadvantages of the ISODATA method can be tolerated (Table 43).

Advantages	Disadvantages
Clustering is not geographically biased to the top or bottom of the data file, because it is iterative.	The clustering process is time-consuming, because it can repeat many times.
This algorithm is highly successful at finding the spectral clusters that are inherent in the data. It does not matter where the initial arbitrary cluster means are located, as long as enough iterations are allowed.	
A preliminary thematic raster layer is created, which gives results similar to using a minimum distance classifier on the signatures that are created. This thematic raster layer can be used for analysing and manipulating the signatures before actual classification takes place.	Does not account for pixel spatial homogeneity

Table 43 Advantages and disadvantages of ISODATA clustering method (ERDAS 1997)

By contrast, the RGB clustering method has disadvantages that can not be accepted; this method does not always create thematic classes that can be analysed for informational level (Table 44) (ERDAS 1997). Because of this, the ISODATA clustering method was selected to apply.

Advantages	Disadvantages
The fastest classification method. It is designed to provide a fast, simple classification for applications that do not require specific classes.	Exactly three bands must be input, which is not suitable for all applications.
Not biased to the top or bottom of the data file. The order in which the pixels are examined does influence the outcome.	Does not always create thematic classes that can be analysed for informational purposes
A highly interactive function, allowing an iterative adjustment of the parameters until the number of clusters and the thresholds are satisfactory for analysis (Advanced version only)	

Table 44 Advantages and disadvantages of RGB clustering method (ERDAS 1997)

5.7 Accuracy assessment

The USGS (2001) defined the accuracy of the spatial data as:

> *"The closeness of results of observations, computations, or estimates to the true values or the values accepted as being true."*

In the classification of the satellite images, the accuracy assessment refers to:

> *"The correspondence between the class label assigned to a pixel and the "true" class."* (Janssen and Van der Wel 1994 : 421).

The accuracy assessment can be performed by comparing two sources of information: (1) the classified image and (2) the reference information (Jensen 1996). The reference information can be obtained from the field or from the maps. The comparison between the "classified" pixels and the "reference" points results in an "error matrix", or "confusion matrix" (Janssen and Van der Wel 1994). From the error matrix, three kinds of accuracy can be measured:

(1) the overall accuracy which can be obtained by dividing the sum of the correct classified pixels by the total number of samples taken (Story and Congalton 1986).

(2) The accuracy of the individual classes. The accuracy of each class or category can be expressed by user's and producer's accuracy or commission and omission errors respectively (Story and Congalton 1986). The difference between the user and producer's accuracy will be explained through the analysis of the error matrix later.

(3) K (HAT) coefficient is a type of the "discrete multivariate analysis statistical techniques" (Congalton *et al.* 1983) and is calculated by:

$$\hat{K} = \frac{\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \qquad (1)$$

Where r is the number of rows in the confusion matrix,

x_{ii} is the number of observations in row i and column i of the confusion matrix,

x_{i+} and x_{+i} are the marginal totals of rows i and column i respectively.

N is the total number of observations.

K (HAT) is a measure of how well the classification agrees with the reference data (Congalton *et al.* 1983).

The first stage in the accuracy assessment is to determine the size of the sample that will be used. Defining the sample size of pixels to assess the accuracy of the classified image is often difficult (Jensen 1996). Some analysts such as Fitzpatrick-Lins (1981) in (Jensen 1996) suggest a formula based on the binomial distribution to calculate the sample size to be used in the accuracy assessment. The sample size can be computed as the following:

$$N = \frac{Z^2(P)(q)}{E^2} \qquad (2)$$

N = the sample size.
Z = 2 (from the standard normal deviate of 1.96 for the 95% two-sided confidence level).
P = the expected percent accuracy.
q = 100 – P.
E = the allowable error.

To estimate a sample size with an expected accuracy of 90% at an allowable error of 10%, the number of samples will be:

$$N = \frac{2^2(90)(10)}{10^2} = 36 \text{ points} \qquad (3)$$

It should be noted that the greater the allowable error is, the fewer points needed to assess the accuracy. This formula gives only the total number of points without any indication how these points will be distributed between the land use/cover classes or categories. Because of this, Congalton (1991) recommends selection of 50 points from each land use/cover as a rule of thumb (Congalton 1991). Congalton rule has been used by remote sensing analysts such as Jensen (1996) and Ward (2000) for the accuracy asessment.

There are many ways that reference pixels may be selected such as:

(1) ***Select the points randomly*** (no rules will be used).

(2) ***Select them stratified randomly*** , the number of points will be stratified to the distribution of thematic layer classes.

(3) ***Select them equalised randomly*** , each class will have an equal number of random points(ERDAS 1997) .

Selection of the reference points stratified randomly is better than the other two methods because it reflects the actual distribution of the thematic data.

5.8 Results

5.8.1 User-defined classification scheme

The available land use classification schemes were not used because most of the specified classes could not be applied in the area of study with its different class definitions. In addition, the spatial resolution of the available remotely sensed data, which in Alexandria prevents detailed classification. Jensen (1996) defines the level of classification that can be applied according to the characteristics of the data being used in (Table 45).

Classification Level	Typical Data Characteristics
I	Landsat MSS (79 x 79m), Thematic Mapper (30 x 30m), and SPOT XS (20 x 20m)
II	SPOT Panchromatic (10 x 10m) data or high-altitude aerial photography acquired at 40,000 ft (12,400m) or above; results in imagery that is ≤ 1:80,000 scale
III	Medium-altitude data acquired between 10,000 and 40,000 ft (3100 and 12,400 m); results in imagery that is between 1: 20,000 to 1: 80,000 scale
IV	Low-altitude data acquired below 10,000 ft (3100 m); results in imagery that is larger than 1: 20,000

Table 45 The Four levels of the US Geological Survey Land Use/Land Cover Classification System and the Type of Remotely Sensed Data Typically used to provide the information (Jensen 1996)

Consequently, a user-defined land use classification similar to level I has been developed to adapt with the type and spatial resolution of the accessible data. The following five classes were therefore chosen for application:

(1) Water bodies, including, the Mediterranean Sea, Maryout Lake, and all other water bodies in the city.

(2) **Shallow water, Saline, and Marsh**, which includes all shallow water areas, the areas that are being used to produce salt, and Marsh.

(3) **Built-up areas**, including all buildings regardless of the use or the pattern.

(4) **Green land**. Including all agricultural lands regardless of type of crops and their level of intensity, this class includes also "urban green lands" such as parks and sporting clubs.

(5) **Coastal plain and desert**, including the western desert and the coastal sand beaches. (Table 46).

Colour	Class Name
	Water bodies
	Shallow water/ Saline/ Marsh
	Built-up Areas
	Green Lands
	Coastal Plain/ Desert

Table 46 the User-defined classification Legend

5.8.2 Image enhancement

As the data being used in this study has been geometrically corrected in chapter two, it is necessary to select a suitable method of enhancement to prepare the data for the classification. A spectral enhancement method such as Principal Component Analysis (PCA) was used to create the base for the classification process.

In this study, band combinations of (2, 3, 4) bands of 1984 and 1993 images were spectrally enhanced using the first two principal components. The first principal component accounts for 86.64% of the total variance and the second component for 9.98%. The first two components give more accurate discrimination than any other pair of principal components. Lark (1995) claimed that first and second components are most important for discrimination. PCA was applied to reduce the dimension of image data as the different spectral data are transformed into some few principal components contained almost the total variance of original images (Phasomkusolsil *et al.* 1998). The new outputs were ready then to perform the classification of the Land use/cover in the area of study.

5.8.3 Image classification

5.8.3.1 1984 Image

In this study, a supervised classification approach was applied initially relating to the analyst's experience of the study area, but this did not provide an adequate separation between the target classes because of the small spectral differences between the major classes (Abdou-Azaz 2001). This is because of the complexity of the urban landscape that demonstrates very heterogeneous cover (Forster 1985). Therefore, unsupervised classification was adopted.

Unsupervised classification using the ISODATA Method was performed using a small number of classes (5). Unfortunately, the result was not acceptable because of the overlapping between built-up areas and Green lands classes in some parts (Abdou-Azaz 2001). Because of this, another unsupervised classification was performed using a larger random number of classes (16). The maximum iteration (maximum times that the ISODATA utility should recluster the data) was 10 and the convergence threshold (maximum percentage of pixels whose cluster assignments can go unchanged between iterations) was 0.950. Topographic maps of the study area helped in combining and recoding the classes, which led to reducing the number of classes from 16 to 5. The overall accuracy of this classification was 88% (Abdou-Azaz 2001).

Because achieving a high accuracy of land use classification is one of the most important objectives of this study in order to establish a good base for change detection analysis, another unsupervised classification using larger random number of classes (30) was carried out, and then the classes were merged, recoded to the pre-defined 5 classes in the customised classification scheme. The overall accuracy of the last test is 93.82%. The detailed analysis of the accuracy assessment is presented in the following section.

5.8.3.2 Accuracy assessment

Selection of the reference points stratified randomly is better than the other methods because it reflects the actual distribution of the thematic data. This method was applied in conjunction with Congalton rule. At least 50 stratified random samples of pixels were taken from each class according to Congalton's rule and the total number of points was 275. The accuracy assessment was carried out using Egyptian-series topographic maps of scale 1:50,000 (EGSA 1997).

The accuracy assessment was done many times with each classification test. The first error matrix shown in table 47 reveals an overall accuracy of 88% in image classification for 1984 image (using 16 classes).

Class Name	Water bodies	Saline	Green lands	Built-up areas	Coastal plain/desert	Row total
Water bodies	53	7	0	0	2	62
Saline	2	46	3	0	0	51
Green lands	0	0	47	7	2	56
Built-up areas	0	0	5	48	3	56
Coastal plain/desert	0	0	0	2	48	50
Column total	55	53	55	57	55	275

Overall accuracy = 242/275 = 88%

Table 47 The first accuracy assessment of land use unsupervised classification for 1984's Alexandria remotely sensed image

To perform an accepted change detection land use analysis, it is better to increase the accuracy of the resulting classified images. A large number of classes (30) instead of the16 in the previous test were used in another unsupervised classification. The final assessment produces an overall accuracy of 93.82% (table 48). The overall final K (HAT) coefficient is 0.92 (table 49).

Class Name	Water bodies	Saline	Green lands	Built-up areas	Coastal plain/desert	Row total
Water bodies	56	0	1	0	0	57
Saline	3	46	0	1		50
Green lands	0	1	49	3	0	53
Built-up areas	0	0	4	48	0	52
Coastal plain/desert	0	0	1	3	59	63
Column total	59	46	55	55	59	275

Overall accuracy = 258/275 = 93.82%

Table 48 The accuracy assessment of land use unsupervised classification for 1984's Alexandria remotely sensed image

Class Name	K (HAT)
WATER BODIES	0.98
SALINE/	0.90
GREEN LANDS	0.91
BUILT-UP AREAS	0.90
COASTAL PLAIN	0.92
Overall K (HAT)	**0.92**

Table 49 K (HAT) coefficient of land use classification of 1984's image

The value of K (HAT) means that the classification process was avoiding about 92 percent (as an average) of the errors that a completely random classification would generate (Congalton 1991).

Furthermore, the user and producer's accuracy can be calculated from the error matrix. The user's accuracy is the number of correctly classified samples divided by the row total (Table 48). It provides the user information about the accuracy of land-cover data (Janssen and Van der Wel 1994). For example, the user's accuracy of the built up areas is 92.31% (Table 50). This means that 92.31% of the pixels classified as built-up areas are built-up areas in reality. Then the accuracy based on the sampled pixels is representative of the total classification result (Janssen and Van der Wel 1994). The producer's accuracy is calculated by dividing the number of correctly classified samples by the column total (Table 48 and Table 49). It refers to the percentage of samples of a certain (reference) class that were correctly classified (Janssen and Van der Wel 1994). Figure 41 indicates the result of land use categories (classes) in Alexandria (1984).

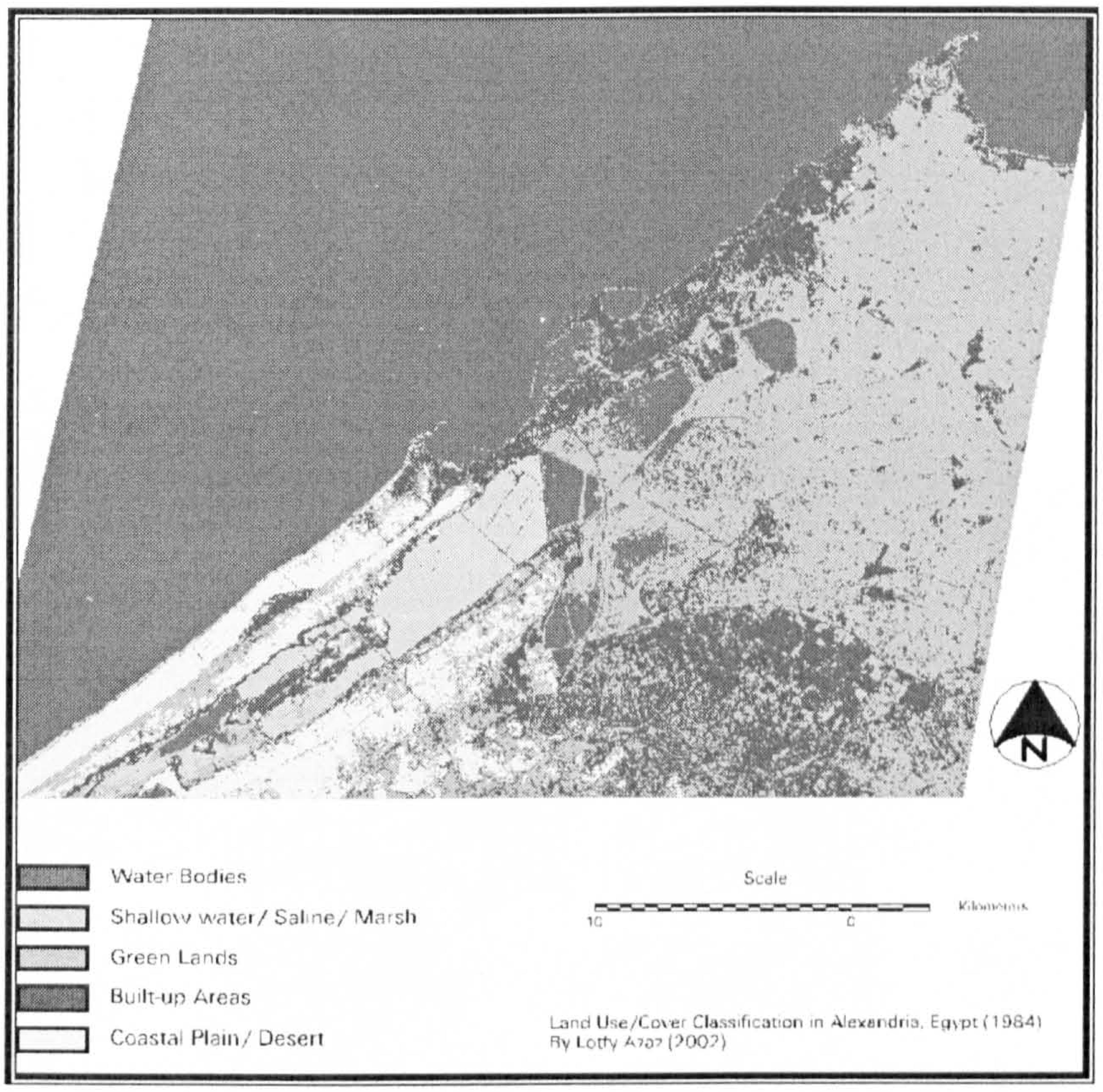


Figure 41 Land use categories in Alexandria (1984)

Class Name	Producer's accuracy		Omission error (%)	User's accuracy (%)		Commission error
Water bodies	56/59	94.92	5.08	56/57	98.25	1.75
Saline	46/47	97.87	2.13	46/50	92.00	8.00
Green lands	49/55	89.09	10.91	49/53	92.45	7.55
Built-up areas	48/55	87.27	12.73	48/52	92.31	7.69
Coastal plain/desert	59/59	100.00	0.00	59/63	93.65	6.35

Table 50 Producer's accuracy (omission error) and User's accuracy (commission error) of the 1984's classified image

5.8.3.3 1993 Image

Unsupervised classification using the ISODATA Method was performed using 30 classes. Then, the classes were grouped and recoded to produce the final preferred five land use/cover classes.

5.8.3.4 Accuracy assessment

The overall accuracy of the 1993 classified image is 95.27% (Table 51). The K (HAT) coefficient stipulates an overall classification accuracy of 0.94 (Table 52). Table 53 indicates the user and producer's accuracy. Figure 42 shows the Land use categories in Alexandria (1993).

Class Name	Water bodies	Saline	Green lands	Built-up areas	Coastal plain/desert	Row total
Water bodies	56	0	0	0	0	56
Saline	1	47	1	1	0	50
Green lands	0	0	51	2	2	55
Built-up areas	0	1	1	49	1	52
Coastal plain/desert	1	0	1	1	59	62
Column total	58	48	54	53	62	275

Overall accuracy = 262/275 = 95.27%

Table 51 The final accuracy assessment of land use unsupervised classification for 1993's Alexandria remotely sensed image

Class Name	^K
WATER BODIES	1.00
SALINE/	0.93
GREEN LANDS	0.91
BUILT-UP AREAS	0.93
COASTAL PLAIN	0.94
Overall K (HAT)	0.94

Table 52 K (HAT) coefficient of land use classification of 1993's image

Class Name	Producer's accuracy		Omission error (%)	User's accuracy (%)		Commission error
Water bodies	56/58	96.55	3.45	56/56	100.00	0.00
Saline	47/48	97.92	2.08	47/50	94.00	6.00
Green lands	51/54	94.44	5.56	51/55	92.73	7.27
Built-up areas	49/53	92.45	7.55	49/52	94.23	5.70
Coastal plain/desert	59/62	95.16	4.84	59/62	95.16	4.84

Table 53 Producer's accuracy (omission error) and User's accuracy (commission error) of the 1993's classified image

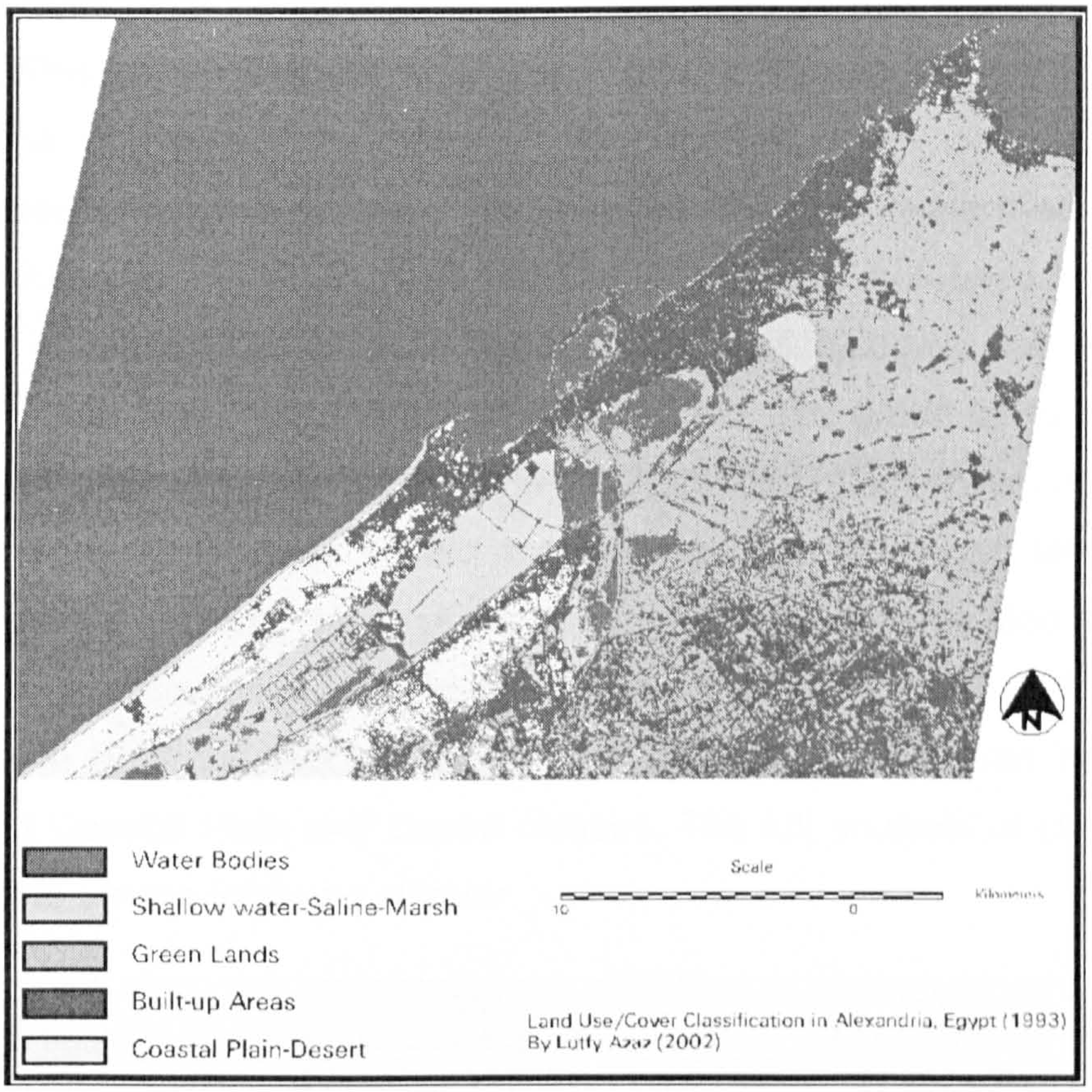


Figure 42 Land use categories in Alexandria (1993)

The achieved high accuracy can be interpreted in the light of the type of map data that being used. The Egyptian-series topographic maps of scale 1:50,000 of the area of study were compiled from aerial photography taken between 1990-1991 (EGSA 1997). It is known that the maps that are being produced using aerial photography have a high accuracy in presenting land features. Furthermore, aerial photography is a form of remote sensing data. That means there is a sort of compatibility between aerial photography and satellite images. From another point of view, the date of aerial photography (1991-1992) that is used in the production of those maps is contemporary to the date of the satellite image (1993). This helped in the selection of more accurate and representing reference land use/cover points.

5.8.4 Land use/cover analysis

Distribution of the interpreted land use/cover categories during the two periods under consideration is shown in Table 54. Coastal Plain and Desert category dominated the study area by occupying 48.91% in 1984 and 45.36% in 1993. This means that this class lost 7.26% of its area between 1984 and 1993. The change in this class is due to the urban and agricultural developments projects. Water Bodies and Shallow water/Saline/Marsh classes occupied 27.78% in 1984 and 1993. This class increased by 37.96% as parts of Maryout Lake were dried. Green land category decreased by about 6% from 15.41% in 1984 to 14.48% in 1993. The green lands lost more than 6% of its area between 1984 and 1993, but this is not shown in the final balance as the green land gained a considerable area through land reform projects in the deserts. Most of the loss of green lands related to urban expansion. Built-up area class, the focus of this study, gained 56.71% where it was 7.9% in 1984 and become 12.38% in 1993. This increase was from green lands and Coastal Plain and Desert classes. The full analysis of change will be presented in the following chapter.

Class	1984 (Area/Hectare)	%	1993 (Area/Hectare)	%
Water Bodies	174,135.294	26.70	171,451.493	26.29
Shallow water/Saline/Marsh	7,043.789	1.08	9,727.590	1.49
Green Lands	100,510.925	15.41	94,438.877	14.48
Built-up areas	51,537.613	7.90	80,778.342	12.38
Coastal Plain and Desert	319,010.714	48.91	295,842.033	45.36
Total	652,238.335	100	652,238.335	100

Table 54 Land Use/Cover Categories in Alexandria in 1984 and 1993

5.9 Summary and conclusion

There is no single internationally accepted classification scheme. Therefore, a user-defined scheme was developed. The initial classification was performed to the geometrically corrected data without applying any sort of image enhancement techniques. Principal Component Analysis (PCA) was then used to enhance the images. This transformation leads to an accuracy that is better than the results yielded from the non-enhanced images. A supervised classification approach was applied initially, relating to the analyst's experience of the study area, but this did not provide an adequate separation between the target classes. Therefore, an unsupervised classification using ISODATA clustering method was adopted. In the first test of the unsupervised classification phase, 16 classes were defined. Then, these classes were merged and recoded to the five predefined classes. The overall accuracy of the resulted image was 88%. In the second test, 30 classes were used and the overall accuracy was about 95%. In sum, enhancing the images before classification and using a large number of classes when performing unsupervised classification can yield classified images with high accuracy. The final overall accuracy for the 1984 and 1993 images are 93.28 % and 95.27% respectively. The K (HAT) coefficient was 0.92 and 0.94 for 1984 and 1993 images. The achieved high accuracy can be understood if we learn that the reference data are maps that are produced from aerial photography which helped in the selection of more accurate and representing reference land use/ cover points. In addition, the date of these aerial photographs (1991-1992), is contemporary to the date of the available satellite images (1993). These results introduce an acceptable base for the change detection analysis in the following Chapter. In terms of land use/cover analysis, the Coastal Plain and Desert class lost 7.26% of its area between 1984 and 1993. The change in this class is due to the urban and agricultural developments projects. The shallow water/Saline/Marsh classes increased by 37.96% as parts of Maryout Lake were drained. The green land category decreased by about 6% in the same period. Most of the loss of green lands related to urban expansion. The built-up area class gained 56.71% between 1984 and 1993. This increase was from green lands and Coastal Plain and Desert classes.

6. CHAPTER SIX: DETECTING URBAN LAND USE CHANGE IN ALEXANDRIA USING SATELLITE IMAGES

6.1 Introduction

Satellite images offer a repetitive coverage of the Earth. This is a significant advantage for environmental monitoring (Gibson and Power 2000). Some satellites systems have been operational for several decades, thus they provide a record of change. Change detection is the process of identifying difference in the state of an object or phenomenon by observing it at different times (Deer 1995).

Change detection techniques provide systematic methods to record and analyse the change. The principal basis in using remotely sensed data for change detection projects is that changes in land cover result in changes in radiance values (Mas 1999). These changes are often caused by human activities. Change detection has a number of applications within the environmental sphere. Urban growth is one of the most dynamic phenomena in the modern world. The accelerated growth and changes in the urban landscape has a great impact on the environment. The growth and direction of urban development should be monitored.

In this chapter, previous studies regarding change detection are examined for the last twenty years. Then, the selection of change detection approach is discussed by presenting the most used methods, showing their advantages and disadvantages leading to the method selection that will be applied in this study. The selected method is applied and image-based change maps, tables, and figures present the results. Accuracy assessment of the change detection products is presented and the conclusions of the chapter are summarised at the end.

6.2 Previous studies

Investigating land use/cover change is one of the most important issues that attract remote sensing analysts. Thus, extensive research has been completed on various change detection methods so it is difficult to refer to all change detection previous studies. However, change detection review can be found in chapter one. The following discussion examines some examples of these studies during twenty years from 1982 to 2002.

Jensen and Toll (1982) applied Landsat multispectral scanner data to an urban change detection problem in Denver, Colorado (Toll 1982). Fung and LeDrew (1987) applied Principal Components Analysis (PCA) for land-cover change detection with multitemporal Landsat Multispectral Scanner (MSS) data (Fung and LeDrew 1987).

Salem et al., (1995) studied the land use change in the coastal agricultural land of Egypt using different vegetation indices. A sub-tropical intertidal wetland in Moreton Bay, Queensland, Australia was physically modified in 1985 to manage a mosquito-breeding problem. Monitoring before and after modification was done using field and remote sensing techniques (Dale *et al.* 1996). Guirguis et al., (1996) applied change detection algorithms to Landsat MSS data for monitoring changes inside and outside the Lake Brullus environment. Pusdata et al., (1996) evaluated land use/cover in Yogykarta using remote sensing, they calculated the index of change by the superimposition of land use/cover images of 1972, 1984 and land use maps of 1990. Sunar (1998) detected land cover changes by using multi-date Landsat TM imagery for the Ikitelli area, Istanbul, Turkey, employing several methods. In another study, Landsat Thematic Mapper (TM) images acquired on 17 February 1986 and 28 February 1993 respectively, were used to demonstrate their usefulness for both surface spectral mapping and temporal change detection in Kuwait city (Kwarteng and Chavez 1998). Alves at al., (1999) analysed landscape changes in a region of pioneer settlements in central Rondonia, western Brazilian Amazon using Landsat TM data. Luque (2000) used a combination of satellite remote sensing imagery and GIS to map and monitor land cover change at landscape level scales in the New Jersey Pinelands National Reserve (NJPNR). A project was carried out in 1997 under the auspices of the China State Land Administration to monitor the dynamics of urban expansion in 100 municipalities throughout China using Landsat Thematic Mapper (TM). Change detection techniques were employed to identify the areas of urban encroachment (Ji *et al.* 2001). Liu and Lathrop (2002) developed a method based on an artificial neural network (ANN) to detect newly urbanised areas depicted in satellite sensor images. Xiuwan (2002) used a post-classification method to detect land cover change from multi-temporal satellite data. There was an attempt to determine the growth of urban areas in the vicinity of Mexico City using a 1993 Landsat Thematic Mapper (TM) image and cartographic data (Prol-ledesma *et al.* 2002). Seto et al., (2002) monitored land-use change in the Pearl river delta through a nested hierarchy of land-cover. In another part of China, Zhujiang delta, land use change dynamics were investigated by the combined use of satellite remote sensing, geographic information systems (GIS), and stochastic modelling technologies (Weng 2002).

6.3 Change detection method selection

The selection of an appropriate change detection algorithm is very important. Firstly, it will define the type of classification to be applied; second, it will delineate whether there is any information about the nature of change or not (Jensen 1996).

Numerous methods of land use/cover change detection have been developed as shown in the previous section. Some authors endeavoured to categorise these methods using different variables. Mas (1999) grouped change detection procedures into three approaches according to the data transformation and analysis techniques employed:

(1) Image enhancement.

(2) Multi-date data classification.

(3) Comparison of two independent land cover classifications.

The image enhancement approach involves the mathematical combination of imagery from different dates such as subtraction of bands, rationing, image regression or principal component analysis (PCA). The direct multi-date classification is based on the single analysis of a combined dataset of two or more different dates. The post-classification comparison is a comparative analysis of classified images obtained at different dates (Mas 1999).

Metternicht (1999) divided the traditional methods of change detection broadly to two categories: Pre-classification and Post-classification. Pre-classification methods detect change according to variations in the brightness values of the compared images. The common approaches of these methods are: image difference, image ratio, selective principal component analysis, and on screen digitising of changes. Post-classification methods identify changes between two or more classified images of different dates.

Deer (1995) categorised digital change detection techniques into two basic approaches: the comparative analysis of independently produced thematic labelling or classifications of imagery from different dates, or simultaneous analysis of multi-temporal data sets.

Further, Johnson and Kasischke (1998) grouped change detection techniques into two general classes: (1) those based on spectral categorisation (classification) of the input data, and (2) those based on radiometric change between acquisition dates. Among the categorisation-based approaches are procedures which: (a) assess change based on categorisation and subsequent comparison of the results from each date; or (b) assess change based on direct two-date categorisation. Among the radiometric approaches are procedures such as (a) band differencing; (b) transformed band differencing (e.g. vegetation indices); (c) ratioing; (d) regression; (e) principal components; and (f) multispectral change vector magnitude and direction. There are also hybrid approaches based on a mix of categorical and radiometric change information.

Jensen (1996) stated that at least seven change detection algorithms are commonly used from the following,

(1) Change detection using write function memory insertion.

(2) Multi-date composite image change detection.

(3) Image Algebra change detection (Band differencing or band ratioing).

(4) Multi-date change detection using a binary mask applied to date 2.

(5) Multi-date change detection using ancillary data source as date 1.

(6) Manual, on screen digitising of change.

(7) Spectral change vector analysis.

(8) Knowledge-based vision systems for detecting change.

(9) Post-classification comparison change detection.

These will be discussed in brief using Jensen (1996) to help the selection of the appropriate method for this study.

6.3.1 Change detection using write function memory insertion

In this method, the individual bands of the images can be inserted into specific write function memory banks (red, green, and or blue) to identify visually the changes. Jensen (1996) inserted band one of a Landsat TM scene of the Fort Moultrie quadrangle near Charleston, South Carolina obtained on 9^{th} of November 1982 in the green image plane and band one of Landsat TM of the same area obtained on 19^{th} of December 1988 in the red image plane. According to the additive colour theory, equal intensities of green and red make yellow so that the area of "no change" was yellow. The change was monitored in many areas; beach and sand bar accretion in red and erosion in green, new urban development in red. The main advantage of this method is the possibility of investigating two or even three images of different dates at one time. The method unfortunately does not give any information about the size of change from one land cover class to another.

6.3.2 Image Algebra change detection (Band differencing or band ratioing)

The quantity of change between two images can be identified by image (or band) differencing or band ratioing. Image differencing involves subtracting the rectified imagery of one date from another. The results of subtracting will be positive and negative values in areas of radiance change and zero values in areas of no change. Band ratioing applies the same concept except the results will be a ratio rather than an absolute value where the area of "no change" will have a ratio value of 1. The analysts have the choice to decide where to place the threshold between change and no change values so it is important to have previous experience with the study area. It is also recommended to perform illumination and atmospheric correction before applying this method (Lillesand and Kieffer

1994). Although this method provides quantitative information about the change, it does not give any information on the nature of change.

6.3.3 Multi-date change detection using a binary mask applied to date 2

In this method, one of the images should be rectified and classified, then, a certain band from both images will be placed in a new dataset. This new dataset will be analysed using some image algebra functions producing a new change image file. The change image is then recoded into a binary mask file to contain only the area (s) of change between the two dates. The change mask is then overlaid onto date 2. Finally, change pixels only will be classified in date 2 imagery. To obtain information about the nature of change, the post-classification comparison method can be applied.

6.3.4 Multi-date change detection using ancillary data source as date 1

Some analysts suggested another source of data rather than remotely sensed data as a base map for change detection projects. Jensen (1996) recommended using digital maps as date 1 in the absence of satellite images and this data should be recoded to be compatible with the classification scheme being used with the image of date 2. Then the date 2 image should be classified and compared on a pixel-by-pixel basis with date 1 information using post-classification comparison method. This method has many advantages:

(1) The detailed information about the nature of change can be obtained.

(2) Only a single classification of date 2 image is required.

(3) Old maps can be updated through this method.

On the other hand, this method needs the ancillary data to be digitised, recoded, and converted to raster format to be compatible with remotely sensed data. This means every error from manual digitising and subsequent processes can lead to unacceptable results of change detection analysis.

6.3.5 Image regression

In this method, pixel values from one time are assumed to be a (normally) linear function of pixel values at some other time. The function that relates the pixel values can be determined using a least squares regression. The changed pixels will have values that differ significantly from that predicted by the determined function, threshold is applied to detect areas of change (Deer 1995). This method has been used in many studies such as (Singh 1986).

6.3.6 Manual, on screen digitising of change

Aerial photographs of high resolution from different dates can be scanned into digital image files, then, they can be displayed on a CRT screen at the same time. The displayed images can be analysed using photo interpretation techniques to identify change. This method can be applied also with satellite images of high resolution.

6.3.7 Post-classification comparison change detection

This method is based on comparing two rectified and classified images pixel by pixel. That means every error in the classification of the images will reflect on the accuracy of the final change map. Hence, it is essential to produce high accuracy classified images for using with this method. This method provides detailed information about the nature and size of change that is valuable for accepted change detection results. In many studies, the post-classification comparison method has provided the highest accuracy of change detection compared to the other methods (Mas 1999). Post-classification comparison method has been used to detect changes in many studies such as detecting changes from non-urban to urban categories (Riordan 1980), and detecting changes in general land use (Gordon 1980).

6.3.8 Selective principal component analysis

In this method, two bands of the multi-date image are used as input instead of all bands. The common information between the two bands will be mapped to the first component and the unique information to either one of the two bands (the changes) will be mapped to the second component (Chavez and Kwarteng 1989).

6.3.9 Change vector analysis (CVA)

Change vector analysis (CVA) is a radiometric technique. This method requires a high accurate geometric registration and radiometric normalization of the input data. CVA is a multivariate technique, which accepts as input *n* bands, transforms, or spectral features (bands) from each scene pair (date 1 and date 2). For each scene pair, these bands comprise the axes of an *n*-dimensional space. A changed pixel plots at two different points [(band1, band2...) Date 1, (band1, band2...) Date 2], whereas an unchanged observation plots at essentially the same position on both dates. Where change has occurred, the relationship between the two points can be characterised by a change vector with a measurable direction and magnitude. The CVA algorithm produces two "channels" of output change information: (1) change vector direction; and (2) multispectral change magnitude (Johnson and Kasischke 1998). The potential advantages of CVA over some other methods include:

(1) Capability to concurrently process and analyse change in all multispectral input data layers;

(2) Avoidance of compounding spatial-spectral errors often inherent in multi-date classifications;

(3) The capability to detect changes both in land cover and condition; and

(4) Computation and separation of multidimensional change vector components, and composition of change images that retain this information and facilitate change interpretation and labelling (Johnson and Kasischke 1998).

Michalek *et al.* (1993) investigated the utility of multispectral Landsat Thematic Mapper satellite data for documenting changes to a Caribbean coastal zone using the change vector analysis processing technique.

6.3.10 Miscellaneous methods

There are also other methods for change detection. Some analysts used the fuzzy set change detection technique (Metternicht 1999). Vegetation Index differencing methods such as the normalised difference vegetation index (NDVI) has been used in many studies (e.g. (Elvidge and Chen 1995) and (Nelson 1983)).

6.3.11 Discussion

The complexity of geographic territory makes it difficult to develop a general method for all applications in different regions in the world (Xiuwan 2002).

In spite of the successful applications of the different change detection methods in monitoring the environment, there is no consensus as to a "best" change detection approach (Seto *et al.* 2002) and no single change detection approach can be considered optimal or applicable in all cases (Johnson and Kasischke 1998). Deer (1995) reviewed change detection literature and admitted the non-existence of a universally "optimal" change detection technique. Any change detection technique possesses its own set of advantages and disadvantages (Johnson and Kasischke 1998).

The selection of a change detection method depends on many factors such as data availability, the area of study, time and computing constraints, the type of application (Seto *et al.* 2002), spectral coverage, analyst skill and experience, and phenomenological knowledge (Johnson and Kasischke 1998).

Considering the literature review of change detection and the controlled factors of this study, change detection using post-classification comparison method was selected for this study for the following grounds:

(1) The need for detailed information about the nature (type) of change.

(2) The need also for the full information about the size of change.

(3) In most cases, this method provided the highest accuracy in change detection compared to the other methods (Mas 1999).

(4) The availability of the important elements of this method, high accuracy geometric correction and high accuracy land use/ cover classification.

(5) This method applies two independent classifications for the images that mean it does not need anniversary date imagery. Anniversary dates mean the used images should be acquired on anniversary dates, for example

19th of September 1984 and 19th of September 1993. This is not the case for the available data in this study, as the acquiring date for the first image is 7th of June 1984, and 29th of April 1993 for the second image.

6.4 Change detection using Post-classification Comparison, an application

6.4.1 Geometric Correction

To acquire an accurate change detection, it is important to apply an appropriate geometric correction approach to minimise the incorporation of false change due to lack of spatial coincidence between the compared images (Metternicht 1999). In this study, many tests were performed to obtain a minimum amount of error (less than 8m) where the Root Mean Square Error (RMSE) of 1984 image is (0.2566) pixel (7.698m), and the RMSE of 1993 image is (0.2498) pixel (7.494 m).

6.4.2 Images classification

The following stage in this method is to classify rectified images that will act as the main inputs of a post-classification comparison algorithm. Unsupervised classification using ISODATA clustering method was applied. The overall accuracy of the classification is 93.82% and 95.27% for 1984 and 1993 images respectively. This level of accuracy provides a good base for post-classification change detection method, which means high accuracy change detection product. The detailed analysis of the accuracy assessment is presented in the previous chapter. Figures 43 and 44, and Tables 55 and 56 show the land use/cover classification of Alexandria for 1984, and 1993 respectively along with the spatial coverage of each class.

6.4.3 Post_classification comparison change detection

Two rectified, classified images with high accuracy (94.55% as an average for both images) were compared pixel by pixel in ERDAS Imagine to perform change detection using post-classification comparison method. The method involves subtracting one image from another image of the same area acquired at different dates. If the result for some classes is zero, this means there is no change. If there is any value more/less than zero, this implies change.

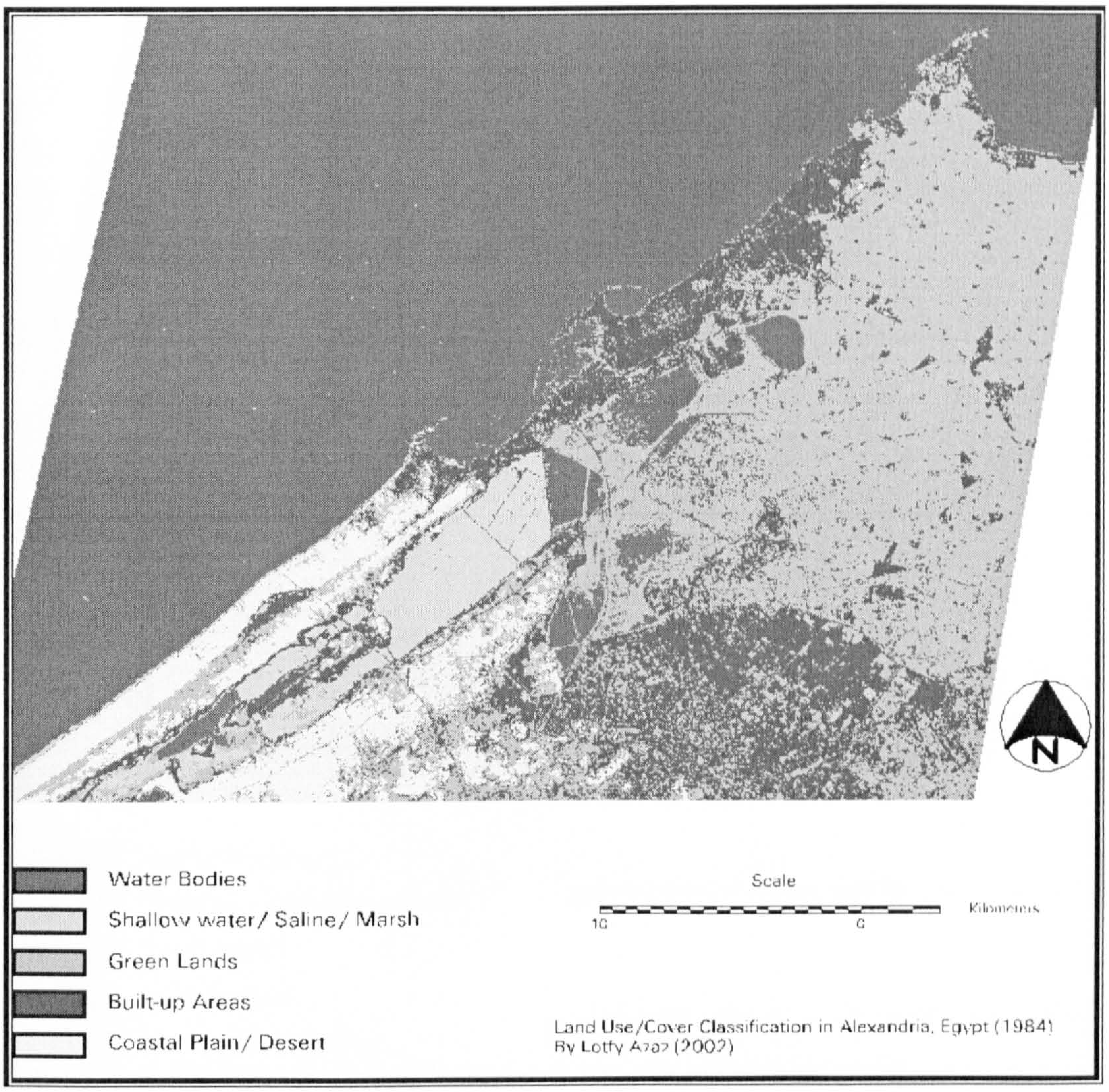


Figure 43 Land Use/Cover Categories in Alexandria (1984)

Class	1984 (Area/Hectare)	Percentage
Water Bodies	174,135.294	26.70
Shallow water/Saline/Marsh	7,043.789	1.08
Green Lands	100,510.925	15.41
Built-up areas	51,537.613	7.90
Coastal Plain and Desert	319,010.714	48.91
Total	652,238.335	100

Table 55 Land Use/Cover Categories in Alexandria (1984)

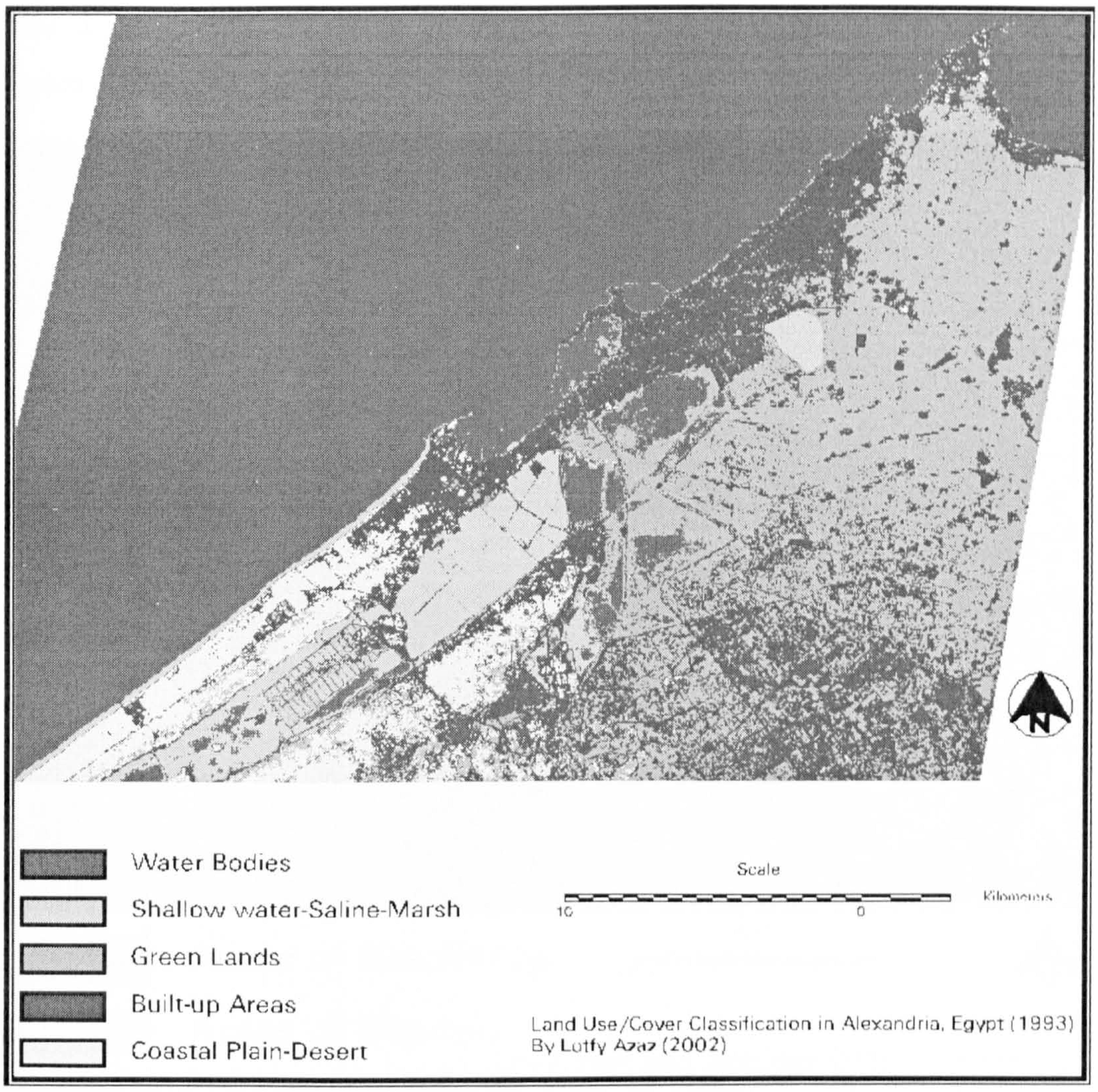


Figure 44 Land Use/ Cover Categories in Alexandria (1993)

Class	1993 (Area/Hectare)	Percentage
Water Bodies	171,451.493	26.29
Shallow water/Saline/Marsh	9,727.590	1.49
Green Lands	94,438.877	14.48
Built-up areas	80,778.342	12.38
Coastal Plain and Desert	295,842.033	45.36
Total	652,238.335	100

Table 56 Land Use/ Cover Categories in Alexandria (1993)

Figure 45 and table 57 show the major detected changes in the area of study between 1984 and 1993.

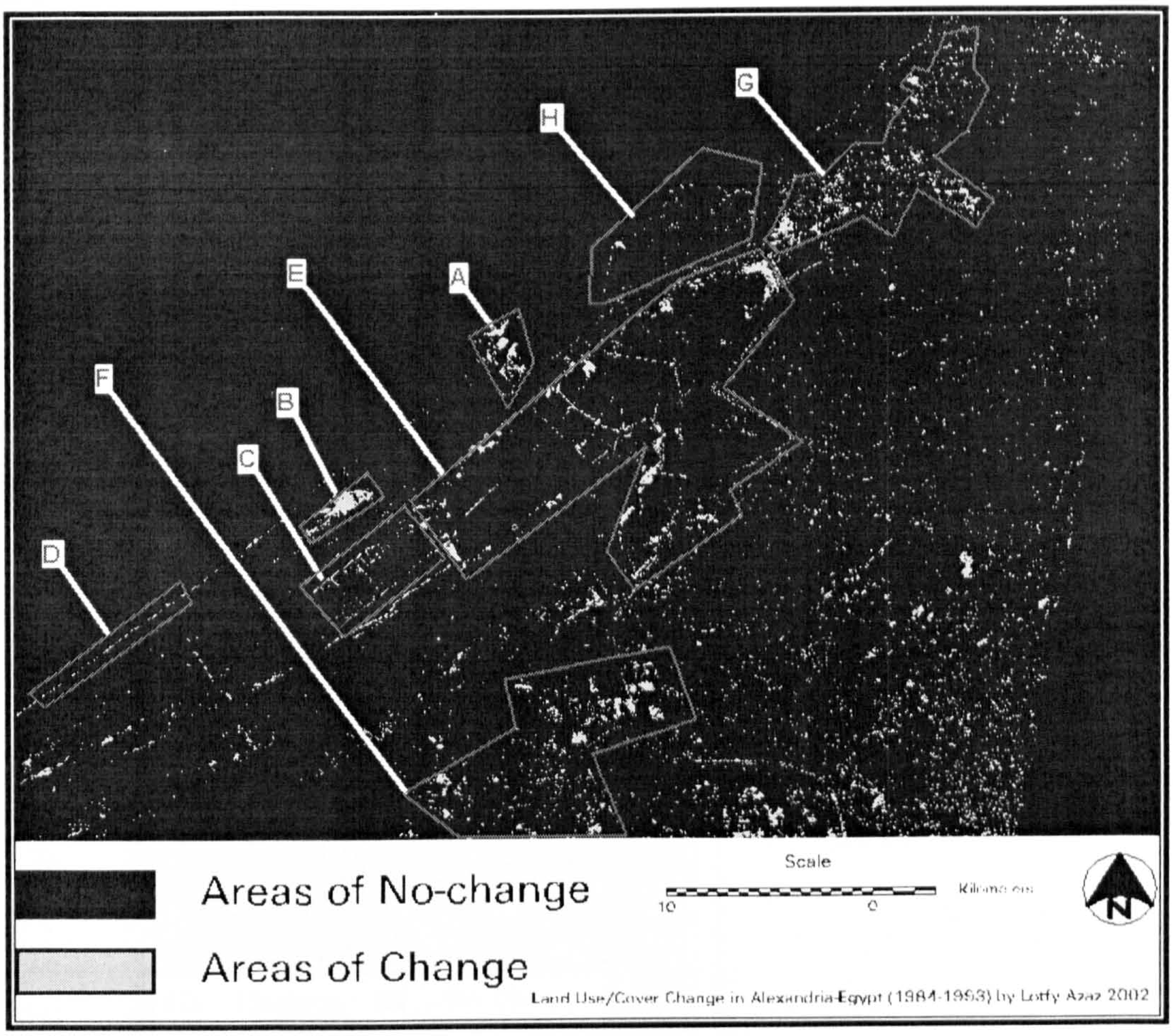


Figure 45 Major changes in Alexandria between 1984 and 1993

Code	Was	Become	Code	was	Become
A	**Desert**	New Dekhila Port	**E**	**Lake**	Changes in Lake Maryout
B	**Desert**	Sidi Krir Power Station	**F**	**Desert**	Lands Reform Projects
C	**Lake**	Fish Farms	**G**	**Cultivated lands**	Urban expansion in the Eastern Areas
D	**Desert**	Western Coast	**H**	**Central Business District (C.B.D.)**	Central Business District (C.B.D.)

Table 57 Major Changes in Alexandria between 1984 and 1993

The main urban changes between 1984 and 1993 can be summarised as the following:

A. New Dekhila port

Figures 46-a and 46-b, this port is located about 7Km west of Alexandria. Dekheila port is a natural extention to Alexandria port, which was developed to deal with increased container movement in Alexandria port and the increased growth of industrial development and free zones in Alexandria west delta. Port constructions started in 1980 and the port became operational in 1986. The total area of the port is approximately 6 km² (600 hectare) and the land area is 3.2 km² (320 hecatre) (Bank 2004).

Figure 46-a New Dekhila Port

Figure 46-b New Dekhila Port (Suez 2004)

B. Sidi krir Power Station

This is one of the largest thermal power plants in Egypt in terms of capacity. It is located 30 km along North Coast Road - Egypt with a value of US $20,000,000. Figures 47-a and 47-b.

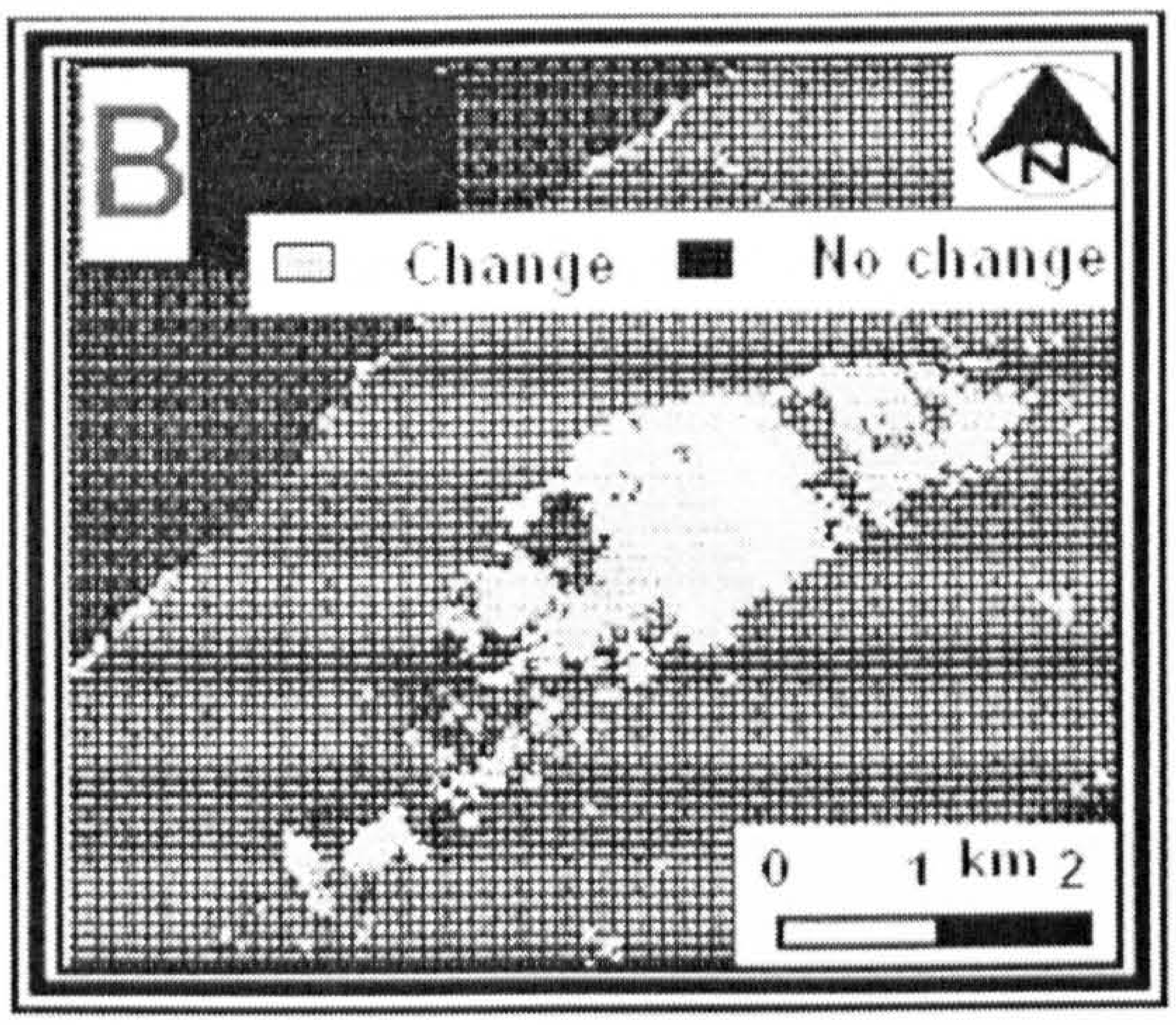


Figure 47-a Sidi Krir Power Station

Figure 47-b Sidi Krir Power Station

C. Fish Farms

Figure 48 shows the fish farms that have been established at the west end of Maryout Lake to produce Nile fish for city residents. Most of the fish comes from its main basin. The total area of this basin is 6000 acres (2428.11 hectare) (El-Rayis 2001).

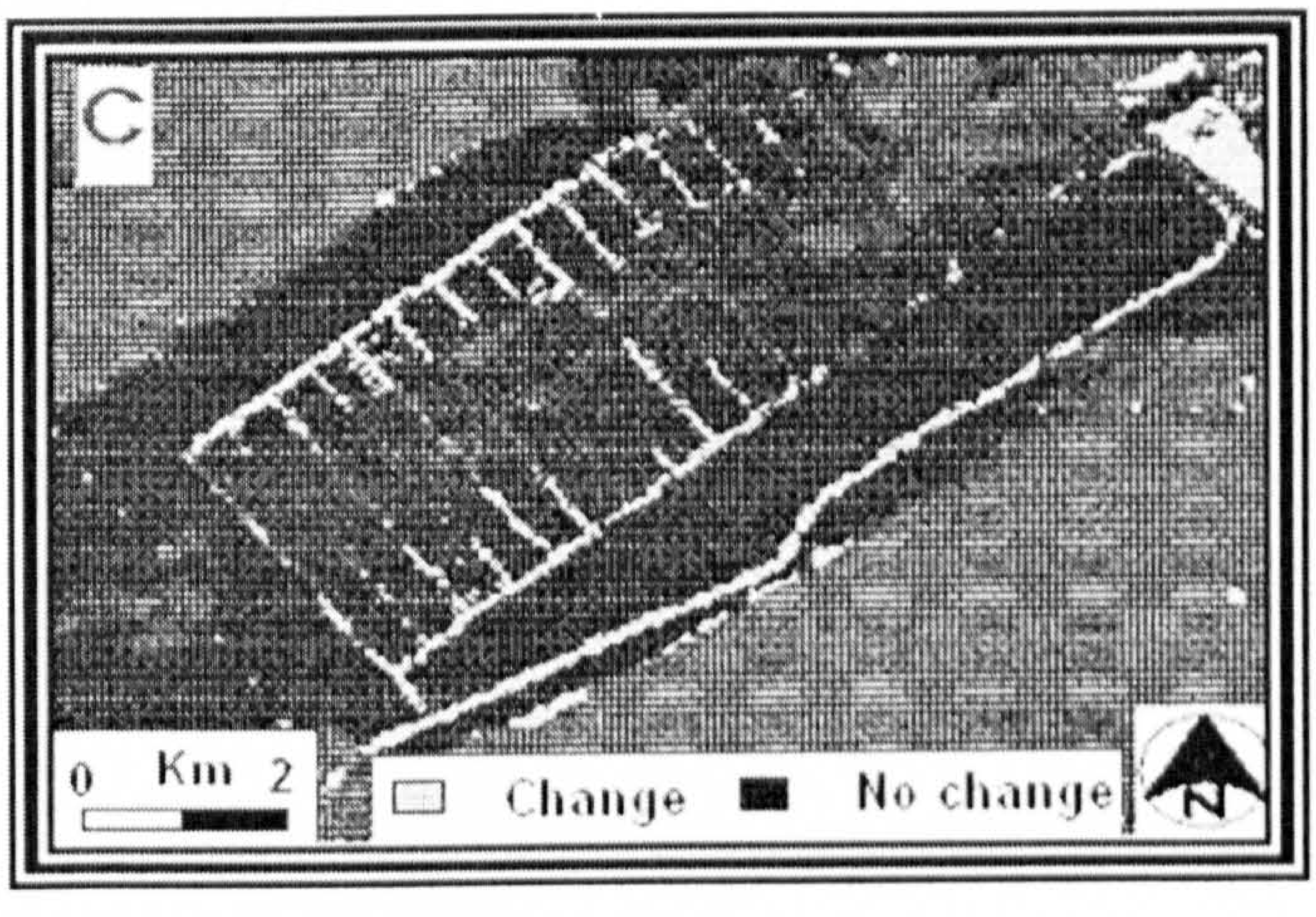


Figure 48 Fish Farms

D. Some changes in the west coast

Figure 49 shows there are some changes in the coast of Alexandria especially the western parts. Some of these changes are located in the adjacent seawater, while the other changes are indications of the recreation development in this part. Tourist development is growing rapidly with many new holiday villages, hotels, and recreation facilities being built particularly between Alexandria and El-Alamein .

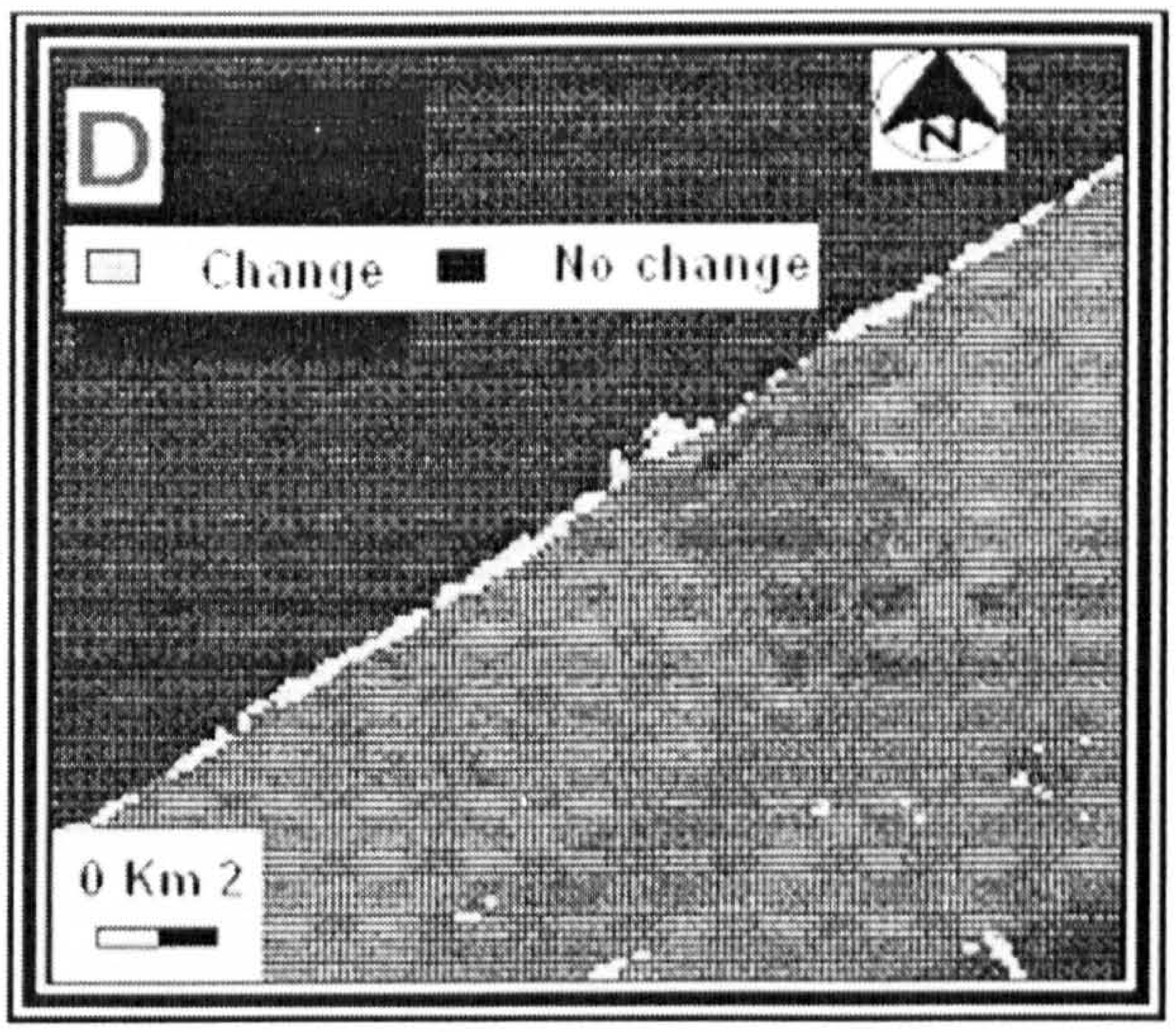


Figure 49 some changes in the west coast

E. Changes in Lake Maryout

Some areas of the lake are subject to a drainig procedure to meet the accelerated demand for land in the future (Figure 50). This is one of the changes in the lake. Maryout Lake witnessed different aspects of changes, (Figure 51). The main activities of land use in these parts are warehouses, manufactories, and some scattered houses. Moreover, some parts of the lake have been used as Salina to produce salt.

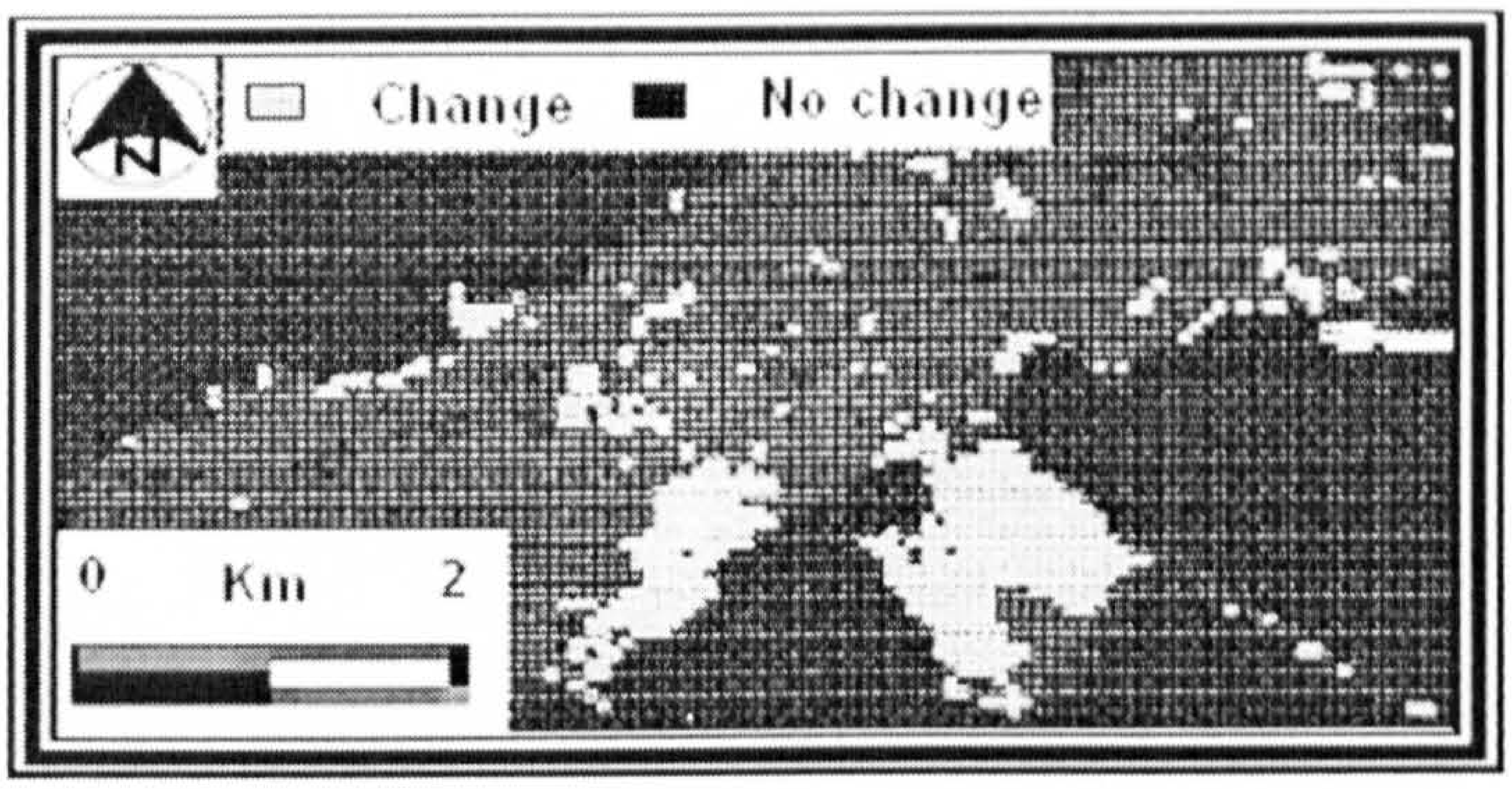


Figure 50 Dried lands from Maryout Lake

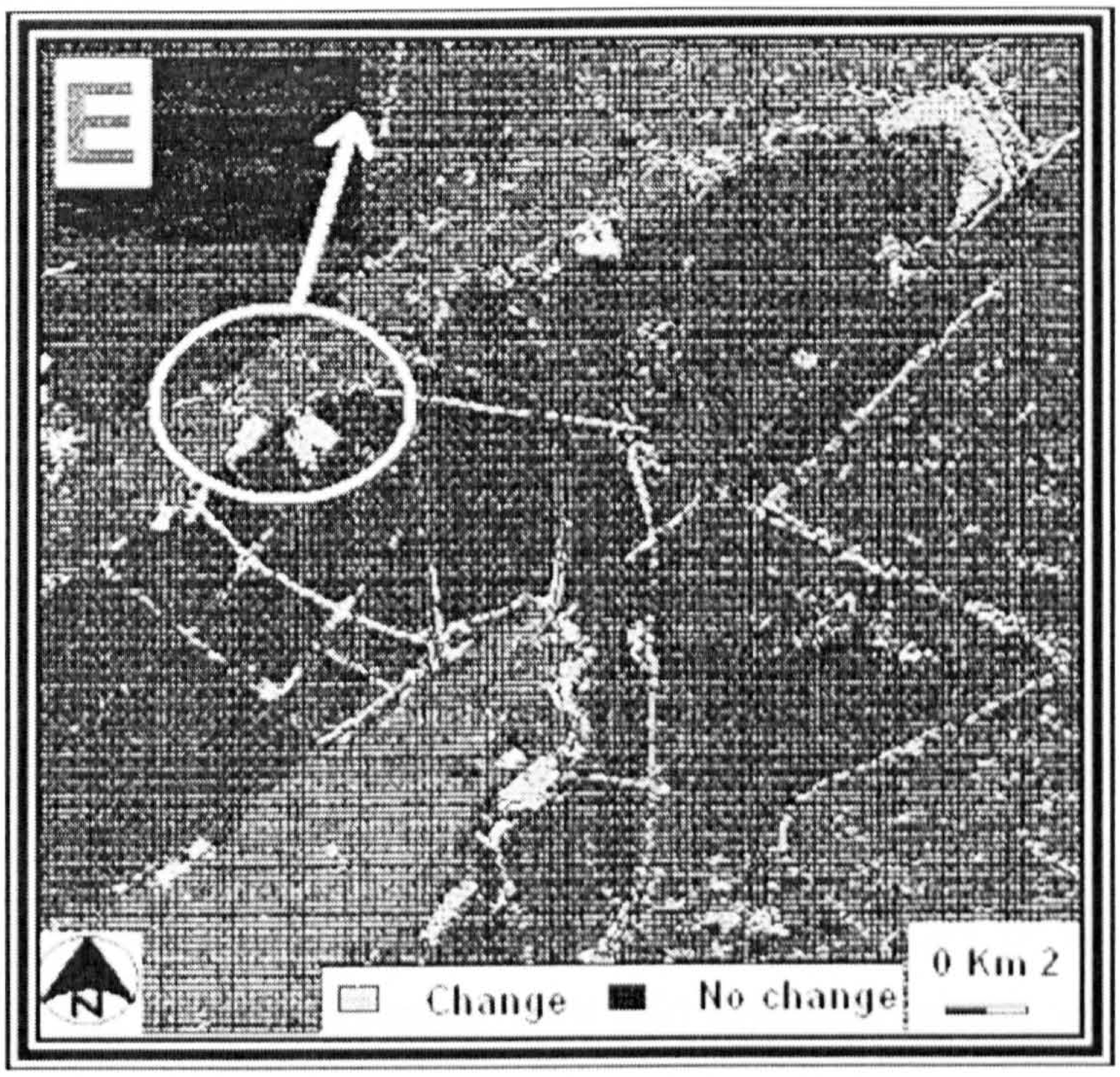


Figure 51 Changes in Maryout Lake

F. Lands Reform Projects

Regardless of the loss of green lands in eastern and southeastern of the governorate (discussed later in this chapter), there are ambitious projects to reform the lands in the desert (Figure 52). These projects are located at the south-west of the governorate and have added about 42,466 feddan (17,842.857 hectare) to the green lands (GACP 1997).

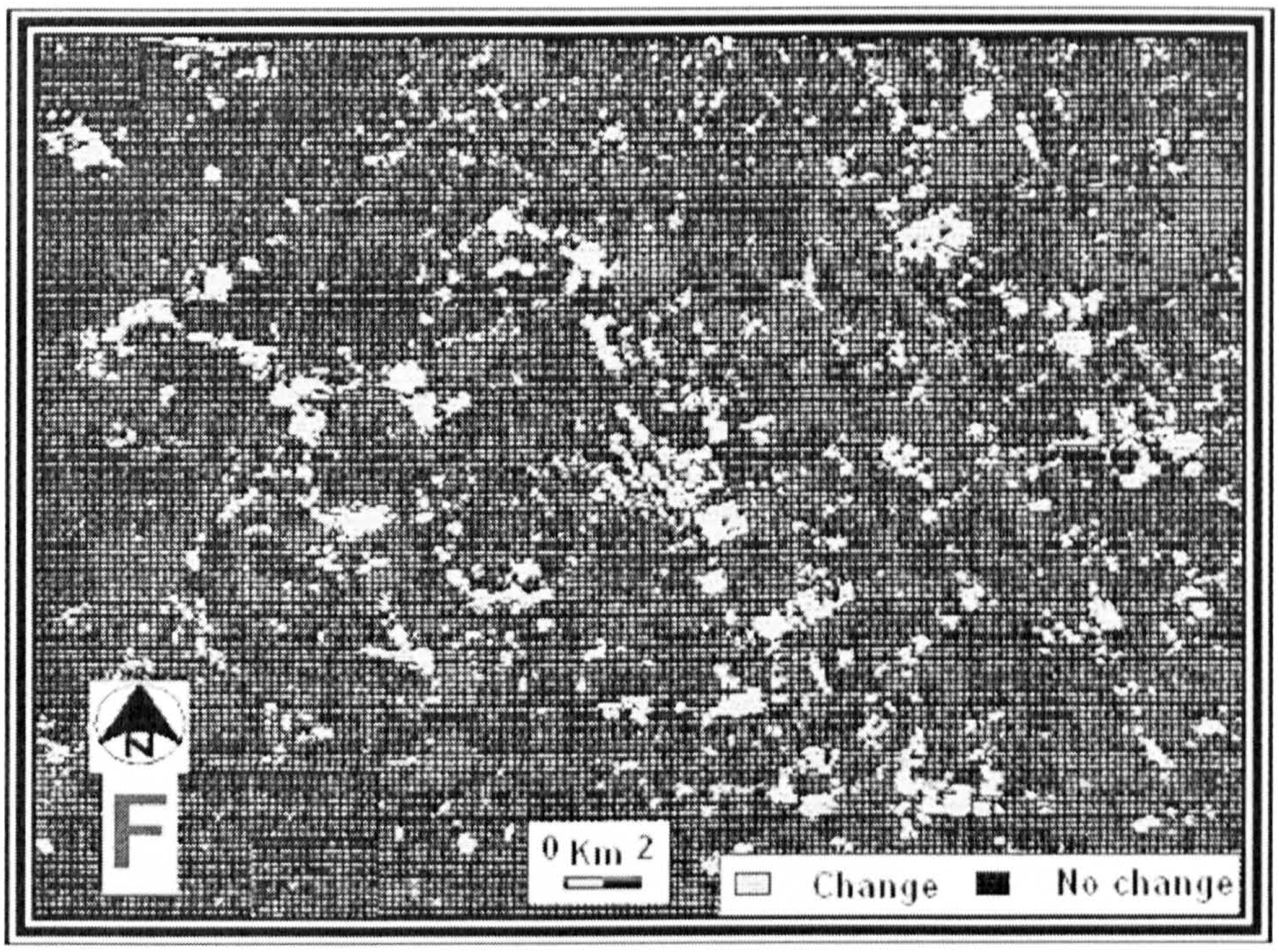


Figure 52 Land Reform Projects

G. Urban growth in the Eastern parts

The city witnesses a large increase in urban population especially in the east and southeast of the governorate (Figure 53). Because of the population growth, a well-noticed urban expansion occurred in those parts. Part of this expansion is unplanned "informal growth". El-montazah and Abou-qir areas, which are located at the east end of the city experience a large share of urban growth (Figure 54). The majority of this growth occurred on the valuable, cultivated land. The detailed quantitative analysis of urban growth change is introduced in section 6.5.

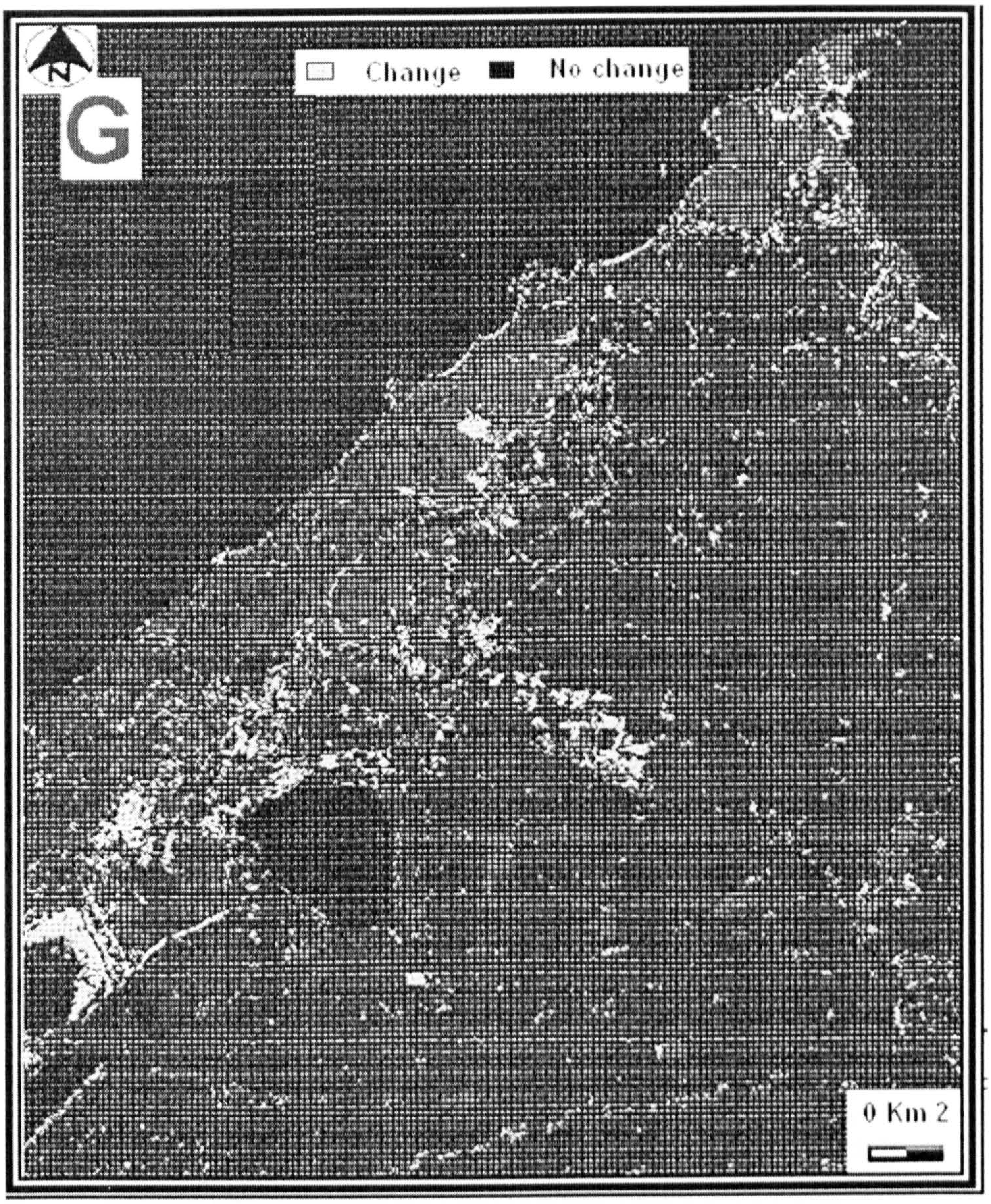


Figure 53 Urban growth in the Eastern parts

H. City Centre

Like most of the old cities in the world, Alexandria's central area did not see a remarkable change, (Figure 55). Some of the buildings in this area are very old and historical. On the other hand, there are some deteriorated homes in the area, which collapse usually in the winter, and new buildings are constructed on their sites afterwards.

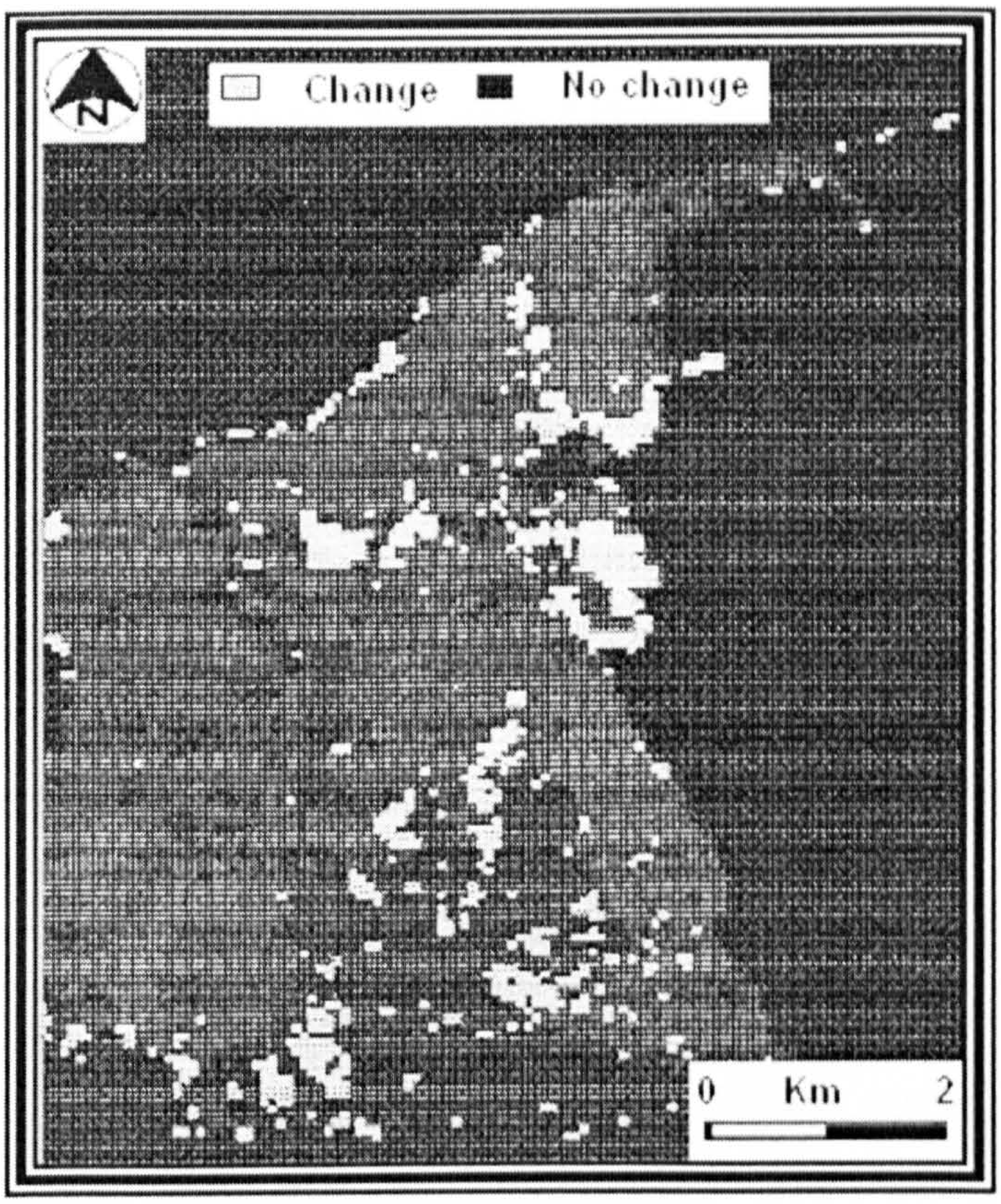


Figure 54 Changes in Abou_qir area

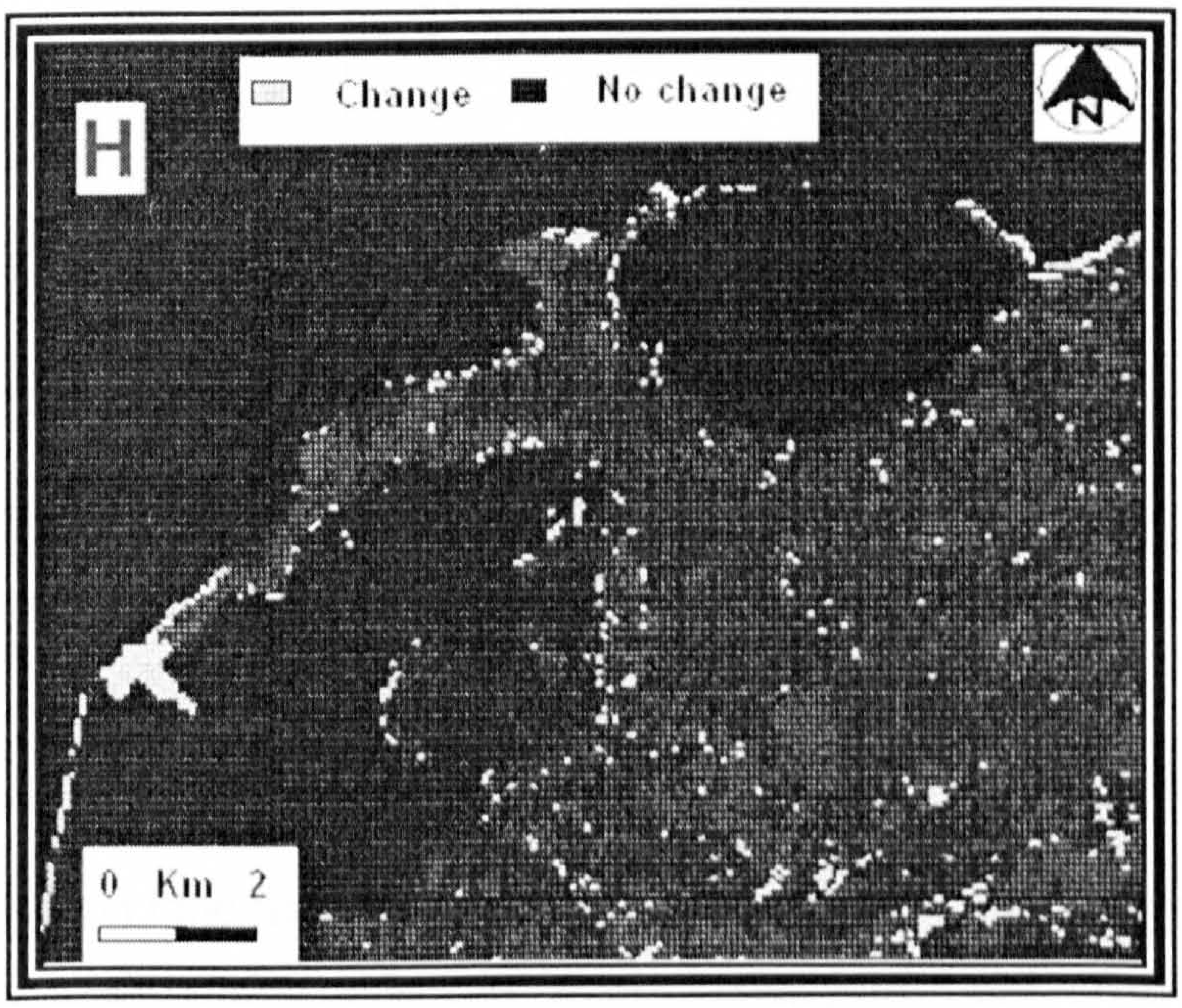


Figure 55 Changes in the City centre

6.5 Results

In terms of quantitative changes, the area of study saw significant changes in the pre-defined land use cover classes.

(1) Water bodies

Water bodies decreased by 1.54% between 1984 and 1993 (Table 58). However, this change does not affect the whole share of the water bodies' class as a part of the total land use in Alexandria, where its share was 26.7% in 1984 (Table 55), and became 26.29% in 1993 (table 56). Most of the changes have been happening within Maryout Lake (as it is part of the water bodies land use/cover category). Some parts of the lake have been transformed to Salina and Marshes, (Table 58) and (Figure 56)

Class Name	Size of Change (Hectare) (1984-1993)	Size of Change (KM^2) (1984-1993)	Percentage of change (1984-1993)	Annual Change (KM^2)	Annual Change (Percentage)
Water Bodies	-2683.801	-26.838	-1.54	-2.982	-0.17
Shallow water/S/M	2683.801	26.838	38.10	2.982	4.23
Green Lands	-6072.048	-60.72	-6.04	-6.747	-0.67
Built-up areas	29240.729	292.407	56.74	32.489	6.30
Coastal Plain/ Desert	-23168.681	-231.687	-7.26	-25.74	-0.81

Table 58 Characteristics of Land Use/Cover change in Alexandria (1984-1993)

- Change was calculated using the difference between the same classes in each date.

(2) Shallow water/ Salina/ Marsh

This is the smallest land use/cover category in the area of study. It was just about 1.08% of the total land use in the area of study in 1984 (Table 55) and it increased to 1.49% in 1993 (Table 56). In spite of its small share of the total area of study, its percentage of change is very high (38.1%) between 1984 and 1993

(4.23% annually) (Table 58) and (Figure 56). Therefore, it comes second after built-up areas class as a significant symbol of change. This size of change can be understood in the light of ongoing activities in the lake for many purposes. This class may increase in the future as a result of the continuous changes in Maryout Lake.

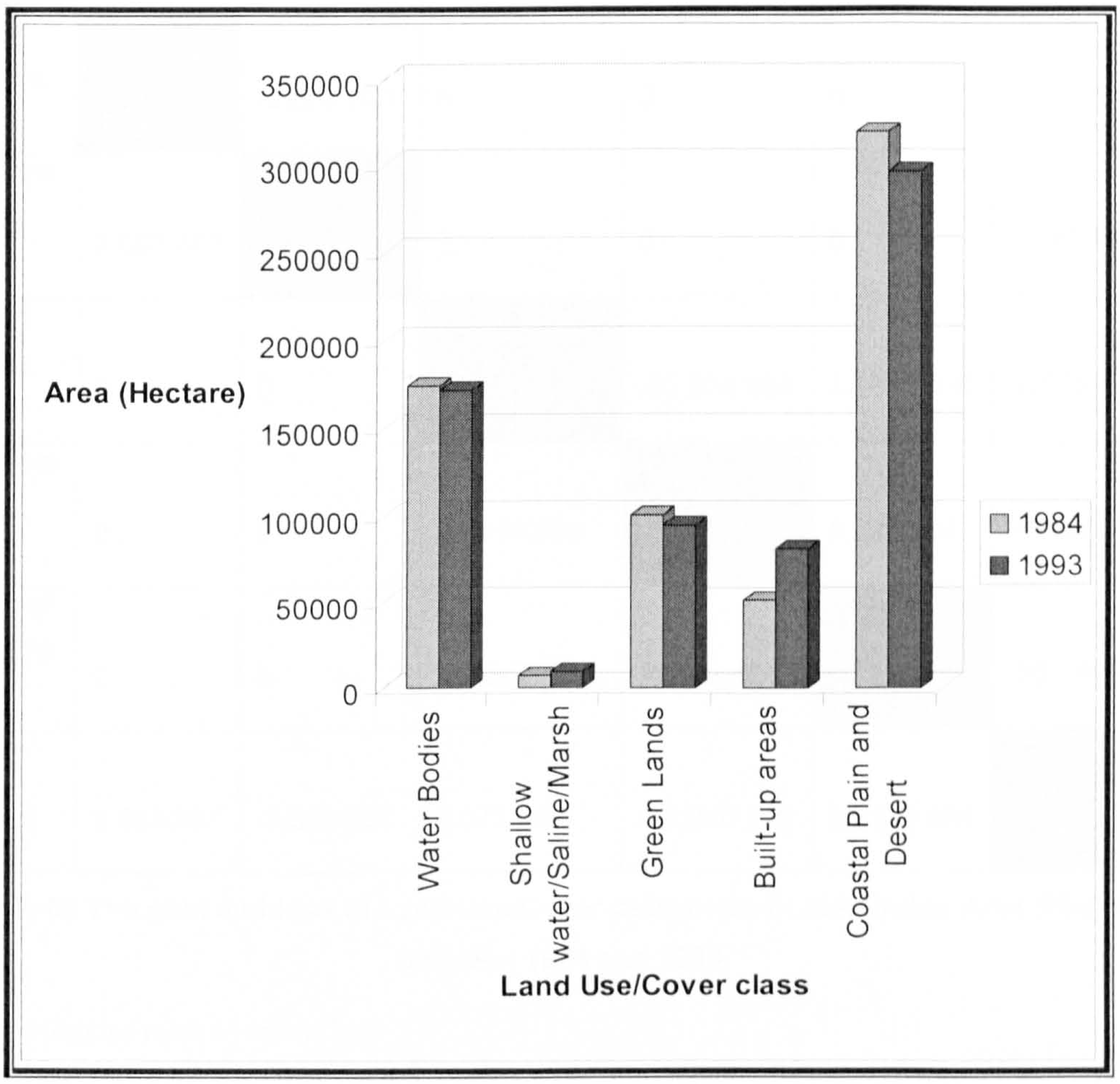


Figure 56 Land Use/Cover change in Alexandria (1984-1993)

(3) Green Lands

Green lands class represented about 15.41% of the total land use in the area of study in 1984 (Table 55) and 14.48% in 1993 (Table 56). This means less than 1% decrease in its share (0.93%) in total, but this does not reflect the true situation of this class in the area of study. Green lands lost about a quarter of its area (23.79%) for the "Built-up" category but this does not appear clearly because it gained about 17.75% from "Coastal plain and desert" category through Land reform projects (Table 59). This concludes that "Green Lands" category lost about 6.04% from its area between 1984 and 1993 (0.67 % annually) (Table 59).

	Water Bodies	Shallow water	Green Lands	Built-up areas	Coastal Plain /D	Total
Water Bodies		-2,683.801	0	0	0	-2,683.801
Shallow water	2,683.801		0	0	0	2,683.801
Green Lands	0	0		-23,914.905	17,842.857	-6,072.048
Built-up areas	0	0	23,914.905		5,325.824	29,240.729
Coastal Plain /D	0	0	-17,842.857	-5,325.824		-23,168.681
Total	2,683.801	-2,683.801	6,072.048	-29,240.729	23,168.681	

Table 59 The gain and loss of Land Use/Cover categories in Alexandria Area (Hectare) between 1984 and 1993

- Negative mark (-) means loss.
- Location of the figure in the table indicates (from/to) which class the gain and loss occurred.
- Land use/cover class (in the row) if compared with any land use/cover class (in the column) will show the gain or the loss depends on the mark.

(4) Built-up areas

This category has the most significant change in the area of study. The total area of the built-up areas category increased by 56.74% between 1984 and 1993, (Table 58). This means a high rate of annual growth (6.3%). The annual growth rate that is calculated from satellite images analysis is consistent with the same rate that is calculated by traditional mathematical method that has been applied in chapter four (City area development) section. Most of urban development (81.79%) consumed the most valuable lands in the eastern and southeastern of study area, figure (53). Meanwhile, 18.21% of this growth was in the desert areas in the west and southwestern parts.

(5) Coastal Plain and Desert

It was expected that the built-up areas category would gain the biggest share of lands from this category; however, the analysis of this category confirms that only 22.99% of the lost lands from this category was used for urban development. Meanwhile, 77.01% of the change area was transformed to green lands through land reform projects (Table 59).

6.5.1 Accuracy assessment

As was stated before, the accuracy of Post-classification comparison method depends on the accuracy of the classified satellite images being used. The overall accuracy of the 1984 classified image is 93.82% and the overall accuracy of the 1993 classified image is 95.27%. According to this, it is expected that the accuracy of the change detection product in this study is high as classification results.

6.6 Summary and Conclusions

The area of study witnessed a remarkable urban growth between 1984 and 1993. Two trajectories of urban expansion can be identified. The first is towards the eastern and southeastern parts of the area of study. This extension consumed the most valuable cultivated lands, which act as the hinterlands of the city (the food basket of the city). If the current loss rates continue (0.67% annually) taking the year of 1984 as a base year, the green lands will face the risk of losing about 75% of its area through this artificial desertification by year 2191[1]. Nevertheless,

[1] For the first scenario ; After the first year there will be 99.33% of land according to the loss rate (0.67% annually), half of this land will be lost after 103.1 years according to the following equation;

if we use a more straightforward linear equation considering the annual loss (674.672 hectare), this means the green land will lose 75% of its area by year 2096. These projections of retaining some green lands are very optimistic. Another study estimated that all the coastal agricultural lands in northern Egypt will be lost to urbanization and other activities by the year 2061 (Salem *et al.* 1995). This indicates the need for strong policies to protect the valuable green lands from this serious continuous risk. These policies must direct urban growth trajectories to the lands that suit urban development. Detailed discussion related to these policies can be found in chapter eight. In the meantime, most of the urban expansion in the eastern parts is unplanned (Abdou-Azaz 1997) so there is a need also for planning solutions to this problem. Meanwhile, land reform projects should be continued to: a) compensate land lost to urban development, b) absorb part of the population increase, and c) provide employment and decrease unemployment rates as well especially for new graduates. The second trajectory is towards the western parts. This direction of expansion consumed only parts of the coastal dunes series. Most of the expansion of built-up areas here is housing, but there are also other forms of built-up area such as storehouses and plants especially for petrochemicals and petroleum industries. Maryout Lake experienced different forms of changes. There is an urgent need to make appropriate decisions about the lake's future. There is some change in the old city areas in the central and eastern parts of the study area; this change occurred as replacement and renewal processes. The results of chapters 3, 4, 5, and 6 will be used to predict the future urban expansion in Alexandria in the following chapter.

Number of Years (N)=Log (0.5)/Log (0.9933)=103.

In another 103 years, half of the remaining land is lost, so 75% will be lost in 206 years, adding this value to the year of 1985, the year will be 2191.

This equation was provided by Professor Murray Aitkin, Head of Mathematics and Statistics Department, Newcastle University.

7. CHAPTER SEVEN: MODELLING URBAN GROWTH IN ALEXANDRIA

7.1 Introduction

Nearly half of the world's total population is living in urban areas nowadays (UN-Habitat 1996). Indeed, there is no doubt urban growth is one of the most important factors which leads to the change of land-use and land cover in the world. Citing Vitousek (1994), Agarwal *et al.* (2002:1) claimed that:

> *"Three of the well-documented global change are increasing concentrations of carbon dioxide in the atmosphere; alteration the biochemistry of the global nitrogen cycle; and ongoing land-use/land cover change."*

Nearly 1.2 million km² of forest and woodland and 5.6 million km² of grassland and pasture have been converted to other uses during the last three centuries. Because of this significant and increased land-use/ cover change, there are many endeavours to predict potential change by designing models which could simulate the future of land use according to the different variables (Agarwal et al. 2000).

There are different types of land use/cover models and urban modelling is a significant part amongst all other models. Hence, this chapter starts with a short review of urban modelling history since the 1960s, following its development to date with some reference to urban model categories. The assessment of land use/cover models generally and urban models specifically will be introduced in the following section. According to this assessment, two models were selected to simulate urban growth in Alexandria. The basic characteristics of the chosen models will be highlighted.

The SLEUTH model was chosen finally to be applied in the area of study for technical considerations that will be underlined in detail in the relevant section. As SLEUTH uses "Cellular Automata" (or CA), the CA method will be reviewed in brief to ease understanding of how the model works, followed by an introduction covering the SLEUTH's background, the model assumptions, the hardware and software needed, and staff requirements. Then, the model implementation part will be commenced with data set preparation followed by a data transformation section. The results of testing and calibration phases of the model are introduced. Future urban growth in Alexandria until 2055 using a prediction phase is produced and the results are introduced using the different types of outputs from the model.

7.2 Urban models

There are different kinds of land use/cover change models. Urban modelling is one of the best known. (Batty 1976) defined urban modelling as follows:

> *"....urban modelling is concerned with designing, building and operating mathematical models of urban phenomena, typically cities and regions."* (Batty 1976:xx).

Transportation models are the roots of urban modelling. Congestion problems resulting from the growing car ownership during the 1940s led to the realization of the need for new problem-solving techniques. Modelling future trip generation was the first attempt to deal with this new problem. Land use was the missing element in transportation modelling till Mitchell and Rapkin (1954) with their pioneering book *Urban Traffic: A Function of Land Use* convinced engineers and planners of the need for integrated land-use and transportation planning (Batty 1976).

Urban modelling emerged in North America during the 1960s as part of the social sciences revolution. Urban researchers coming from the fields of geography, urban economics, sociology, planning, architecture, and engineering, are the key players in the urban modelling field. The common base of urban modelling is mathematics; therefore, the only available form to present modelling outputs was numeric until the end of 1980s. Since the, urban modelling has seen two significant breakthroughs; the first was using computers, which made sophisticated urban modelling possible (Batty 1976). The second great advance occurred with the evolution of the new visualization techniques and GIS. GIS served visual urban modelling by acting as a medium for data preparation and analysis. Since then, modelling outputs can be offered in both visual and/or numeric formats. Batty (2001) summarized urban models as follows:

> *"Before 1950, models of cities meant architectural representations of its physical form. Mathematical models dominated the 1960s and 1970s; data models then came to dominate the 1980s and 1990s. But now the focus is once more on traditional representations of cities as digital models of three-dimensional form, thus heralding a move back to the iconic models that had dominated physical planning hitherto."* (Batty 2001:252).

Batty (1976) emphasised the importance of developing and using urban modelling in three fields: science, practical applications, and education. Science achieves its main traditional goal through the analysis of and experiment with urban phenomena. Urban modelling provides the facilities of prediction, prescription, and invention of the urban future that help decision makers and the community. In education, help can be offered by demonstrating theory limitations and potential simulation.

Urban models can be categorized using different criteria. Batty (1976) divided urban models into two broad categories; operational and theoretical models where the former can be implemented using real data while the latter are essentially theoretical in nature.

Batty (1976) also suggested another method to group models according to the techniques used: (i) conventional linear statistical models such as the EMPIRIC model of the Boston Region, and (ii) non-linear models such as the Delaware Valley (Penn-Jersey) Activities Allocation model. However, some models might be both linear and non-linear at different levels of specification or in its different parts.

7.3 Land-use change models review

Currently, there are an large number of models, which are being used to simulate land-use/ cover for different purposes. Indeed, the assessment of all land use/cover change models is not one of the main objectives of this study as there is an unavailability of the needed capacity of the different resources (especially time and financial resources) to perform such an assessment. However, there are many attempts to review and assess those models, so there is no need to perform another assessment exercise. Batty (1976) cited some excellent reviews of the first generation models such as Lowery (1968), Harris (1968), Kilbridge, O'Block and Teplitz (1969), Brown, Ginn, James, Kain and Straszheim (1972), Lee (1973), and Boyce, Day and McDonald (1970).

Batty (1976:10) claimed that these first generation models faced relative failure as

> *"..many models were so ambitious in terms of their scale, the data required and computer time and capacity needed, that real time and money ran out and the models were then abandoned or drastically pruned."*

Because of this, the new generation of models will be considered for this study. Two of the most recent and comprehensive assessments reviewed the new models, thus they will be adopted in this study. The two assessments are:

1- A Review and Assessment of Land-Use Change Models: *Dynamics of Space, Time, and Human Choice* ", (RALUCM) (Agarwal et al. 2000).

2- " Projecting Land-Use Change " (PLUC)- A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns, (EPA 2000).

In the following sections, both studies will be reviewed to select the best model(s) that can fit with the requirements of this study.

7.3.1 RALUCM

Agarwal et al. (2000) prepared a study entitled *"A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice "or* (RALUCM). The main goals of this study were to identify appropriate models or propose new modelling requirements and directions for estimating spatial and temporal variations in land-cover (vegetation cover) and forest-management practices (e.g. biomass removal or re-vegetation through forestry, agriculture, and fire, and nutrient inputs through fertilizer practices) in terms of extent and distribution of land-cover and land management practices and historic, current, and potential future scenarios of land-cover and land-management practices.

RALUCM proposed that land-use change models can be compared in terms of scale and complexity, and how well they incorporate space, time, and human decision making (HDM) (Agarwal et al. 2000).

Agarwal et al. (2000) narrowed a list of 250 land-use change relevant citations to a set of 136 possible references, and then to a list of 19 land-use models that they found to be the most relevant and representative. The 19 land-use change models surveyed are:

1. General Ecosystem Model (GEM) (Fitz *et al.* 1996).
2. Patuxent Landscape Model (PLM) (Voinov *et al.* 1999).
3. CLUE Model (Conversion of Land Use and Its Effects) (Veldkamp and Fresco 1996a)
4. CLUE-CR (Conversion of Land Use and Its Effects - Costa Rica) (Veldkamp and Fresco 1996b)
5. Area base model (Hardie and Parks 1997).
6. Univariate spatial models (Mertens and Lambin. 1997).
7. Econometric (multinomial logit) model (Chomitz and Gray 1996).
8. Spatial dynamic model (Gilruth *et al.* 1995).
9. Spatial Markov model (Wood *et al.* 1997).
10. CUF (California Urban Futures) (Landis 1995), (Landis *et al.* 1998).

11. LUCAS (Land Use Change Analysis System) (Berry *et al.* 1996).
12. Simple log weights (Wear *et al.* 1998).
13. Logit model (Wear *et al.* 1999).
14. Dynamic model (Swallow *et al.* 1997).
15. NELUP (Natural Environment Research Council [NERC]-Economic and Social Research Council [ESRC]: NERC/ESRC Land Use Program (O'Callaghan 1995).
16. NELUP – Extension (Oglethorpe and O'Callaghan 1995).
17. FASOM (Forest and Agriculture Sector Optimization Model) (Adams *et al.* 1996).
18. CURBA (California Urban and Biodiversity Analysis Model) (Landis *et al.* 1998).
19. Cellular automata model (Clarke *et al.* 1996), (Kirtland *et al.* 2000).

In the current study, all these models were reviewed to exclude irrelevant models by investigating their components and modules; irrelevant models are those models, which do not represent the urban environment in its components and modules or have some problems that prevent them from application in this study. The irrelevant models can be categorized into the following:

1. Some models focus totally on physical and environmental issues such as GEM, PLM, Univariate Spatial model, Simple log weights, Econometric (multinomial logit) model, and spatial dynamic model.

2. Some models focus on predicting natural land cover only such as CLUE, CLUE-CR, LUCAS, Logit model, and dynamic model.

3. Some models are irrelevant because they have interlocked components (i.e. population per acre - land quality for farming) such as Area base model and CURBA.

4. Some focus on economic issues such as NELUP, NELUP Extension, and FASOM.

5. Some models are currently under development such as Spatial Markov model.

The final relevant models are:

1. CUF model which explains land use in a metropolitan setting, in terms of demand (population growth) and supply (underdeveloped land) available for redevelopment of land.
2. Cellular Automata model, which explains changes in urban areas over time.

Those models will be introduced in detail after the following section to understand why they are relevant to this study.

7.3.2 PLUC

"Projecting Land-Use Change" or PLUC; A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns, is another attempt to assess land use change models. Because of the growing need for better information on the features, strengths, and limitations of various land-use change models, the US Environmental Protection Agency (EPA) has developed a selective summary of 22 leading land-use change models currently in use or under development (EPA 2000).

The PLUC report provides the avenue through which one can begin the process of identifying the best land use modelling tool to help accomplish effective "Smart Growth Planning" which means the determination of the models applicability, data and resources requirements, strengths and limitations, and costs (EPA 2000). The models summarized in the PLUC report are:

1. California Urban Futures (CUF) Model: CUF-1 (Landis 1994), (Landis 1995)
2. California Urban Futures (CUF) Model: CUF-2 (Landis and Zhang 1998a), (Landis *et al.* 1998b)
3. California Urban and Biodiversity Analysis Model (CURBA) (Landis *et al.* 1998)

4. DELTA (formally DSCMODE)
5. Disaggregated Residential Allocation Model of Household Location and the Employment Allocation Model (DRAM/EMPAL)
6. Growth Simulation Model (GSM) (Tassone 1997)
7. INDEX® (Brail 2001)
8. IRPUD Model (formally Dortmund)
9. Land Transformation Model (LTM)
10. Land-Use Change Analysis System (LUCAS) (Berry *et al.* 1996)
11. Markov Model of Residential Vacancy Transfer (Philip *et al.* 1995)
12. MEPLAN
13. METROSIM
14. Sub-Area Allocation Model-Improved Method (SAM-IM) (formally LAM) (Planning Technologies 1999)
15. The SLEUTH Model (formally Clarke Cellular Automata) (Clarke 1998)
16. Smart Growth INDEX®
17. Smart Places
18. TRANUS
19. Ugrow (College 1999)
20. UPLAN
21. UrbanSim (Waddell 2002)
22. What if?

Those models not referenced are described in the PLUC report. Again, all models were reviewed to select the most relevant ones and most of them were excluded for the following reasons:

1. The high cost of using some models such as:

- Some models cannot be used because of high costs of purchase (Cost more than $5000), such as TRANUS, DRAM/EMPAL, INDEX, MEPLAN, METROSIM and SAMIM.

- The software of some models, such as Ugrow, is free but the model developer must adapt the model to fit a particular community at a high cost ranging from $30,000-$200,000.

- Some models, such as DELTA, are part of a consulting service and unavailable for direct purchase. The affiliated consulting firm must be hired.

- Some models will be included as a component of overall consulting service by the model developer, such as the IRPUD model.

2. Some models, such as Urban Sim, Smart Growth Index, require detailed GIS data and transportation modelling expertise, and the method used for spatially allocating the growth forecast is "hard coded" and cannot be readily modified by users.

3. Some models do not explicitly simulate land use changes. Others depend on a stable, semi-closed system of residential moves between census years such as the Markov Model of Residential Vacancy Transfer.

4. Some models, such as UPLAN, What-if?, Smart Places, do not provide the sophisticated modelling capability and/or theoretical basis to examine the interrelated factors of fiscal policies, and other planning decisions on the amount and type of future development and land-use change that will occur.

5. Some models, such as the LTM model, take several large "C" programs to couple the GIS and neural network simulation software.

6. Some models do not allow a measurement of the confidence or goodness of fit, such as CUF-1.

7. Some models have not yet been adapted as applications that can be distributed to other users, such as GSM.

The final conclusion, after the review of the two assessments, is to select two models that could be used to simulate urban growth in Alexandria in the light of available resources and data, these models are :

1. **California Urban Futures (CUF) Model: CUF-2.**
2. **The SLEUTH Model (formally Clarke Cellular Automata).**

These models have been chosen for their ability to be applied to other sites, and compatibility with the available data of this study. Finally, the dual application of the selected models may give a panoramic view about urban land use/cover change using most of the driven variables. Table 60 shows the basic characteristics of the selected models.

	CUF-2	**SLEUTH**
Model Type	Land use change	Cellular Automata
Thematic Scope	Urban development evaluation and simulation	Urban growth-Environmental impacts
Underlying math structure	Deterministic-Stochastic	Stochastic
Operational method	Multinomial logit-Regression	Cellular Automata- time series- Monte Carlo imaging
Measure of Confidence or Goodness of fit (Y/N)	Yes	Yes
Spatial and Temporal characteristics		
Spatial resolution	One-hectare (100x100m) grid cells	User defined
Spatial extent	Customized for user needs	User defined
Temporal resolution	5 years	Yearly
Temporal extent (Future and Past)	5+ years into the future	As far into the past or future as available data will allow
Land use categories- Urban land use categories		
Residential	Single-family; multifamily	User defined
Commercial	Yes	User defined
Industrial	Yes	User defined
Other	Residential, commercial, and industrial redevelopment	User defined

Table 60 Basic characteristics of the selected models

Non-urban land use categories		
Agriculture	Yes	User defined
Forest	Yes	User defined
Wetlands	Yes	User defined
Water	Yes	User defined
Preservation	As identified by user	User defined
Parkland	Yes	User defined
Models utility and integration		
Linking to other models	2*	2*
Transferring to other location	2*	2*
Application sites	1	13
Hardware and Software needed to run the models		
Hardware		
Machine	Sun Sparc or PC	PC, workstation, or mainframe
CPU required (MHz)	300	Not applicable
Disk space required (MB)	2 GB/32	Not applicable
Peripherals	Colour monitor	None
Software		
Operating System	MS Windows95, Sun Solaris	UNIX
Program Compiler (Y/N)	No	Yes; gnu C compiler (gcc)
Data Management tools	Not specified	Not specified
Statistical Software	SAS	Not specified
GIS Software	Arc Info or Arc View	Not specified
Other	Not specified	X Windows required for graphical version
Users/ Skills needed		
Target user group	Non-technical community participants	Academic and government researchers, planners
Technical expertise	2*	2*
Consultant experience required	No	No
Computer Skills for Usage	3*	2*

*1= easy, 3= hard

Table 60 (Cont.) Basic characteristics of the selected models

I initiated preliminary contacts with both model developers to ask their permission to apply the models in this study and seek their technical support if needed in any stage. I have tried to contact the CUF developer' using different means, as we need an electronic version in order to use and test the model. As we have not received any reply, we cannot use this model. However, we received a very encouraging response from Keith C. Clarke, the developer of the SLEUTH model, to apply and test this model in the current study. The model is available on the Internet with a clear documentation about its implementation, including all phases from data preparation to final prediction. There is also a discussion board involving interested users who can share their expertise and problems. Moreover, we received further support from Prof. Clarke and his team when technical problems arose. In the following sections, the SLEUTH model will be applied and tested using the available data of the area of study.

7.4 Modelling urban growth using the SLEUTH model

As the SLEUTH model uses the so-called cellular automata (or CA), it is beneficial to shed some light on this method.

7.4.1 Background of Cellular automata

Cellular automata (CA) was developed by Ulam in the 1940s and soon used by Von Neumann to investigate the logical nature of self-reproducible systems (Yeh 2002). Usually, a CA consists of six elements: cells, states, neighborhood, spatial space, temporal space and transition rules. Figure 57 illustrates a one-dimensional CA at time *t* and time *(t + 1)* in its evolution.

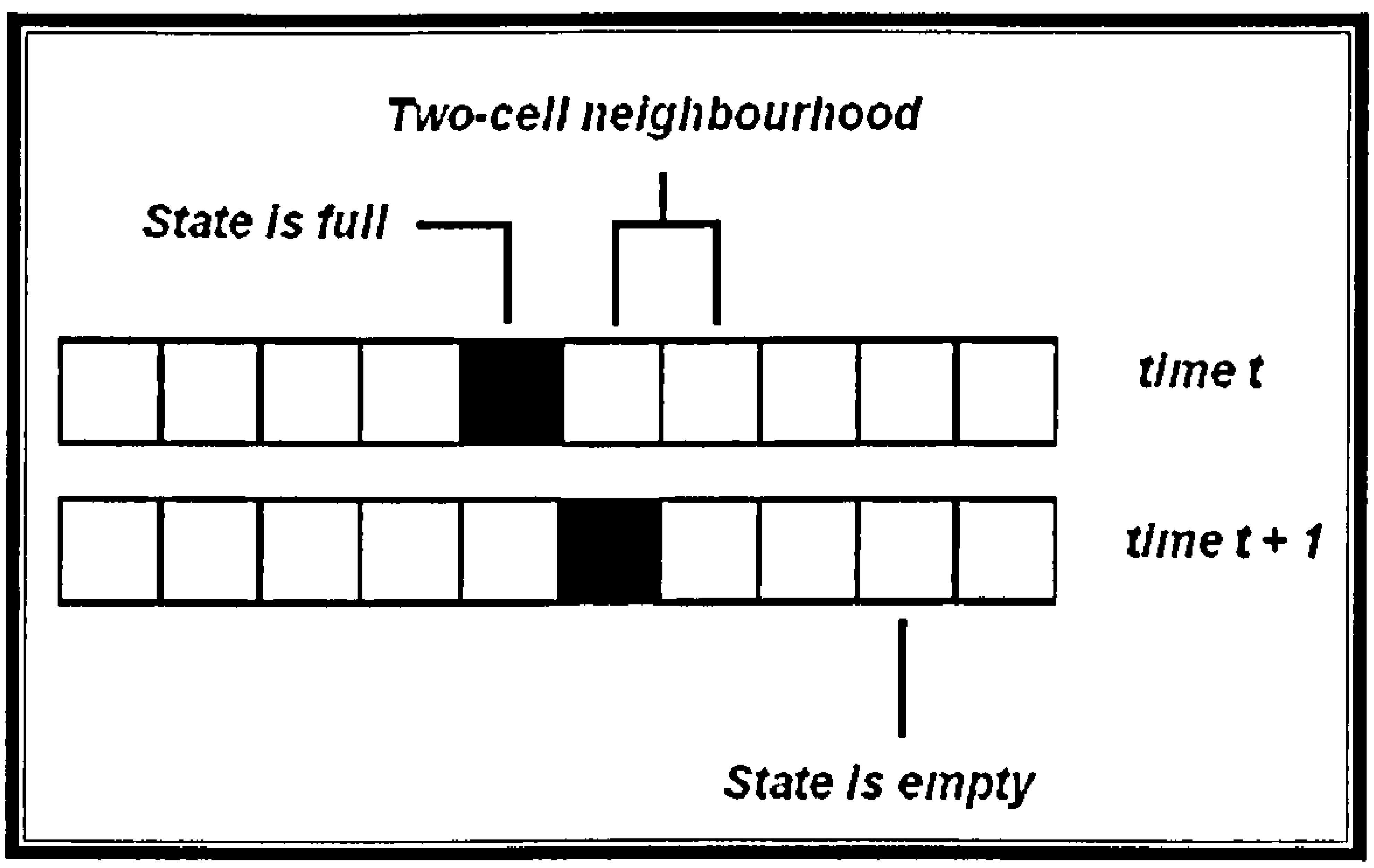


Figure 57 One-dimensional cellular automata (Torrens 2000)

The lattice consists of 10 finite cells. Each cell can be in one of two states, "empty" (white) or "full" black. Each cell is driven by a transition rule, which controls the state of the cells in each time-step. In the first time step, each cell draws input from its neighbourhood, upon which a cell's finite state can base its behaviour in the nest time step. In the first part, the transition rule picks out those cells in the lattice that are "full". In the second part, the rule asks the "full" cells to examine their two-cell neighbourhood, both to the left and to the right. If that examination discovers that neighbouring cells in its right-hand side neighbourhood are "empty", then the "full" cell is directed to 'move' one cell to the right along the lattice in the next time step (Torrens 2000).

CA was first used as a growth modelling technique in the biological sciences (Varanka 2001). Silva and Clarke (2002) claimed that modelling geographic systems with CA is a relatively recent process and was used first in planning during the 1980s, and widely used in the 1990s. Ward et al. (2000:540) interpreted the recent popularity of CA models as these models

> *"....have proven useful space-time modeling environments in which raster-based information on spatial and temporal landscape change (derived from remotely sensed imagery) and information on factors that influence change (e.g. friction-of-distance and topographic factors) can be brought together"*

Almeida *et al.* (2003:482) added to this context emphasizing that CA models

> *"...are tractable, generate a dynamics which can replicate traditional processes of change through diffusion, but contain enough complexity to simulate surprising and novel change as reflected in emergent phenomena."*

Silva and Clarke (2002) admitted that, despite the value of GIS in providing real-world environments for CA, the full integration of CA with GIS has not been achieved yet.

7.4.2 SLEUTH Background

> *"SLEUTH is the evolutionary product of the Clarke Urban Growth Model that uses cellular automata, terrain mapping and land cover deltatron modeling to address urban growth"* (USGS 2000).

Prof. Keith C. Clarke of the Department of Geography, University of California, Santa Barbara developed the model. The SLEUTH model consists of two sub-models; the first is the Urban Growth Model (UGM) that is a C program running under the UNIX platform, the second is the Land Cover Deltatron (LCD), which can be called and driven by the UGM. Although the LCD is tightly coupled with the urban code, the UGM can run independently of it. The name of the model (SLEUTH) was derived from the simple image input requirements of the models: **S**lope, **L**and cover, **E**xclusion, **U**rbanization, **T**ransportation, and **H**illshade (USGS 2000).

The model is developed with sets of predefined growth rules applied spatially to grided maps of the city(s) in a set of nested loops; an outer loop executes each growth history and retains statistical data, while an inner loop executes the growth rules for a single year (Silva and Clarke 2002). The model is intended to simulate urban growth in order to aid in understanding how expanding urban areas consume their surrounding land, and the environmental impact this has on the local environment. The model simulates the transition from non-urban to urban land-use using a grid of cells (cellular automata) each of whose land-use state is dependent upon local factors (e.g., roads, existing urban areas, topography), temporal factors, and random factors, (Figure 58).

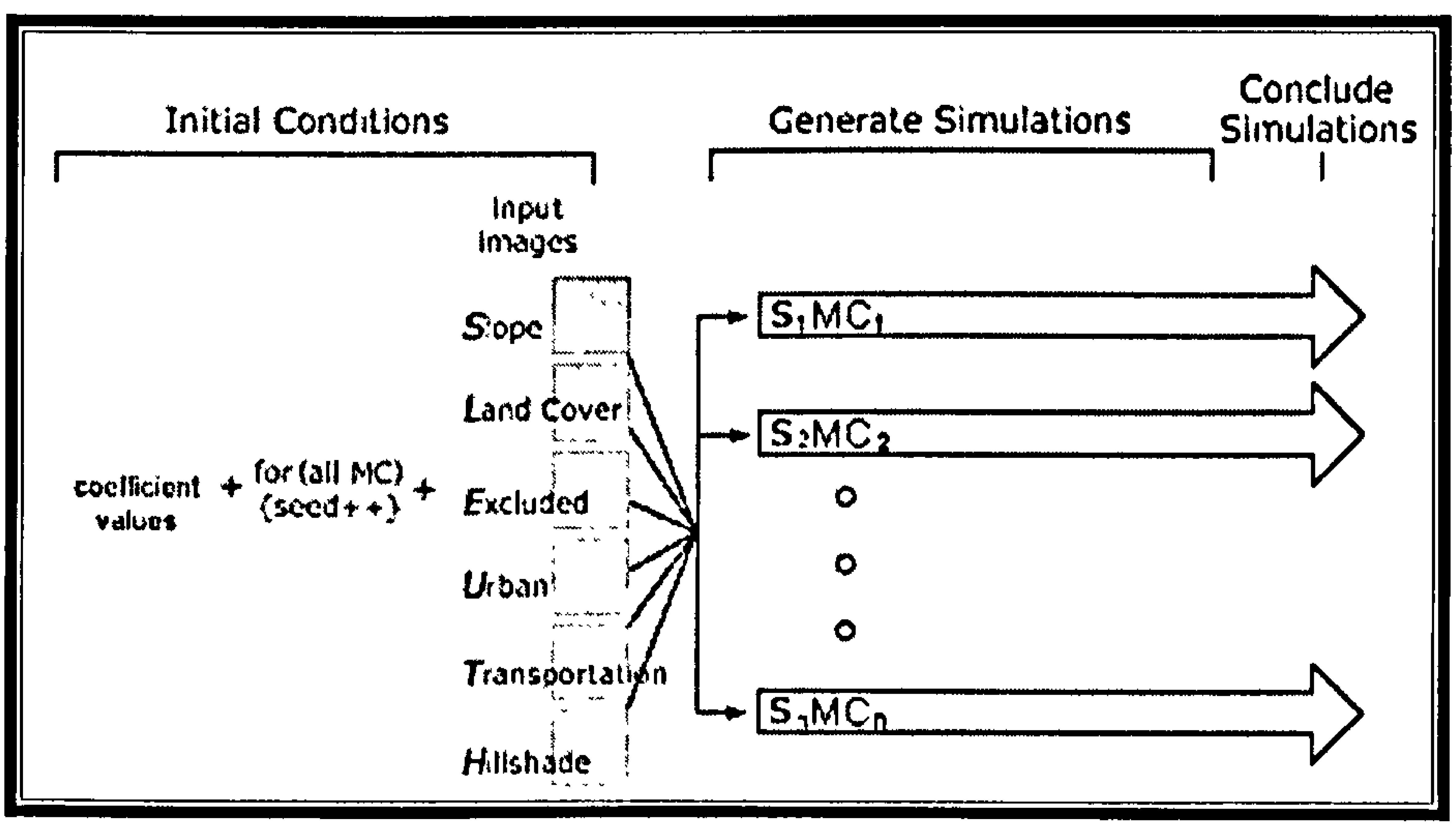


Figure 58 The basic simulation of SLEUTH model (USGS 2000)

The model does not explicitly deal with population, policies and economic impacts on land use change, except in terms of growth around roads. Users can customize the SLEUTH model for use with their own data sets. After performing a three-phase calibration process, which allows the user to derive the best coefficients for historical modelling, the user runs the model to obtain projective information on urban growth. The outputs provided by the SLEUTH model include animations that illustrate how urban areas grow over time and the impacts associated with growth (EPA 2000).

The SLEUTH model has successfully projected urban expansion for communities on a regional level, including the San Francisco Bay area and the Washington-Baltimore area. In the near future, the SLEUTH model will project urbanization in other major metropolitan areas, such as Portland-Vancouver, Chicago-Milwaukee, Philadelphia-Wilmington, and the New York metropolitan area (EPA 2000). The test of this model in the current study might be the first tryout of this model outside USA and Europe and this meets with the long-term goal of the project to develop suitable tools to predict urban growth on a regional, continental and global scale (USGS 2000).

Urban models in general did not use GIS as a stand-alone tool; some models used GIS in data preparation only or in analysis of the model's output, but GIS was not used as a tool for programming so far. Varanka (2001) criticises the SLEUTH model as it assumes that previous growth perseveres, while the built-up area itself goes through life cycles that may lead to old areas deterioration and this is not considered in the model. Other critical challenges for the model are the socioeconomic factors, which are totally avoided in the model. It gives much attention to the physical environment by using the topography element as a controlling factor, and this means following the steps of classical geographical thought which was predominant before the 19^{th} century. Therefore, the selected input factors suggest a traditional theory of urban growth, drawn from urban ecology theories of the Chicago School. As urban growth is considered as a natural system to which CA is applicable, the mathematical expressions should accommodate this assumption, but the model offered only a limited set of these mathematical expressions. Moreover, Varanka (2001) claimed that the model does not allow variability either in the form of input factors or non-equilibrium change. The model is rule-based and not behaviour oriented. Therefore, it is likely to replicate existing conditions rather than extrapolating future possible trends that may result from the interaction between systems and choices. The calibration phase is dependent on the historical growth, and this is one of the model weaknesses.

Despite these limitations which restrict the model outputs, some environmental researchers have found this model acceptable to explain environmental land use change (Varanka 2001). The SLEUTH model emphasized the importance of the animation as a cartographic tool for communicating the results of the model's predictions as that is important to produce spatial representations of modelling by using GIS-based cartographic and scientific visualization tools (Clarke et al. 1996).

7.4.3 SLEUTH Assumptions

According to the PLUC report, the model assumes zoning and other policy-making does not change overall coverage of urban growth but the SLEUTH model can incorporate some zoning alternatives using the excluded layer. This fact means that the model can help in enhancing urban growth management processes by involving urban planning practices into it. The main assumption of the model is that the future can be projected by the past, assuming historic growth trends continue (EPA 2000).

7.4.4 The model's urban growth types

The urban growth dynamics are implemented in the Urban Growth Model (UGM) through four growth steps:

- **Spontaneous growth;** this defines the occurrence of random urbanization of land which means any non-urbanized cell has a certain probability of becoming urbanized in any time step (Figure 59) (USGS 2000). The dispersion coefficient controls the number of times a pixel will be randomly selected for possible urbanization (USGS 2000).

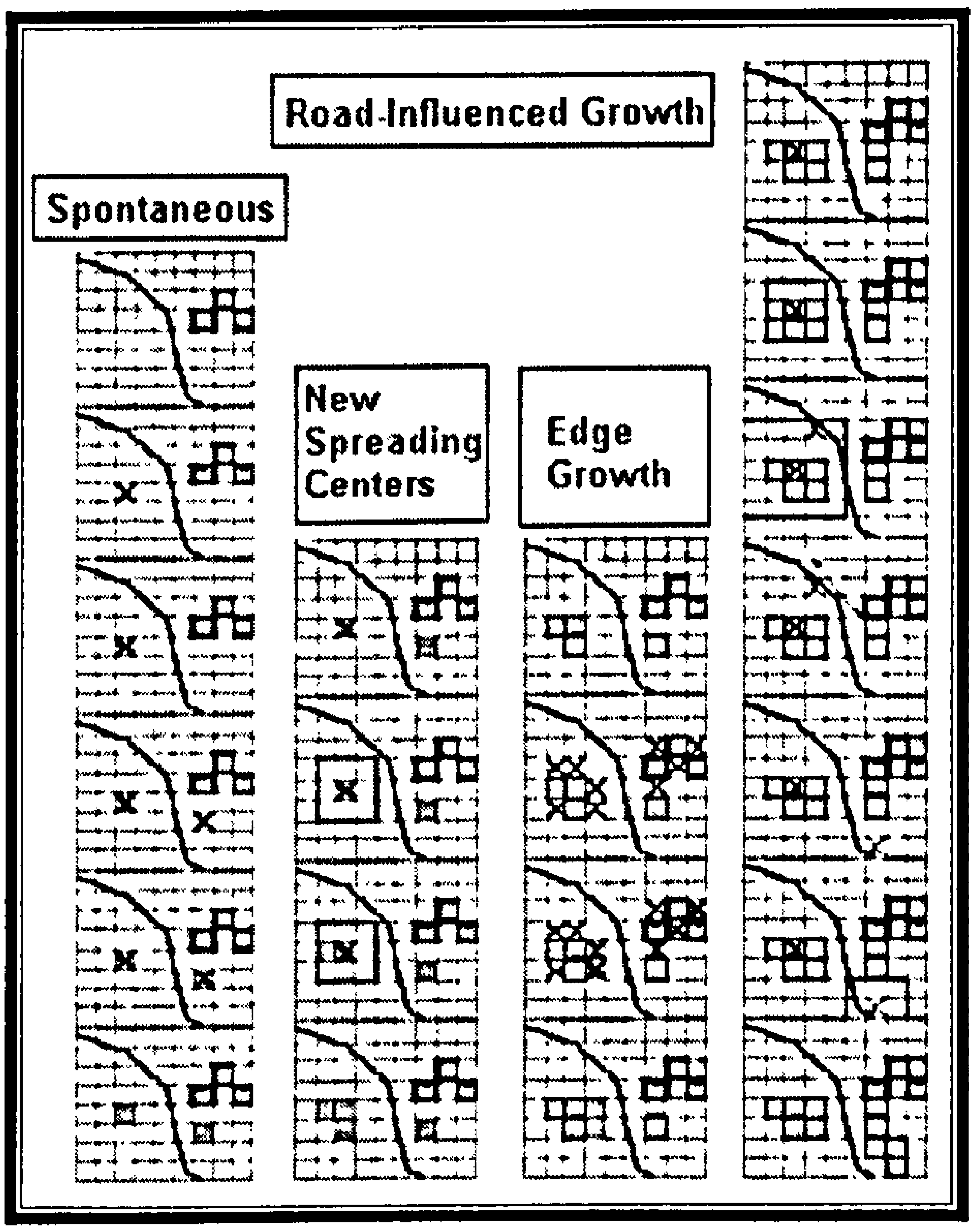


Figure 59 Urban Growth types as used in SLEUTH model (USGS 2000)

- **New spreading centres;** this step determines whether any of the new spontaneously urbanized cells will become new urban spreading centers (Figure 59). The breed coefficient defines the probability for each new urbanized cell to become a new spreading centre (USGS 2000).

- **Edge growth;** if a non-urbanized cell has at least three urbanized neighbouring cells (new or existing spreading centre), it has a certain probability to become urbanized defined by the spread coefficient (figure 59) (USGS 2000).

- **Road-influenced growth** is defined by the existing road networks and the most recent urbanization derived from the above stages. The new urbanized cells (that were defined by the breed coefficient) search roads in their neighbourhood, and if it found a road within a given maximal radius (defined by road gravity coefficient) of the cell(s), a temporary urban cell is created on the road at the closest point to the cell. Then, this newly created urban cell conducts a random walk along the road using the dispersion coefficient. If there is one cell or more adjacent to this new urbanized cell available to be urbanized, it will be randomly selected among the similar candidates (Figure 59) (USGS 2000).

The model provides outputs as a set of GIF image files that can be merged into an animation or brought into a GIS as data layers. Spatial resolution of output images depends on the resolution of the input data. The following represents the typical output files (EPA 2000):

1. Snapshot of a particular year (GIF image file).
2. Cumulative image that results from multiple runs and show a probability of urbanization for a given year (i.e., Monte Carlo[1] image that results from Monte Carlo probability runs) (GIF image file). Table 61 shows the detailed information about the image outputs according to the model's mode.
3. A set of best fit metrics between modelled and real data for calibrating the model.
4. Actual values of model output for control years averaged over the number of model simulations.

File Name	Mode	Flag dependent
animated_urban.gif	P	YES
animated_z_growth.gif	P	YES
cumulate_urban.gif	P	NO
<location>_cumcolor_urban_<stop_date>.gif	P	NO
<location>_urban_{date}.gif	T, P	NO
echo_of_<location>.{attribute}.gif	T, C, P	YES
key_{colormap_type}.gif	T, C, P	YES
z_growth_types_{run}_{monte carlo}_{date}.gif	T, C, P	YES

T=Test, C=Calibration, P=Prediction, <>=Static identifier, {} =Variable identifier

Table 61 SLEUTH image outputs (USGS 2000)

5. The standard deviations of the average actual values.
6. Ending coefficient values.

[1] Monte Carlo simulation is an analytical technique for solving a problem by performing a large number of trial runs, called simulations, and inferring a solution from the collective results of the trial runs. It is a method also for calculating the probability distribution of possible outcomes (MarketVolume.com, 2004).

7. The start and stop times for an entire model execution. Table 62 shows the statistical output of the model.

File name	Mode	Flag dependent
LOG_#	T, C, P	YES
avg.log	T, C, P	YES
coeff.log	T, C, P	YES
control_stats.log	T, C	NO
restart_file.data#	T, C, P	NO
std_dev.log	T, C, P	YES

T=Test, C=Calibration, P=Prediction

Table 62 Statistical output of the model (USGS 2000)

7.4.5 Hardware and software needs

The SLEUTH model requires a PC, workstation, or mainframe with a UNIX operating system and gnu C compiler (gcc). X-Windows is required for graphical version (EPA 2000).

7.4.6 Staff Requirements and Expertise

Installation and calibration of the model requires land-use expertise and familiarity with UNIX operating system, text editor, and gnu C compiler (gcc). Familiarity with X-Windows and X-libraries are also important for graphical Versions (EPA 2000).

7.5 Application of the SLEUTH model to Alexandria

7.5.1 Data set preparation

Modelling urban growth using the SLEUTH model requires intensive data handling where the main inputs of the model can be produced only using remote sensing and GIS techniques. Modelling urban growth is a multi-level analysis that requires hundreds of runs that consume a significant amount of computer processing time, therefore modelling cannot be done using a traditional method such as visual interpretation of the input elements. In this study, urban growth only will be modelled. However, the only available data for the model were the urban extent data that were derived from the Landsat satellite images and GIS analysis of the area of the study. The project also required collection of the rest of the needed data to test the model. Slope and

Hillshade data inputs are commonly derived from a digital elevation model (DEM). There was difficulty in obtaining digital data generally not only about the area of study, but also about Egypt in general because of the high cost of such data as it will be prepared at the direction of the user(s) by the mapping agency in Egypt (Abdou-Azaz 2000).

Another alternative was tried is to get these data from another source at a reasonable cost. The National Imagery and Mapping Agency (NIMA) of USA has a Geospatial Engine that provides access to imagery of the Earth, maps and other geospatial information produced by the National Imagery and Mapping Agency (Agency 2002). Digital Terrain Elevation Data Level 0 (DTED® 0) is one of these products that can provide DEM for places outside the USA. Digital Terrain Elevation Data Level 0 is a uniform matrix of terrain elevation values which provides basic quantitative data for systems and applications that require terrain elevation, slope, and/or surface roughness information. DTED Level 0 elevation data has a spacing of 30 arc second (nominally one kilometer) (Pike and Aftergood 2000). The file which covers the area of study according to its map extent was downloaded into a UNIX environment and two new files (slope/hillshade) were created using Arc View to prepare the needed inputs of the model. A general road map was downloaded as well from ESRI ARCDATA (ESRI 2000). The general urban coverages and excluded inputs were prepared by the author in Arc View as well.

The SLEUTH model requires as input of five types of grayscale gif image files. For all layers, zero is a nonexistent or null value, while zero $< n <$ 255 is a "live", or existing, value. The model requires all input layers to have a consistent number of rows and columns. All layers should be checked for agreement; urban areas should not be including any locations defined as un-developable in the excluded layer (USGS 2000).

The standard formats for all the input data should be as follows (USGS 2000):

- Grayscale GIF images; therefore, all data must be rasterized.
- Images are derived from grids in the same projection.

- Images are derived from grids of the same map extent and resolution so that the row and column count is consistent across all grids.
- Images follow the required naming format where the attribute names must read as urban, roads, landuse, excluded, slope or hillshade. The date must be a four-digit integer. If the file names deviate from this format, the model will not read them.

Example: File name= <location>.urban. <Date>. [<User info>].gif

< > = user selected fields, [< >] = optional fields

e.g. URBAN_DATA= demo200.urban.1930.gif

7.5.2 File transformations

A series of file transformations were undertaken. Originally, all files were shape files except DTED files, which were converted into grids using the DTEDGRID command. Shape files were transferred to grids inside the Arc View program. Then, all grids were imported into ERDAS IMAGINE where all files were registered to the same projection and resampled to the same cell size where the count of the rows and columns in all files were consistent (227 X 148). The final images were exported from ERDAS IMAGINE as GEOTIFF files. GEOTIFF files were transformed again to GIF format inside the PhotoShop 5.5 program. Then the file names were changed using the above-mentioned naming convention approach. The following final input images were created and standardised according to the model format.

- **Slope**

The final image of slope was created. The cell values are in percent slope not degrees according to the model conditions, and the pixel value range is between 0 and 100.

- **Excluded**

The excluded image defines all parts that are resistant to urbanisation such as The Mediterranean Sea in the north and Maryout Lake in the south. The excluded areas are given a value of 100 or greater and the available lands for development have a value of zero.

- **Urban**

The model requires a binary classification of urban and non-urban areas (USGS 2000). The non-urban areas are given zero value and the urban areas can be any value between 1 and 256.

- **Transportation**

The road networks can simulate the tendency of urban growth as the new development may be attracted by the locations of high accessibility (USGS 2000). Road network images may be binary (road=1-256/non-road=0) or have relative values according to the level of the roads (Table 63). In this study as only general road maps were downloaded from the ESRI website, the binary method was applied.

Accessibility	Weighting 1 (Pixel values)	Weighting 2(Pixel values)
High	4	100
Medium	2	50
Low	1	25
None	0	0

Table 63 Road levels schemes and their weights (USGS 2000)

- **Hillshade**

To give a spatial context to the urban extent results, a background image is needed and a hillshaded DEM is commonly used (USGS 2000).

All these created files were stored in a new directory under UNIX to be called when the model was implemented. These inputs are general maps for the area of study. Most of this data is incompatible as some are from different sources, and the author prepared the rest. A significant amount of data handling was required to integrate the different data types to produce consistent inputs for the model. As there is no accurate digital data available for the area of study, the main objectives here are testing the model to understand how far this model can be applied outside the USA, and understanding the general trend of future urban growth in Alexandria. Depending on the results of this study, further investigations may be carried out using accurate and compatible data sets for this area or/and other areas when the needed different resources are available.

7.5.3 Downloading and verifying model functions

The model was downloaded from its own website (http://www.ncgia.ucsb.edu/projects/gig/v2/Dnload/download.htm), and then the directory was decompressed in a UNIX platform. The libraries codes were compiled. Figure 60 illustrates the contents of the model directory after compiling.

```
SLEUTH3.0beta:      root directory and SLEUTH3.0beta
  |                 source code
  |
  |--GD*:           GD image libraries
  |
  |--Input**:       input files
  |   |--demo50:  demo_city coarse calibration files
  |   |--demo100: demo_city fine calibration files
  |   |--demo200: demo_city final calibration files
  |
  |--Output**:      where all SLEUTH3.0beta out files will be directed
  |   |
  |   |--demo200_land_test  /* test run w/ land cover
  |   |--demo200_test       /* test run w/o land cover
  |   |--demo50             /* coarse calibration
  |   |--demo100            /* fine calibration
  |   |--demo200            /* final calibration
  |   |--derive             /* coefficients for
  |   |                     prediction are derived
  |   |--predict            /* prediction with land cover
  |   |--preNoland          /* prediction w/o land cover
  |
  |--Scenarios:     scenario files that control model execution
  |
  |
  |--Whirlgif**:    gif compiler libraries for creating animated gifs

*path defined in SLEUTH3.0beta/Code/Makefile
**path defined in SLEUTH3.0beta/Scenarios/ scenario.* files
```

Figure 60 SLEUTH contents after compiling (USGS 2000)

7.5.4 Model Application Phases

7.5.4.1 Testing

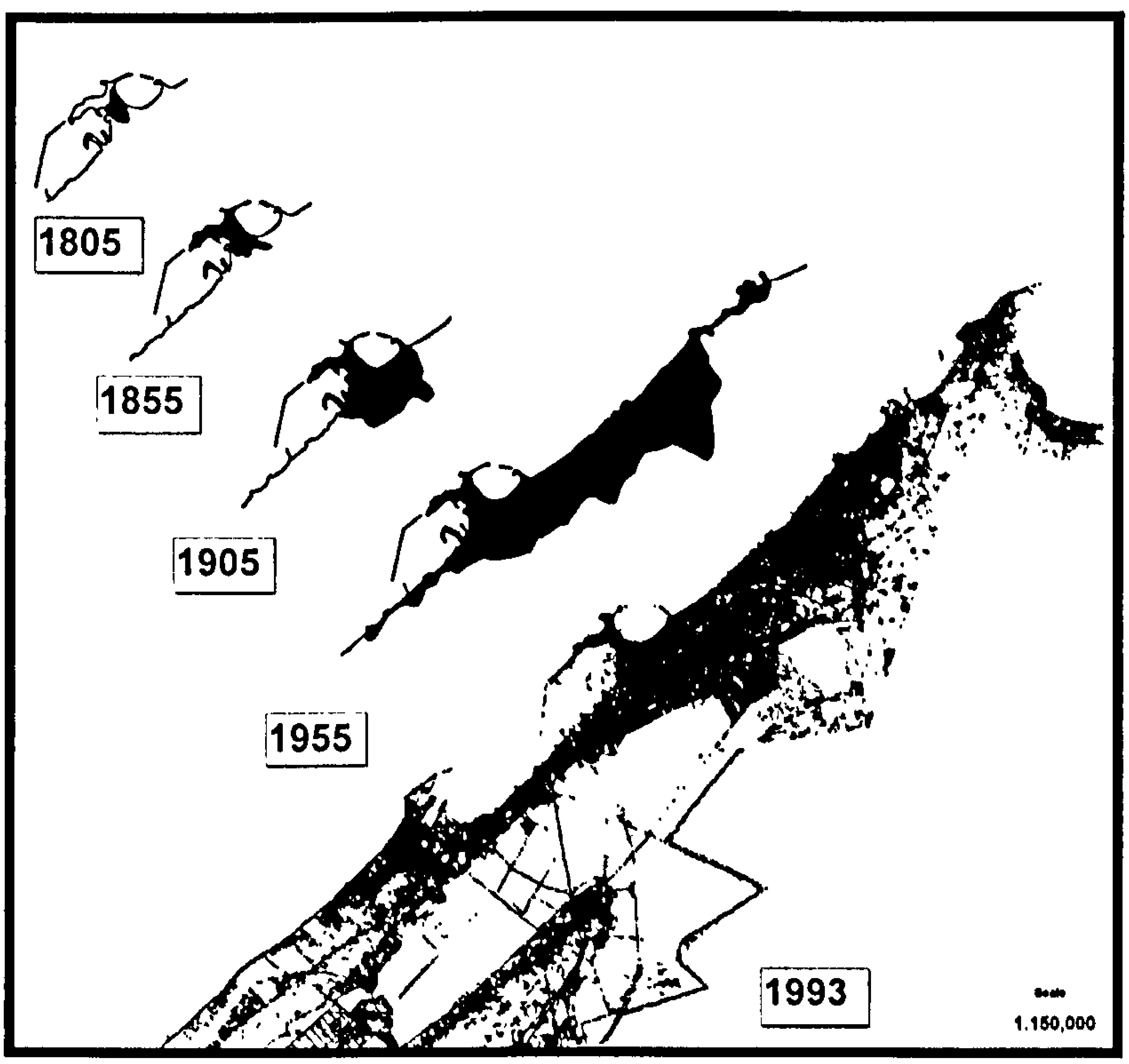
The downloaded scenario files are organised to run on a provided sample data set. It is recommended to test the model using its own data to understand its image and statistic files outputs as this will help to confirm that the model is functioning properly (USGS 2000). The model was tested many times and it seemed to be working appropriately. The next stage is to use the data of the area of study instead of the model data. Some changes were made to the scenario file to enable the model to read the new inputs files and write the output files in the new predefined directories (see Appendix 1). The model has worked well with the data of the current study in the test phase (see Appendix 2). The model outputs (Appendix 3) were checked. In the test mode, annual GIF images of simulated urban growth change are generated and written to the output directory, and this is not the case for the calibration mode (USGS 2000). The log file was investigated to check the validity of used data (Appendix 4).

7.5.4.2 Calibration

The main objective of the calibration mode is to find the coefficient values that best model urban and related land cover change through time. Calibration requires many (often thousands) of single simulations of land cover change. Therefore, output requirements can greatly add to the total application time (USGS 2000). The author shared this experience with Tommy E. Cathey, Model developer, (Appendix 5):

> *"One iteration takes about 3 minutes and the total No. of iteration is 5 which takes about 15 minutes in total, and we have about 3125 Run so this will take 15 X 3125 = 46875 minutes / 60 = 781.25 hours /24 = 32.55 days!!"* (Abdou-Azaz Urban Growth Model, E-Mail Contact with Tommy E. Cathey (Model Developer) 2003).

This was not the only case to take such time. In another study, the run time on the PC for the first coarse calibration lasted about 55 days, 6 hours and 30 minutes (Varanka 2001). "...*The full calibration process is quite time consuming.*" Keith Clarke, model developer admitted (Abdou-Azaz 2003). The calibration phase needs three consequent runs (Coarse, Fine, and Final), and the running time will increase with the move from coarse to fine and from fine to final calibration as the number of Monte Carlo Iterations is increasing from 4 or 5 in the coarse calibration to more than 100 to derive forecasting coefficients. Therefore, the calibration phase was avoided as the model can be executed in the predict mode with any set of coefficients with values between zero and 100 without the need of the calibration mode (USGS 2000). In the search for a method to generate model's coefficients, Keith Clarke advised the author to calibrate the model first but he indicated that it is quite time consuming. Thus, a user-defined mathematical calibration method was developed using historical and contemporary mapping data of area of study (Figure 61).



1 *Data of urban expansion between 1805 and 1955 from (Abdel-hakeem 1958)*

2 *Urban expansion of 1993 was produced from satellite image by the author*

Figure 61 Physical Expansion of Alexandria during the 19th and 20th centuries

In this method, the area of the city between 1805 and 1993 has been calculated in Arc View. Both physical expansion and population growth rates have been generated as it is shown in chapter four (city area development) section. Only, urban expansion rate is used to generate coefficient model, however, this rate reflects a strong relationship with population growth rate as results show that every one per cent of population growth leads to 1.4 per cent of physical expansion. In other words, modelling urban growth in this study using SLEUTH model will depend on physical expansion rates that reflect also population growth. This means that projecting urban growth in Alexandria assumes that the current trends of population growth will continue. Many investigations have been practised to generate model coefficients. According to previous urban growth trends in Alexandria, spread growth is given the highest weight, as it was the most dominant trend of city expansion. Meanwhile, both diffusion (spontaneous growth) and breed (new spreading centres) are assigned the least weight. Slope is one of the most important factors of urban development; therefore, it is allocated the second highest weight. Road maps are allotted the third priority after many tests to investigate whether the increase in road map coefficients would have any impact in the potential growth or not. It was found that there is not much increase in urban expansion if the road coefficient is more than 40. Table 64 illustrates the final prediction coefficients. These are based on the urban expansion figures from above and interpretation of land use/cover change described in chapter six. Indeed, the model outputs change according to the value of the different coefficients.

Coefficient	Value
Diffusion (Spontaneous growth)	20
Breed (New spreading centers)	20
Spread (Edge growth)	99
Slope	65
Road	40

Table 64 Model's coefficients of urban growth prediction in Alexandria

7.5.4.3 Predication

Prediction mode was tested initially using the years ranging between 1995 and 2015 to estimate the running time. The first run lasted about 30 minutes. Appendix 6 shows the processes of this phase. Then, another prediction run was implemented using a larger date range (1995-2055) to give much more indication of the future urban growth; the Monte Carlo iterations were increased to 100, and the generated coefficients of the area of study were used in this run (Appendix 7). Appendix 8 shows the final output files and images from the last running of the prediction mode.

7.6 Results

Figures 62-65 illustrate urban growth extent in selected years using the background image (hillshade). As it was indicated before, the model used what can be considered general data inputs, so the expected model' outputs may show only the general trend of urban growth. In addition, it is important to indicate that the resulting spatial pattern of urban growth was derived using growth parameters based on the history of physical expansion of the city. Therefore, the potential growth pattern is sensible.

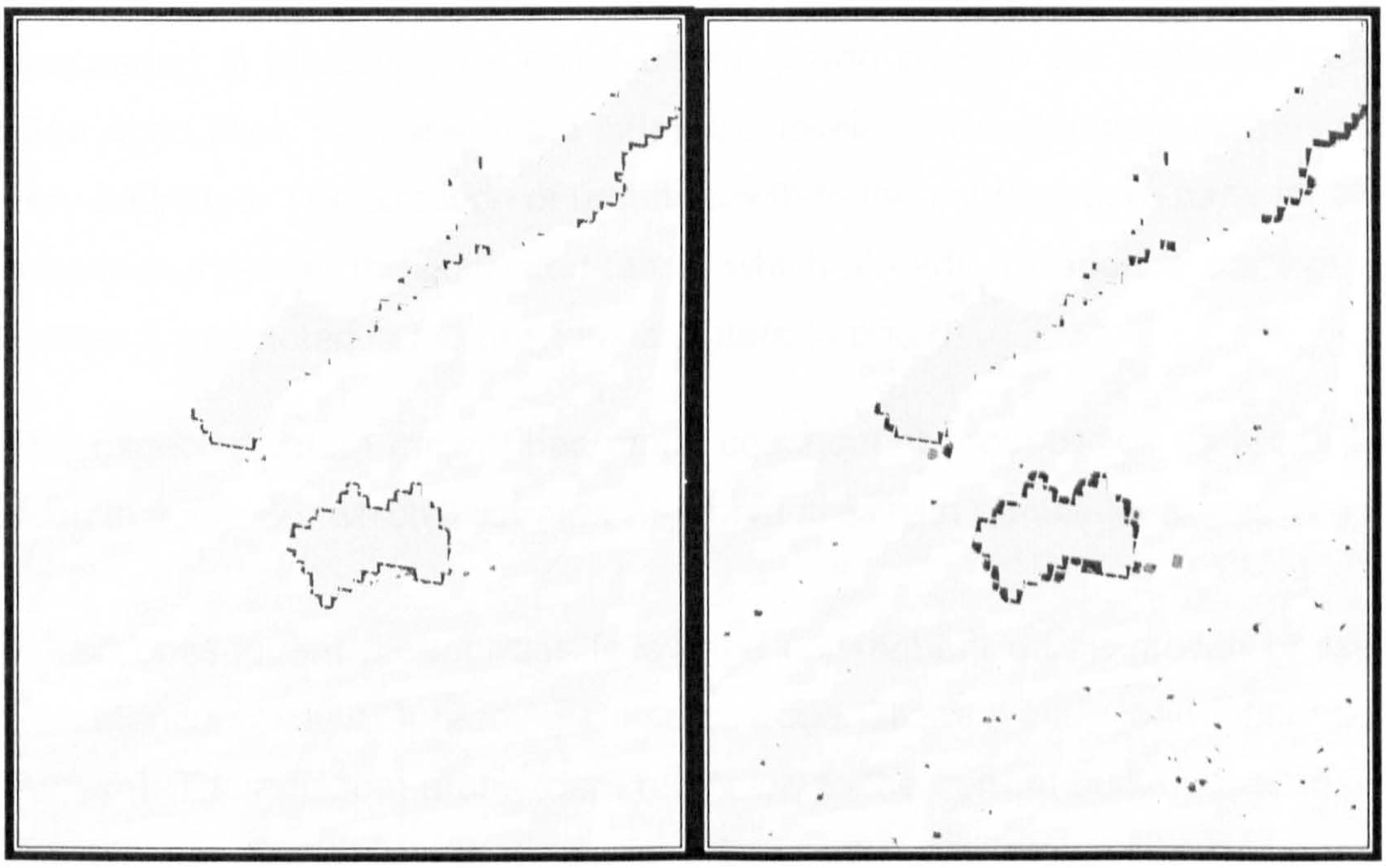


Figure 62 Urban extent up to 2010 **Figure 63 Urban extent up to 2025**

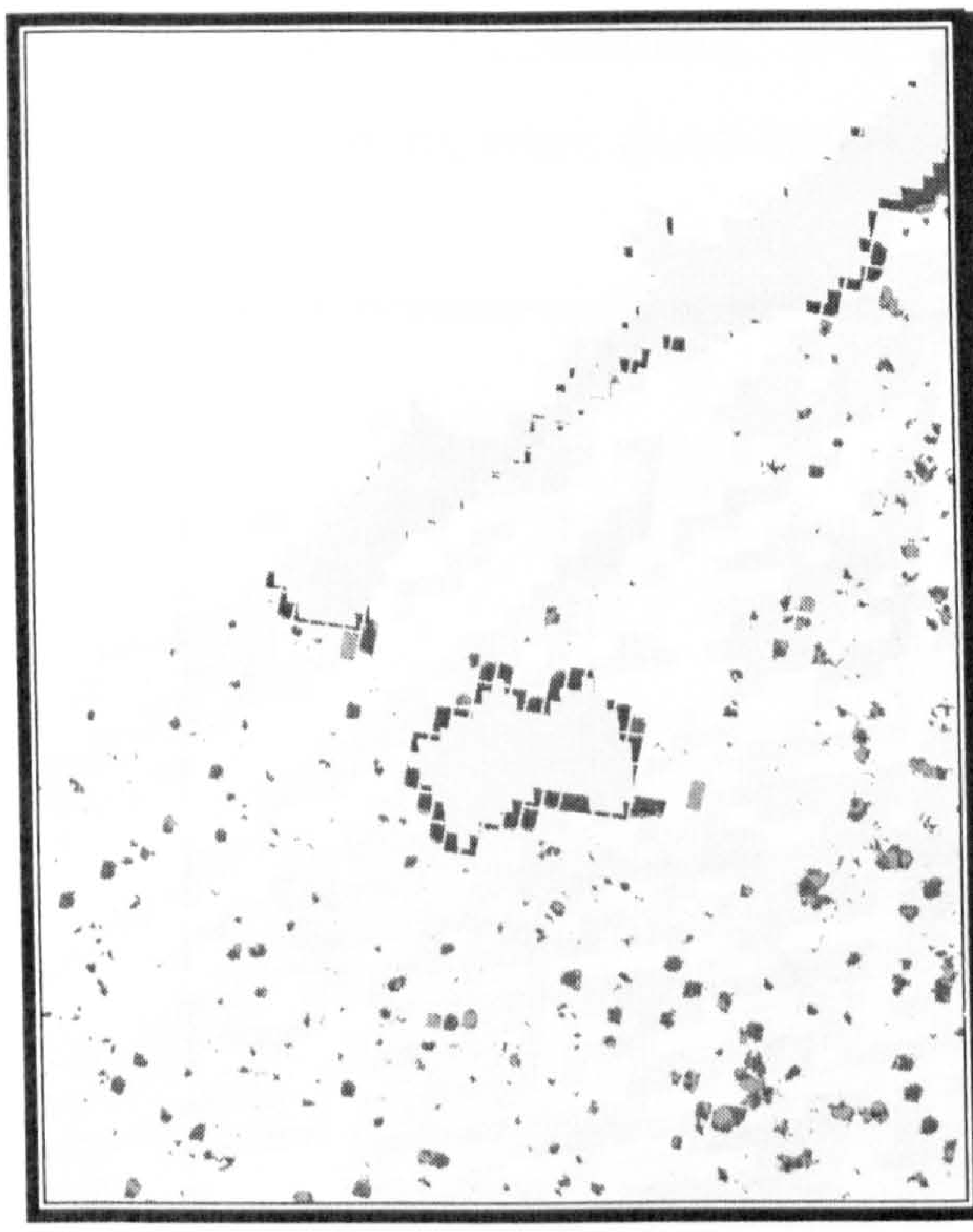


Figure 64 Urban extent up to 2040

Figure 65 Urban extent up to 2055

If the current physical urban expansion will continue with the same rates, it is expected that urban growth will continue in the edges of the current urban extent. This can be detected easily in the west, south, and the southeast directions as appeared clearly in Figure 66. Much development is expected to occur also around Al-Amrya area in the southwestern parts. The model succeeded in allocating expected urban growth outside the excluded parts (Sea and Lake). Because of the latter, the available development options are very restricted. The direction of urban growth to the southeastern parts means a serious threat to the cultivated lands, which already experience continuous loss as it was noted in the previous chapters (3 and 6).

The expected urban growth has many consequent probabilities as it can be seen in figure 66, which illustrates Al-Amrya area with a multi-level zooming in.

These consequent probabilities follow the consequent urban growth phases (Spontaneous, New Spreading Centers, Edge Growth, and Road-Influenced Growth). The adjacent areas (dark red color) to the current built-up area have the highest probability to become urban, and the probability decreases through moving to the edges. Moreover, the figure shows that urban growth can occur away from the current built-up area as an indication of the Road-

Influenced Growth coefficient, and this may appear much more clearly, if detailed road maps were used in the model.

Figure 66 Urban growth probability key as appeared in Al-Amrya area

The background image can affect visualisation of future urban expansion on the final output. Therefore, the future urban growth appears around the current built-up area or the so-called "seed area" only by the model terms, but this is not true in reality as there are many occurrences of urban growth of different types outside current urban areas. Because of that, the model allows another type of output to show up urban growth types without the use of the background image (Figure 67). In this figure, urban growth appears in all the area of study not only around the current urban area.

Indeed, the final outputs have been affected by data limitations especially for roads and slope inputs; as roads inputs are generally made with very low resolution. Therefore, there is not much development depending on the roads coefficients or developing new centers but most urban expansion can be considered as spontaneous and edge growth in general. In fact, Alexandria has a complicated road networks at different levels, but there are no accurate, up-to-date or contemporary data to be used here.

In addition, for the slope element, the current slope input is so general as well that there is no idea about the accuracy of data. It is believed that if accurate and up-to-date data are available especially for those two elements, they will have a great impact on the final outputs of the model. Therefore, the work in modelling urban growth may be continued using better data, if available, for the area of study or any other area.

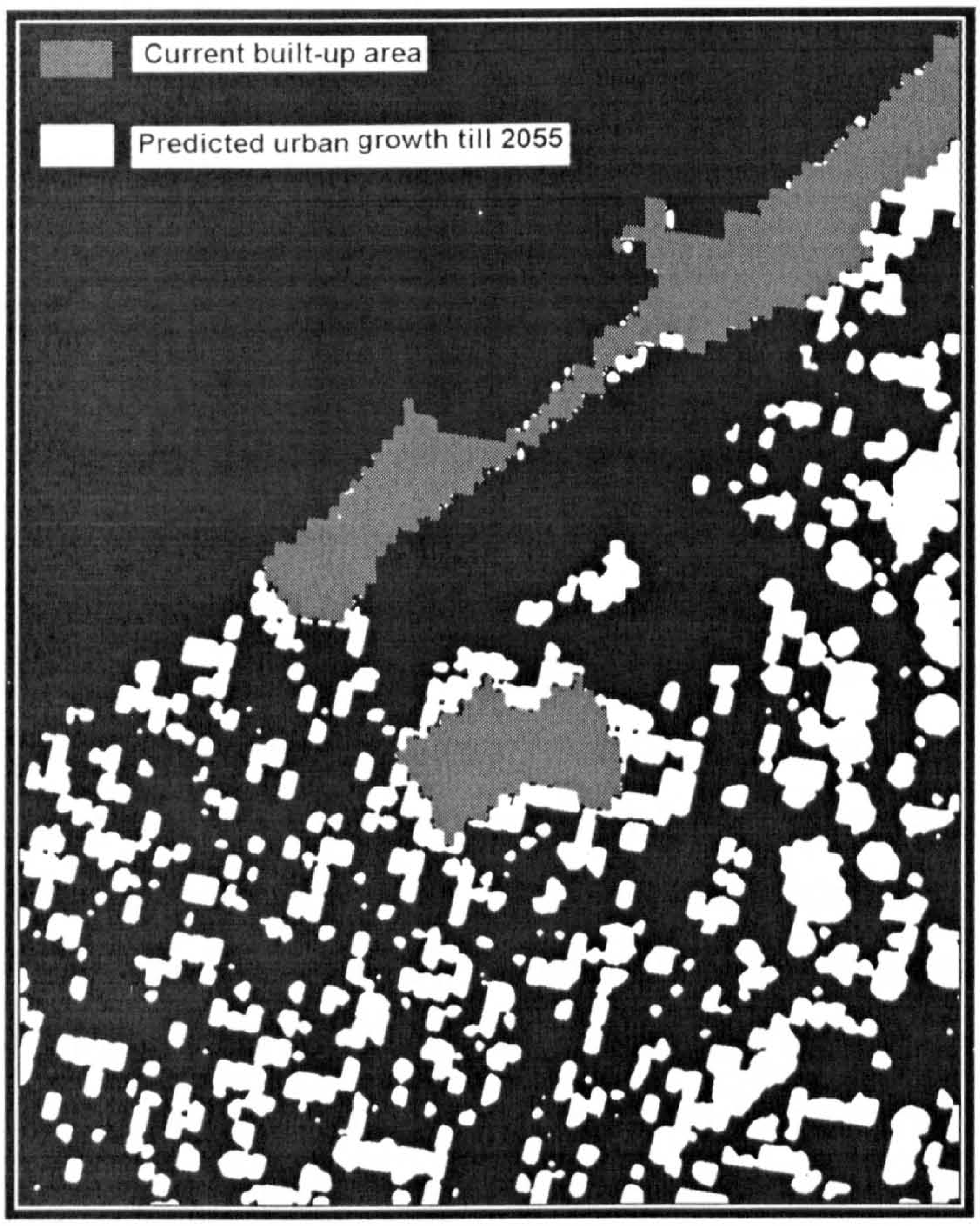


Figure 67 Urban Growth in 2055 in all the area of study

It is valuable to note that, even with the availability of appropriate required data, the final outputs of the model must be treated as probabilities as these predictions can not be verified any time soon (Clarke et al. 1996).

Last, but not least, it is important to note that the model simulates physical urban growth without involving the socioeconomic factors. This deficiency cannot be disregarded. Therefore, there is a need for an urban growth model that can incorporate these factors, as this would help to achieve better prediction outputs.

7.7 Summary and Conclusions

Land use/cover change models were reviewed to select the most appropriate model according to the conditions of this study. Two models were selected using different criteria to be applied in the area of study. However, only one model was decided to be applied because of technical reasons. The chosen model is SLEUTH. The model uses cellular automata (CA) as a growth procedure to model urban expansion in a spatial two-dimensional grid (Silva and Clarke 2002). The model has been applied in many cities within the North America context, and applied also for the first time outside the USA in Lisbon and Porto in Portugal (Silva and Clarke 2002). The application of the model in Alexandria of Egypt, with its different environmental and geographical characteristics, is the first attempt outside USA and Europe. The model was applied in the area of study to predict urban growth to 2055. According to the current growth rates, urban growth is expected to continue in the edges of the current urban extent in all developable directions. There are no environmental problems resulting from this growth except in the eastern and southeastern parts where there is serious risk to the cultivated lands that already suffer from constant damage, as shown by the change detection analysis. From the technical point of view, the results show the potential success of the model if applied outside the originally meant context, and this is a great advantage itself as it encourages further studies using this model. In this context, it is important to report that the data used in this study were collected from different sources with different spatial resolutions, as there was difficulty in obtaining the data that can be considered appropriate. The results of this chapter provide a good base for urban growth management discussion in the following chapter. Urban growth management recommendations will be discussed with reference to Alexandria and Egypt. Moreover, urban planning in Alexandria will be assessed as well. Meanwhile, the results of chapters seven and eight provide decision makers with valuable information and data to manage urban growth in Alexandria effectively.

8. CHAPTER EIGHT: MANAGEMENT OF URBAN GROWTH WITH REFERENCE TO ALEXANDRIA

8.1 Introduction

As we have learnt through this study, Alexandria has seen a significant urban expansion and this expansion is anticipated to continue in the near future. This urban expansion comes at a price of consuming agricultural lands to form kind of inefficient land use pattern. Any urban growth management strategy in this area should consider *Sustainability* as an important element to preserve the quality of the environment. As such, efforts should be made to examine the issues in search of better means of controlling and managing urban growth for sustainable environment. Management of urban growth is one of the most important issues in the world in recent decades as it will provide better life for current generations in urban and rural areas, and sustain the environment as well for the future generations. Countries dealt with this quandary by different approaches. This chapter commences with a distinction between urban management and urban growth management, with reference to urban growth management principles and strategies. Then, the previous experience in managing urban growth in both developing and developed countries will be reviewed followed by the lessons learnt from both experiences. The main core of this chapter is to introduce some recommendations of managing urban growth. These principles will be discussed with reference to the current situation in Egypt to find out how far these principles have been applied in Egypt - at national level - and in Alexandria - at local level. Traditional and modern urban plan types will be addressed followed by urban growth management techniques. In more focus, the available urban plans of Alexandria will be reviewed in reference to urban growth management aspect.

8.2 Urban growth management, a background

Urban expansion without appropriate management in serving the increasing population has prompted the search for methods to control and manage urban growth. Urban growth management presents one of the great paradoxes facing the contemporary government officials as well as various concerned groups (Lee *et al.* 1999).

In the beginning, it is instructive to distinguish between urban management and urban growth management. There is often confusion in use between urban management (UM) and urban growth management (UGM) terms. Sometimes, urban management is used to refer to urban growth management and vice versa. For example, Davey (1993: ix) defined urban management as follows;

> *"Urban management is concerned with the policies, plans, programs, and practices that seek to ensure that population growth is matched by access to basic infrastructure, shelter, and employment."*

While, Rakodi (2003:538) defines urban management as;

> *"incorporating a corporate policy and resource allocation strategy dealing with health, education, transport, local economic development, poverty reduction, infrastructure provision and land use, translated into programmes and projects for implementation. Operations involve the management of assets and services, involving planning and allocating responsibility for service delivery, maintenance, regulation and revenue generation".*

Urban management is the subject of international interest since 1980s where the Urban Management Programme (UMP) was established in 1986 by joint effort of UN-HABITAT, World Bank, and UNDP. Over the past 18 years within four phases, UMP has been able to disseminate innovative urban management practices, establish and reinforce urban networks, and manipulate local and national urban policies and programmes. UMP continues to develop and apply urban management knowledge in the fields of participatory urban governance, urban poverty alleviation, urban environmental management and HIV/AIDS. In phase 1 (1986 - 1991), the UMP, concentrated on the development of urban management frameworks and tools on the issues of land management, municipal finance, administration, infrastructure and urban environment. Phase 2 (1992 - 1996) used the frameworks and lessons learned from phase 1 to build capacity at the regional level to introduce new policies and tools. In phase 3 (1997 - 2001)

UMP built on and re-focused the work of the first two phases to the city level. Phase 3 had three themes: urban poverty alleviation, urban environmental sustainability and participatory urban governance, with gender as a crosscutting issue. In phase 4 (2001 - 2006) UMP continues with the themes from Phase 3 and HIV/AIDS is added as a new focus theme. (UN-HABITAT 2003).

As we have learnt in this study, Alexandria experiences a significant physical urban expansion in all developable directions. Part of this expansion has a negative impact on the agricultural lands in the eastern and south eastern parts. Therefore, the question here is not about how to manage the city, but it is about how to manage the growth of the city to protect its environment to achieve sustainable urban growth.

In this study, urban growth management (UGM) may be defined as the processes that are part of urban planning activities and involve;

1. Monitoring urban growth elements (demographic growth and physical expansion).
2. Predicting the potential urban growth.
3. Preparation of growth plan depending on the available resources.
4. Continuation of urban growth monitoring and following up of the growth plan.

By this definition, urban growth management is a large subject, with many parameters and components. In addition, urban growth management does not mean only controlling or stopping urban growth (anti-growth), but it implies also promoting urban growth (pro-growth) if needed. Moreover, urban growth management does not imply that less land is consumed by urban areas, but involves the effective use of land considering economic, environmental, and planning factors achieving sustainable urban growth (Hare 2001).

Urban growth management is not a new concept as it emerged in the 1940s in North America. Many urban growth management strategies were developed; these strategies have adopted principles such as:

1. Preserve the character of the community and promote community

identity.

2. Conserve agricultural land and preserve open space.
3. Encourage full utilisation of existing facilities.
4. Control development of new areas to ensure coordination with existing and proposed facilities.
5. Maintain or improve the level of community services.
6. Improve housing opportunities, increase diversity, and promote better housing developments.
7. Avoid environmental problems.
8. Prevent sprawl.
9. Promote aesthetics and preserve historic or cultural features.
10. Reduce traffic congestion and improve the road system.
11. Promote public safety.
12. Provide for flexibility to meet future needs (Eisner *et al.* 1993).

These common principles have been applied in a wide range of growth management techniques. Bengston *et al.* (2003) categorized the commonly used instruments for managing urban growth into three broad types;

1. Public acquisition of land.
2. Regulatory approaches.
3. Incentive-based approaches.

Public acquisition of land is used often for protecting open space, but it can be used also for managing urban growth. In this approach, urban planners support public investment in green infrastructure. This approach provides a framework for urban growth and can define where not to grow (Bengston *et al.* 2003).

Regulatory approaches for managing urban growth involve different strategies such as;

- Development moratorium, which means simply absolute prohibition on the issuance of building permits until preparing long-term urban growth plan.

- Interim development regulation is another approach where only forms of development that cause urban growth problems are prohibited.

- Rate of growth controls means defining an upper limit on the number of building permits issued annually.

- Growth phasing and adequate public facility ordinances (APFOs) regulations link the development (maximum number of building permits in a given year) with the availability of public facilities (sewers, drainage, roads, etc...).

- Zoning is the principal technique in urban growth management, where upzoning (for example) encourages more intense development by allowing small lots.

- Greenbelt, which means a green space that surrounds a city as a permanent barrier to urban growth.

- Urban growth boundary (UGB) is a dividing line drawn around the city to accommodate expected urban growth for some time, and is regularly checked and expanded as required.

- Urban service boundary is a line also drawn around the city and means no public service will be provided to any area beyond this line.

- Planning mandates which suggest that local government to prepare comprehensive land use plans.

Incentive-based approaches for managing urban growth include several types such as ;

- Development impact fees and taxes can discourage development if they are high in areas without infrastructure.
- Infill and redevelopment incentives such as waiver of development fees, subsidized land costs, tax exemptions, and low-interest loans to direct development into already urbanised areas.

These above mentioned approaches have been used in USA and different countries around the world. The most important lesson that can be learnt from these practices is that there is no single strategy for growth management that is valid for all urban areas. Thus, every community needs to review, learn and innovate locally based efforts. Urban communities must learn from the precedent and current lessons of the powerful growth management strategies that are being employed in United States, England, and Europe, but bearing in mind that the contexts of these strategies are quite different (Hare 2001). In the following section, different experiences in managing urban growth will be introduced.

8.3 Previous experience in managing urban growth

Various approaches have been used to deal with the urban growth problem. A number of countries have tried to manage and control urban growth by adopting some tough policies. These experiences were introduced in Devas and Rakodi (1993). South Africa, for example, practised a firm policy to control black population movement. This policy was part of racial exclusion (apartheid) but it led indirectly to control of urban growth. Urban growth annual rate between 1970 and 1985 was 3.4 per cent, which was lower than most other African states. This policy was unsuccessful as half of Soweto population were illegal immigrants. Under other severe policies, Khmer Rouge regime in Cambodia reduced urban population by 18.75 per cent between 1970 and 1980 from 800,000 to 650,000 by enforced rustication. Indonesia tried to apply residence permits policy during the 1970s but it had little success.

Devas and Rakodi (1993:29) claim, *"Perhaps the only real "success story" of urban population control has been China."* China implemented a multi-dimensions policy; one-child per family policy, rural development, and food and services for registered residents only. These policies combined to keep the annual urban growth rate down to 2 per cent between 1965 and 1985. However, these policies were not completely effective as there was a return migration current since the 1970s.

Fortunately, these experiences are not transferable because of their brutal intention in our free world. On the other hand, many lessons can be learnt from policies that are more humane. Hare (2001) reviewed growth management strategies in North America, specifically Baltimore (Maryland), Portland (Oregon), Calgary (Alberta), Cobourg, London, and Waterloo (Ontario). This review involves the following components:

1. Overall growth management story.
2. Community description.
3. Growth management efforts.
4. Roles (Canada case studies only).
5. Tools.
6. Issues/challenges identified (Canada case studies only).
7. Lessons learned.

Some of these urban areas experienced urban decline, particularly Baltimore, while the rest face urban growth challenge. Therefore, different policies were applied. In most cases comprehensive and local plans were found the most appropriate means for establishing local priorities for growth and this was linked with methods that promote efficient growth such as directing state funding to areas designated for growth, and defining an urban growth boundary to reserve agricultural and natural areas (Hare 2001). Indeed, there are many lessons learned from each case, but introducing all individual lessons is out of the aim of this chapter as these lessons are unique to their local context. Therefore, the lessons learned from all cases will be grouped in the next section to provide common and comprehensive themes, which can benefit our case study.

8.4 Urban growth management, lessons learnt

These lessons were summarised from Hare (2001). One of the most important lessons is that no single growth management strategy is valid for all. Therefore, it is important to develop local policies that can respond to local problems. Growth management strategies should be designed to respond effectively to the different economic cycles (decline, stability, growth). Partnership between government agencies, private sector, and community can lead to win-win outcomes that benefit all. National and local policies must be linked, coordinated and complementary. This governmental collaboration should contain a clear definition of roles to avoid conflict of interests. It should be noted also that urban growth strategies (when implemented) take a long time and huge investment to yield their benefits (e.g. between 10 and 25 years in the London and Portland experiences respectively). Urban growth management strategies should be comprehensive in scale and can integrate with urban fringe and rural areas policies. Taxes were used in different ways (grants, tax abatement, waiving of levies) as means of financial incentives. In the following sections, the recommended principles for managing urban growth will be covered underlining some good experiences with reference to Alexandria (if applicable) and Egypt in general.

8.5 Recommended principles for managing urban growth

Learning from other experiences around the world in managing urban growth is inevitable. In addition, there are some recommended principles that should be applied. Management of urban growth is a kind of planning. Therefore, El-Shakhs (1997:512) claimed that planning for future urban development should be based on promoting:

- *Flexibility, adaptability, and speed of response.*
- *Democratization, participation, and the harnessing of local community initiatives.*
- *System-wide coordination and cooperation.*
- *Privatization and greater reliance on the informal sector."*

Urban growth management does not only need a plan, but it also requires the means by which the plan will be implemented, the needed resources, and policies. Walters in (Eisner *et al.* 1993:466) claimed, "Growth management is not the mandate to plan; it is the mandate to implement your plan". For example, growth management plans in Florida rely on the existence of a truly comprehensive plan and policies and financial resources to implement the crucial parts of the plan (Eisner *et al.* 1993). In the following sections, the basic principles of managing urban growth will be underlined. It is important to emphasise this is not a comprehensive study for all the principles of urban growth management, but this study tried to introduce most of these principles in the light of the availability of different resources.

8.5.1 Good urban governance

The high rate of urban growth has outgrown the capacity of cities to plan and control it (Stren *et al.* 1989). Using the conventional practice of planning which based on centralisation, top-down urban management, unrealistic legal norms, and unachievable standards will not help in managing and controlling urban growth (Kombe and Kreibich 2000). This calls for a new approach of urban governance.

"Governance" and "good governance" terms are being increasingly used recently in the development literature. However, "governance" concept itself is not new. There are many definitions for governance according to the variety of research and thoughts. Paproski (1993) defines governance as the process of interaction between the public sector and the various actors in civil society. Governance suggests an action space between government and civil society (Harpham and Boateng 1997). In addition, governance can be defined as "*the process of decision-making and the process by which decisions are implemented (or not implemented)*"(UN-ESCAP 2004). The decision-making process here involves public interests' articulation, national and local governments, and civil society and the private sector. This is the basis to introduce the concept of governance, which is particularly important at the urban level and will tend to grow in importance within the next 30 years (Rabinovich 2004). Kaufmann et al. (2003) define governance as traditions and institutions by which authority in a country is exercised. That definition includes (1) the process by which governments are selected, monitored and replaced, (2) the capacity of the governments to effectively formulate and implement sound policies, and (3) the respect of citizens and the state for the institutions that govern economic and social interactions among them.

Good governance has become one of the important issues of the international institutions. A UN inter-agency meeting to discuss the principles of good urban governance, held on the occasion of the Istanbul+5 meeting in June 2001 in New York, agreed on five core principles of good urban governance: equity, effectiveness, accountability, participation and security. UN-HABITAT's proposed a list of seven norms for good urban governance; sustainability, subsidiarity, equity, efficiency, transparency and accountability, civic engagement and citizenship, and security (Jokinen 2002). UNDP claimed that good governance has the following major characteristics; participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and follows the rule of law, and has a strategic vision (Abdellatif 2003). Most of these institutions agreed on the elements of good governance. These common norms are discussed in some detail in the following section.

Participation means that all men and women should have a voice in decision-making, either directly or through legitimate intermediate institutions that represent their interests. Consensus orientation where good governance mediates differing interests to reach a broad consensus on what is in the best interest of the group and, where possible, on policies and procedures. Accountability indicates that decision-makers in government, the private sector and civil society organizations are accountable to the public, as well as to institutional stakeholders. Transparency is built on the free flow of information. Processes, Institutions and information are directly accessible to those concerned with them, and enough information is provided to understand and monitor them. Good urban governance should be responsiveness to the needs of the city and urban growth. In addition, it should have effectiveness and efficiency where processes and institutions produce results that meet needs while making the best use of resources. Equity denotes that all men and women have opportunities to improve or maintain their wellbeing. Rule of law implies legal frameworks should be fair and enforced impartially, particularly the laws on human rights. Strategic vision means leaders and the public have a broad and long-term perspective on good governance and human development, along with a sense of what is needed for such development. There is also an understanding of the historical, cultural and social complexities in which that perspective is grounded. (Abdellatif 2003)

To achieve urban governance, local governments will have to collaborate with other local authorities, research institutions, NGOs and community groups, private sector entities, national agencies and ministries, and UN agencies. In this context, there is a need to educate and build awareness of good governance, by developing a 'governance inventory' that will document good governance practices (Hari Srinivas 2004).

As the national and local governments are the main key-players in the urban development process, it is important to support them with the necessary skills and abilities in order to intervene effectively in the process of urban development as the previous experiences in cities in both developed and developing countries revealed that the city offices may not have these skills (Devas and Rakodi 1993). The official organisations must have the necessary human resources with continuous training programmes to deal with any apparent deficiencies (Devas and Rakodi 1993).

The UN-Habitat (1996) acknowledged the effectiveness of urban governance in paragraph 104 of its Agenda:

> *"104. In the process of urbanization, policies and programmes for the sustainable development of human settlements in both rural and urban areas require strong subnational governmental institutions working in partnership with all interested parties. Such institutions are still weak in many countries, and their effectiveness is threatened by increasing problems of political regionalism and ethnic strife. All these concerns and demands require a regional and cross-sectoral approach to human settlements planning, which places emphasis on rural/urban linkages*

> *and treats villages and cities as two ends of a human settlements continuum in a common ecosystem."*

In the same context, it is imperative to establish networks between and within existing organisations and institutions as that would facilitate information flows and enhance coordination throughout the process (El-Shakhs 1997). Information flows are one of the main objectives of the participatory GIS approach or P-GIS. P-GIS applications in the world now provide the basis for examining the relationship between the uses of geo-information and governance. Many P-GIS applications foster different dimensions of good urban governance such as accountability, transparency, legitimacy. In addition, GIS itself is considered as a tool for better governance (McCall 2003).

Nakuru in Kenya is a good example of promoting good urban governance. The town is a rapidly growing centre and was known as "the cleanest town in East-Africa", but it has lost much of its past glory because of the inter-relation between human settlements and the Lake Nakuru National Park, and the expansion of the town into geologically fragile areas and rich agricultural land. This situation is worsened by the falling standards of urban services, calling for a new approach towards urban planning and management. To promote good urban governance, the programme strategy emphasises the need for a shared vision for the future development of the city. Its parallel urgent problems are addressed through action planning and environmental conflict resolution. A continuous broad-based consultation process underpins this process. A Strategic Structure Plan (SSP) for Nakuru has been prepared and a Town Planning Unit is being established to reinforce the Council's planning capability and to coordinate the implementation of the SSP (UN-Habitat 2004).

It is important to mention that there are no "formula" for good urban governance approaches as all cities are different. What works for one city may not work for another. Good urban governance cannot be based on the same foundations in all societies. It should consider the local culture and the modern history of the state and its institutions (Harpham and Boateng 1997). There are no magic formula: cities require "tailor-made" approaches, not "one-size-fits-all" approaches. (Rabinovich 2004). This calls for each city to develop its own local formula of good urban governance. However, developing such locally-based formula does not mean avoiding best practices in similar cities that experienced similar problems. Alexandria may have much to learn from Nakuru's experience for example.

8.5.2 Decentralisation

Decentralisation has many definitions and several dimensions according to the variety of institutions and scales of application. However, decentralisation can be defined as *"the transfer of political power, decision making capacity and resources from central to sub-national levels of government"* (Hadingham *et al.* 2002:3)

The literature on decentralization identifies at least four types (Rabinovich 2004):

- **Devolution** which is the transfer of responsibility for governing in the broad sense (i.e., strengthening sub-national units of government);

- **Delegation** which is the assignment of specific decision-making authority (i.e., transfer of managerial responsibility for undertaking specific tasks);

- **Deconcentration** which is the spatial relocation of some administrative functions of government (i.e., physical transfer of central government agencies);

- **Divestment** that occurs when planning and administrative responsibility is transferred from government to voluntary, private or non-governmental institutions.

One important concern is that a transfer of resources (human, financial and material) should usually follow the transfer of responsibility so that decentralisation results in clear benefits to the public (Rabinovich 2004).

Hadingham *et al.* (2002) presented some of arguments that support decentralization as follows;

- Local authorities are more informed than central government about local realities as they can consult local communities and be more sensitive to local priorities and needs;

- Local government is closer to users and should be able to keep them informed more easily about decisions;

- Given sufficient autonomy, local government will not need to seek approvals from above, and can act more rapidly and responsively than central agencies;

- Some local tax rates, fees and user charges can be fixed locally, allowing local government to optimize local sources of revenue.

Watson (2002) distinguishes five key areas that contribute to successful decentralisation:

- Clear division of roles, responsibilities and powers between levels of government;

- The transfer of adequate financial resources to the local level;

- A clear distinction between the roles of elected councillors and technical officials at the local level;

- Capacity for planning, budgeting and project management;

- Appropriate mechanisms of accountability between the local authority and the users of its services.

The UN-Habitat (1996) prepared a set of actions to achieve decentralisation (paragraph 180). Amongst these actions are;

(a) Benefiting from the previous experience of the countries that are implementing decentralization effectively,
(b) Exchanging experience between government and local authorities in all urban management aspects, and
(c) Enabling local authorities to engage the local private and community sectors in the planning process at local level.

Decentralization is one of the good practices in the West in planning generally, and urban planning specifically. For example, the city and regional planning and implementation are not reviewed by national planning agencies except when the economic support of the national government is needed to meet local needs (Eisner *et al.* 1993). Devas and Rakodi (1993) claimed the allocation of responsibilities for decision-making, operation and maintenance must balance the relative advantages of centralisation and decentralisation as the government at national level can ensure the achievement of national service standards whilst the local government can ensure an effective response to local needs and problems. The UN-Habitat (1996), in paragraph 102 of its Agenda emphasized the importance of local government, as it is the level of administration that is closest to the people. Therefore, it can establish local policies and assist in implementing national and sub-national policies as well.

India realised the importance of the decentralisation of governance in 1994 by amending its Constitution to implement Local Agenda 21 recommendations. Among many benefits of this immense legislation are; giving constitutional status to the urban local bodies, setting up a State Finance Commission to recommend guidelines for strengthening municipalities finance, and formation of local committees (ward committees) to take up local issues (Bharat and Chawla 2004).

Seven African countries namely, Botswana, Malawi, Mozambique, South Africa, Swaziland, Zambia and Zimbabwe, have seen considerable political and economic liberalisation. These reforms produced a trend to decentralise planning functions and resources and to build local capacities. Therefore, many governments have formulated policies that decentralise decision-making from the national to the local level and devolve responsibility for planning, delivery and finance of local infrastructure and service to autonomous, democratic local governments (Hadingham *et al.* 2002).

Centralisation is an important characteristic of planning as a whole in Egypt. There are two ministries and a number of agencies responsible for urban development in Egypt; Ministry of Planning is responsible for allocating financial resources for all ministries and governorates, Ministry of Housing, Public Utilities and New Urban Communities is responsible for housing, public utilities, construction, new town development, and desert land development. Under the rule of this ministry, there is a number of governmental agencies including, the General Organization for Physical Planning (GOPP), which is responsible for urban master plans and implementation of the master scheme of Cairo, the Central Authority for International Development (CAID), and New Urban Communities Authority (NUCA). In addition to the above, there are some agencies that have the right to modify local development projects without any co-ordination with the other concerned agencies, such as the National Investment Bank, the Ministry of Development, and the Ministry of Local Management. This complex central system results in incoherence in the planning and implementation of urban development projects (ElAraby 2003). However, the General Organization for Physical Planning (GOPP) has started to establish regional urban planning centres in six (out of seven) planning regions in the country (ENCHS 2000) as a first step towards decentralisation.

It is important to link decentralisation with greater local autonomy as the failure to do that will lead to strengthening the presence of the central government through the allocation of responsibilities to local levels of administration (Rakodi 1997). It is not wise to transfer the current central system in Egypt to a complete decentralised system in a day and a night as this might produce complicated impacts. Therefore, the gradual transmission and the integration between centralisation and decentralisation in the form of policy coordination might be the right tools in the early stages for effective urban growth management in Egypt.

8.5.3 Public participation

Public participation is a wide issue and it has diverse definitions, which reflect the different ideologies of planning approaches. Definitions of public participation range from including the public in every step along the process to getting the public's reaction when the decision is close to being made. Public participation is not merely allowing the public to react to an already-made decision, but neither is it involving the public extensively in every single aspect of the planning process. Public participation is rarely simple or straightforward. It is a complex organisation of activities and processes during which the concerns, problems, ideas and issues of the public are addressed (Lewis 2000).

The Environmental Protection Agency (EPA) of USA gives a very good definition of the public participation process, which refers to activities where organisations encourage public input and feedback, conduct a dialogue with the public, provide access to decision-makers, assimilate public viewpoints and preferences, and demonstrate that those viewpoints and preferences have been considered by the decision-makers (Roy 1998).

Public participation is an important element in successful planning for two reasons; first, it acts as a process of attaining insights into local conditions and the needs of local people. Second, it is assumed that, if individuals are involved in plan preparation, they are more likely to be committed to it. This emphasises the notion of "Planning is for people" (Potter 1985).

El-Shakhs (1997:513) claimed that:

> *"Many of the current problems of overconcentration in cities and failure of planning responses lie in the excessively centralized and often undemocratic nature of state. Without democratization of the state itself, it is hard to envisage truly responsive planning and development*

> *processes that can be sustained, particularly at the local level through community-based organizations."*

Citizen involvement in public issues is the best way to obtain effective, responsible, and responsive government (Eisner et al. 1993). This involvement or participation should have the necessary power to contribute effectively in urban management processes. El-Shakhs (1997:515) claimed that:

> *"Citizen Participation without empowerment could simply lead to the transfer of added burdens and responsibilities and not of economic and political power to local groups. Thus, localities should acquire control over much of their resources, be given taxing powers, and retain a good portion of their taxes, fees, and other locally granted income."*

The UN-Habitat (1996) acknowledged the importance of the "participatory" approach as a means for sustainable development in paragraphs 100 and 103 of its Agenda. The application of participation requires cooperative actions among interested parties. This recommended "participation" should adopt the "enabling approach" that was introduced in chapter 7 of Agenda 21 to achieve partnership among the public, private, and community sectors to improve the different aspects of human settlements of all people.

Pelcl et al. (2002) stress the importance of participatory approach as; *"Appropriate public participation is more and more recognised as a key factor for the successful planning of regional development".*

Public participation is one of the most important factors to improve governance by involving a wide range of stakeholders to deliver services and programmes that are consistent with local conditions (OECD 2001).

Public participation must involve all the population without any discrimination because of economic ability or sex. The urban poor and women should be involved in management and planning processes. Administrative and political reforms are needed to initiate public participation. Planners and managers in neighbourhood offices that work closely with local urban residents can encourage public participation. In the mean time, the residents can make every effort to make their views known by organising themselves in either a community-based participatory approach or NGO channels (Devas and Rakodi 1993).

GIS-Participation (GIS-P) is one of the recent developments to enhance public participation in urban planning. GIS-P combines GIS and other methodologies to give local government the basis for policy formulation by building on insights from local people. This approach has been shown to be successful not only into urban management policy process but also into computer simulation as well (Forrester et al. 1999).

A good example of general participatory approach comes from South Africa where Integrated Development Planning or IDP approach has been implemented. The IDP methodology recommends that local governments initiate a participatory process to work their way from the visions and objectives for the respective municipality to localised strategic guidelines. Participation in the integrated development planning process is only one of several arenas of participatory interaction between local government and citizens. Other means of ensuring participatory local government are:

- Offering people choices between services;
- Citizen and client-oriented ways of service delivery and public administration;
- Partnership between communities/stakeholder organisations and local authorities in implementation of projects; and
- Giving residents the right of petition and complaint and obliging municipal government to respond. (GTZ 2004).

In Egypt, public participation in urban growth management would be helpful. Urban planning in Egypt generally lacks this important element, as public participation is absent in planning activities. However, The Ministry of Housing, Utilities and Urban Communities through the General Organization for Physical Planning (GOPP) started to include local communities and private sector in development projects such as the Human Settlements Development

Project in the south of Egypt by encouraging discussions in open seminars in Al-Farfra city (ENCHS 2000). In addition, there is a new dawn of public participation in Alexandria as the city now sees many improvement projects based on the cooperation between the governorate, represented by its governor Mr Al-Mahgoub, on one side and Alexandria community, and private sector representatives on the other side. The success of this initiative is well known not only in Egypt, but also at an international level where some cities asked to benefit from this experience.

8.5.4 Legal framework

Urban management may not need new or additional laws, as the existing laws are not being applied appropriately because of its overlapping and contradictory characteristics; simplification and clarification are likely to be the solution. Nevertheless, if there is any need for new laws to manage urban growth; these laws should be equitable, flexible, participative and easily manageable, simple, efficient, administratively fair and environmentally conscious (Devas and Rakodi 1993).

Furthermore, Some authors believe that imported regulatory frameworks are rarely appropriate with only two exceptions; the first is building regulations applicable to large multi-storey and international buildings such as airports; the second is pollution control regulations applicable to toxic and hazardous processes and waste (Devas and Rakodi 1993). Therefore, there is a need for locally-based legal models. However, it is important to study previous experiences around the world and adopt the most appropriate models, which can be adapted to local conditions as there will be lessons from these experiences.

There were some endeavours in the USA, between 1970 and 1980, to manage urban growth by applying some laws such as provisions in zoning ordinances to limit the extent and direction of the growth of the cities to a certain number of dwelling units per year. Other provisions applied to protect agricultural land from being exhausted by urban growth. Eisner et al. (1993) claimed that these provisions were a separate part of the comprehensive plan and were supported by separate ordinances rather than by zoning. Some counties in the USA adopted some regulations to permit urban growth only in or adjacent to the existing development and then only if the developers provided the fund to establish essential infrastructures. The UK experience is providing a better example as the greenbelts around the cities have been quite successful in limiting urban growth as shown in section 8.8.2.

8.5.5 Effective land development policies

Land development is an essential part for any urban growth management plan. Continuous urban growth results in an increasing demand for land, which makes prices rise. Therefore, land becomes a source of profitable investment, which leads urban land in some cities to be well beyond the affordability of even middle class families. Thus, improving access to the urban land market would have two advantages; first, improving the housing situation and economic prospects; second, direct urban growth to the appropriate land which will protect the valuable land (Payne 1999) leading to sustainable urban growth.

Some governments have tended to adopt one of two approaches to manage urban land market; land nationalisation and tight regulations. For example, in Egypt, after the revolution of 1952, the national government became a major owner of Egypt's agricultural land. Land Law No.100/1964 gave the national government the authority over urban and building areas (ElAraby 2003). Some authors understand this "Nationalisation movement" in Egypt as a way of preventing speculation in urban land by foreigners as well as by the local elite (Stren *et al.* 1989). Stren *et al.*(1989) see this movement to be inappropriate in urban land as it has completely different kinds of use from agricultural land, as urban land accommodates buildings of different types which cost far more than the land itself so they suggest a system whereby the government keeps the land ownership and allocates only the use of the land on the basis of a one hundred year leasehold. These policies failed because of the absence of key urban actors and the lack of human and financial resources. On the other hand, the private sector may speculate and/or develop land to more profitable uses such as commercial or high-income residential purposes. Therefore, partnerships between public and private sectors are now being widely promoted (Payne 1999). This partnership shall maintain a balance between different and conflicting interests of the key actors of urban land market (Soliman 1999).

Public-private partnership is present in Egypt in three forms: formal (direct), informal (indirect), and hybrid. In the first form, the government delivered land in the new towns and the private sector developed it, while in the second form, the government adopted a laissez-faire policy on housing the low-income population, giving the private sector more of a role to play through informal housing. The third form involved one group consulting with others for their common benefit. The only successful form is the formal partnership as the government has the capacity and capability over the land delivery system, as it is the main owner of land in Egypt. Therefore, the government as a key player is recommended to cooperate with the other actors to implement an appropriate partnership. This appropriate partnership requires several changes in the orientation of the current land delivery systems, which includes:

(d) Establishing suitable financial means to minimise risk and maximise profits for all concerned parties,
(e) Widening the scope of planning systems to involve all markets in the system,
(f) Enhancing the institutional framework (Soliman 1999).

At a micro scale, subdivision and servicing of peripheral sites, and supply of land at low prices is one of the advocated strategies (Devas and Rakodi 1993). However, providing the basic services is a major obstacle in developing land in Egypt (Soliman 1999).

In addition, an important element in management of urban land is "concurrency" which means simply "No infrastructure, No occupancy permission". In other words, occupancy permits should never be issued before completing the needed infrastructure, i.e., roads, water, drainage lines, and solid waste disposal; and schools.... etc. Laws should not allow detrimental development that occurs without the existence of the essential services (Eisner *et al.* 1993). This policy will not be successful in Egypt case unless it is accompanied by very tough regulations and procedures to prevent informal housing that does not bother with occupancy permits.

Moreover, before developing any peripheral lands, it is strongly advised to develop intermediate lands (land left inside the city) first to gain the most benefits of the existing infrastructure and services. The UN-Habitat (1996) emphasised that in paragraph 111 of its Agenda:

> *"111. Many cities are using peripheral land for urban-related purposes in a wasteful manner while existing serviced land and infrastructure may not be adequately developed and used. To avoid unbalanced, unhealthy and unsustainable growth of human settlements, it is necessary to promote land-use patterns that minimize transport demands, save energy and protect open and green spaces. Appropriate urban density and mixed land-use guidelines are of prime importance for urban development. National, subnational and local policies and development plans must be carefully re-examined to ensure optimal land use and geographically better balanced economic development, including the protection of indispensable agricultural land; land that sustains biodiversity, water quality and groundwater recharge; fragile areas, including coastal areas; and other sensitive areas in need of protection. "*

8.5.6 Conservation and rehabilitation of historical places

A successful urban growth management programme should include conservation and rehabilitation elements for the important and historical places in any given city as this would maintain the cultural identity of the city, which makes it unique amongst other cities at both national and international levels. The UN-Habitat (1996) in paragraphs 153 and 154 of its Agenda recommended some actions to be followed in this context such as:

(a) Identifying and recording the historical sites and buildings to provide the basis for a conservation and rehabilitation plan,

(b) Integrating development with conservation and rehabilitation goals to avoid environmental degradation of historical and cultural areas.

Alexandria is an open museum and the home of countless historical places from different ages distributed over many locations in the city. Greek and Roman monuments and relics from the 3rd century B.C. to the 7th century AD such as Pompey's Pillar, The Roman Amphitheatre, The Catacombs of Kom al-Shoqafa, Al-Shatby Greek Necropolis, and The Ptolemic Tombs of Al-Anfushi are located in the city centre. Other monuments are located to the east of the city, such as The Tombs of Mustafa Kamel. The city centre also houses some Islamic monuments such as The Fort of Qaitbay and The Mosque of Abul Abbas El-Mursi. In addition, the city has great gardens such as El-Shallalat Gardens (city centre), The Antoniadis Gardens (east), and Al-Montazah Palace gardens (east). Moreover, the city has many building with unique architecture and design distributed around it. The charm of this city lies in its architecture and there are wonderful examples of Baroque, Art Deco and even neo-Pharonic buildings. *The heart of Alexandria is the old city, the cosmopolitan city. If this is not preserved, Alexandria would become indistinguishable*, warned Abu Zahra (Farag 2001). The heart of the city is heavy with modern burdens. The push for profit and high real-estate values has repeatedly beaten the concept of conservation. The most demoralizing thing is the demolishing of old villas and buildings to be replaced by new buildings with extra floors which spoil the city's beauty. Therefore, it is important to include conservation and rehabilitation elements in any urban growth management programme in the city.

Beside these land archaeological sites, Alexandria has two sites in shallow water as well. Preservation of all three sites requires an integrated and interdisciplinary approach that would include integrated urban management. Therefore, the University of Alexandria, the Supreme Council of Antiquities (SCA) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) jointly organised an international workshop on Submarine Archaeology and Coastal Management in April 1997 to preserve these sites and eventually open them to the public and scholars as a museum. This workshop claimed that there is conflict between the conservation of natural resources and economic development. However, the identification, rehabilitation and preservation of historic sites must remain a priority. A database of these sites including mapping should be compiled. Community participation is also needed in the development and implementation of the coastal management plan (UNESCO 1999).

8.5.7 Financial resources

Urban development and management needs considerable financial resources. There are different means to generate revenues but there is no single optimal tool as each means has some disadvantages. Many factors should be considered for the choice of revenue generation system such as; expected profits, population growth, and economic activities. Some authors suggested that cities should be able to finance their own development and management from internally generated resources (Devas and Rakodi 1993).

Devas and Rakodi (1993:284) suggested an approach to improve revenue generation through an integrated financial and urban management system, which may include:

"

1. *Improved budgeting based on realistic estimation of revenues, and the use of demand projections, appropriate standards and unit costs of providing for the recurrent costs of expanding basic services.*
2. *Regular revision of user charge tariffs.*
3. *Improved systems of revenue administration including effective enforcement action against defaulters.*
4. *Decentralisation of budget management to operational levels, where service branches are likely to be more responsive to local needs and problems and be able to deploy resources more effectively.*
5. *A greater concern with the cost-effective provision of services and with 'value for money'.*
6. *Clearly defined and measurable performance targets to which service managers and revenue administrators can be held accountable.*
7. *Greater transparency of decision-making over the allocation of financial resources and about the use of subsidies, with clearer identification of the costs of benefits of particular services and activities."*

It is important to create a stable and strong financial base for urban development, as The UN-Habitat (1996) suggests:

"158. To establish an effective financial base for urban development, Governments at the appropriate levels, including local authorities, in cooperation with trade unions, consumer organizations, business, industry, trade organizations and the financial sector, including the cooperatively organized business sector and non-governmental organizations, as appropriate, should:

> *(a) Formulate and implement financial policies that stimulate a broad range of urban employment opportunities,*
>
> *(b) Encourage the formation of new public-private sector partnerships for institutions that are privately owned and managed but public in their function and purpose, and promote transparency and accountability of their operations."*

In addition to that, the UN-Habitat (1996), in paragraph 189 of its Agenda, implied the importance of making significant efforts in improving the economy at both national and local levels to provide a strong base for urban growth management by adopting the following:

(a) Supporting the capacity of local authorities to attract investments especially in urban development projects,
(b) Promoting increased savings and facilitate their use in housing activities,
(c) Improving national and local tax collection capabilities and expenditure control to control costs and enhance profits, and
(d) Application of full-cost recovery concept for urban services, with the exception of public safety services.

It is recommended that the city should raise its revenues through an effective land and property taxation system so that it can manage and control urban growth effectively. In Alexandria (and Egypt in general), there is a tax for building called "returns" (Alawaaed), but this tax does not provide enough profit to fuel the city budget. It is recommended for Alexandria and any other city suffering from an urban growth challenge to have a categorised taxation system for land and property. The suggested system would have two objectives; the first is to increase the profits through a comprehensive taxation system, the second is to direct and control urban growth. This system may offer reduced rates where the urban growth needs to be directed and high rates where the urban growth requires being restricted. The zoning plan will contain the areas where urban growth is prohibited and another tax category may be applied according to the type of land use. The suggested taxation system may rely on GIS technology to produce up-to-date cadastral maps and to update maps as well when needed. An efficient registration system, regular assessment of property values collection of taxes, and sufficient political support are essential requirements for system success. Moreover, land taxes may be used to prevent speculation by applying high rates in case of frequent transactions of undeveloped land such that used in Malaysia with the Property Gains Tax Act 1976. Also, there are wide resources to generate revenues at the city level such as entertainment, vehicle, and some utilities taxes (Devas and Rakodi 1993).

8.5.8 Rural and regional development

A key factor of managing urban growth is not just trying solving the problem locally in the affected area(s), but the solution should adopt an integrated approach that can deal with the problem in a boarder view at national, regional, and local levels and also between urban and rural areas. Cullingworth (1997) after the review of urban growth management policies in the USA claimed that these policies could not be satisfactorily planned and executed on a local basis, as a regional view is essential. Improving the quality of life in human settlements considering regional scale of policy requires improved agricultural technologies, economic diversification, expanded employment opportunities, and infrastructure and basic services provision (UN-Habitat 1996).

In Egypt, it is recommended also to develop rural areas, especially in Upper Egypt, to reduce internal migration and this should be applied at national, regional, and local levels. Some attention should be given also to the capitals of rural governorates so that it may encourage their people to stay instead of moving to central urban areas. Creating opportunities and providing needed services in the rural areas would increase rural productivity and this may lead to reduce the flow of migrants and even open the way to the migrants from over populated urban governorates. Feedback of internal migration currents can be clearly followed in Alexandria, as there are some indications for that as we have noticed in Chapter 3 "Demographic Characteristics of Urban Growth in Alexandria".

8.5.9 Sustainable urban development

Meeting the current and future needs of urban population should not produce a threat to sustainability of the development. Therefore, sustainable urban development, sustainable urbanisation and sustainable cities have become frequently used concepts in the literature since the 1990's. Sustainable urban development means that urban planning is directed to minimise travel needs, promote public transportation, conserve fertile agricultural lands, avoid wasting sensitive and non-renewable ecological resources and enhance energy savings in building designs and layouts. In other words, sustainable urban development may be understood as the maximisation of efficiency in the use of resources, maintaining natural resource, and social equity in the distribution of development costs and benefits (Keles 2001).

Sustainability will be achieved by giving much attention to the environment, so it is important to integrate environmental consideration into urban management and development through an integrated approach to managing natural resources as a whole. Different kinds of waste (solid, liquid, and gaseous), which are produced from different urban activities, affect the city environment and its surrounding area. There is a need to increase the ability of public authorities to deal effectively with these environmental problems (Devas and Rakodi 1993).

Sustainable city requires an integrated decision-making framework and a fundamental shift in traditional approaches. Therefore, there is a need for a change in focus from curative measures such as pollution reduction and end of pipe treatment to the measures that based on anticipation and prevention, from consumption to conservation, and from managing the environment to managing rising demands on the environment. Therefore, it is necessary to provide a framework for guiding the spatial development of human settlements. Implementation of such frameworks is a shared responsibility of different levels of government, particularly the local authorities, the private sector, the business community and the local people (Keles 2001).

Also to achieve sustainable urban development, there should be an equitable access to urban resources as inequalities of purchasing the necessary elements of urban life such as food, energy, water, and land, lead to malnutrition, informal housing on even the most dangerous sites, and illegal access to electricity and water. These necessary elements of urban life must be incorporated into regional development planning for the cities and their hinterlands. To maintain these resources, there is a need for environmental audits. Increasing the environmental awareness of existing public authorities is likely to be much better than establishing new ones so long as the environmental impacts and sustainability are incorporated in all policies at the different levels of planning (Devas and Rakodi 1993).

Rees (1988 cited in Devas and Rakodi 1993:291-292) concluded that; *"a combination of regulation, monitoring and persuasion is needed for pollution to be tackled successfully."*

Alexandria faces a significant challenge to achieve sustainability. 355,000 cars crowd streets designed to assimilate only less than a third of this size. Pollution pervades the city, as more than 40% of the nation's industry is located in the city. Many plants have yet to comply with the environment laws. As a result, the areas of King Maryout, Al-Max and Abu Qir have been identified as international hot spots in terms of environmental disasters. In addition, the city is blamed for a staggering 30% of the Mediterranean's pollution. The city's produces about one million cubic metres of sewage daily. About half of this amount (400,000 m^3) is discharged raw into the Mediterranean Sea, while the remainder (600,000 m^3) is released into the already over-polluted Maryout Lake after only primary treatment (Farag 2001).

Sustainable urban development requires an integrated and multidisciplinary approach, combining aspects of participatory land-use planning, pollution control, transport planning, environmental impact assessment, economic instruments, administrative reform and public education. Appropriate land-use planning can provide substantial environmental benefits ranging from better living environments to lower greenhouse gas emissions (Keles 2001). In case land use planning fails to achieve its location objectives, it often pushes low and medium income households to the city's peripheries. This leads to conversion of agricultural land into informal housing that can be damaging for sustainable development as the case in Alexandria nowadays.

8.5.10 Easy access to information and data

In the global village, we live in, information and data are the sinews of effective decision-making. Therefore, we need accurate and up-to-date information and data about urban growth problem(s) to deal with it effectively. This will be achieved by developing, upgrading and maintaining information technology infrastructure and encouraging their use by all levels of key actors, i.e., government, public institutions, civil society organizations and community-based organizations. This should be accompanied also by providing the necessary training for all key parties. These reforms will not be effective without supporting policies that make information technology available and more accessible to the public. These reforms also must provide free flow of information to increase the knowledge available to all interested parties. Specifically, these reforms must promote research on economic, social and environmental aspects related to urbanization and its problems, focusing on research priorities that would be identified from national requirements. Meanwhile, it is important to adopt efficient and sustainable methodologies developed by systematically incorporating research results and by compiling, analysing and updating data for urban areas. This includes also the dissemination of research indicators and mainstreaming their results in policy-making at all levels and ensuring a two-way flow of information between producers and users of information (UN-Habitat 1996).

8.5.11 Using GIS, remote sensing, and modelling in urban planning

Traditional planning practice in general is often criticised by slow processes and reactions, poor quality products and this planning lag is due to poor technology utilization (Nghi 2003). Planning and managing cities in the new era of globalisation and economic liberalisation would be a demanding task calling for new skills and approach (Patkar 2002). The continuous urban growth is inescapable and irreversible. Therefore, it is necessary and fundamental for policy makers to make technologies like GIS and remote sensing essential for the urban planning (Uttarwar 2004).

Geographical Information Systems (GIS) are computer aided decision support and planning tools that integrate different data formats and other auxiliary data for a geographical area of interest. They can be used to create and maintain geographic databases and are very suited for what-if-analysis in any planning related activity. By querying the geographic database in several ways, the planner can present the available information in a variety of formats: as printed tabular reports, graphically as map display, and map outputs on paper (Jere and Sarin 1998). GIS has a record of accomplishment in handling urban information, especially in the field of urban planning (Han and Kim 1990;Mohd Zaki 1998; Laurini 2001; Brail and Klosterman 2001). The benefits of GIS to planning activities can be summarised in three categories:

- Spatial mapping: GIS tools can provide digital map processing instead of traditional drafting methods.

- Spatial query; GIS queries functions can help planners to obtain quick response to single or multi-level query(s) about objects, themes using stored map data and statistics.

- Spatial analysis and modelling; GIS can help in by different ways, e.g., identifying best sites for potential development, protection of sensitive areas using buffer function, best route definition, and predicting future land development.

A key function of planning is the projection of future population and economic growth. GIS can be used for prediction and projection (Longley *et al.* 1994). GIS can be used to forecast the future impact of development on the environment if the current trends continue. This can be implemented by the projection of future demand of land resources from population and economic activities, modelling of the spatial distribution of such demand, and then using GIS map overlay analysis to identify areas of conflict. With the socio-economic and environmental data stored in the GIS, environmental planning models have been developed to identify areas of environmental concern and development conflict (Schuller 1992). GIS can also model different development scenarios (Yeh and Li 1998; Li and Yeh 2000). Planners can use such information to formulate different planning options and help guide future development so that they avoid such conflicts (Yeh 2002).

GIS is being used in planning agencies in both developed and developing countries. Many planning departments have shifted to GIS in lieu of mapping software. The decrease in the price of hardware, computer storage and peripherals, and accompanying improvement in the performance of hardware and software and advancement in the data structure, has made the once expensive and time-consuming GIS more affordable and workable (Yeh 2002).

At international level, United Nations Development programme (UNDP) utilised GIS in urban planning and city management in Kigali, Rwanda. The major aims of this project are building a decentralised capacity for effective functioning, and strengthening of institutions responsible for urban management and local resource mobilisation in Kigali. In addition, this project aimed at the transfer of demand-driven local initiatives while at the same time contributing to good governance, sustained public-private partnerships, community participation and responsible resource management. Application of GIS in this project has integrated different professionals into a single framework, which made urban planning and management of Kigali easier and more practicable. Moreover, this system provides the capability of responding adequately to rapid urban growth with possible scenarios for resolving urban problems (AIBINU 2001).

The increasing demands in urban planning and management sectors call for co-ordinate application of remote sensing and GIS for sustainable development of urban areas. There is an urgent need to adopt remote sensing and GIS approach in urban development, and monitoring process for implementing urban development plan. Remote sensing data provides reliable, timely, accurate, and periodic data, while GIS provide various methods of integration tools to create different planning scenarios for decision-making (Tiwari 2003).

Patterns of sprawl and analyses of spatial and temporal changes can be detected cost effectively and efficiently with the help of spatial and temporal technologies such as GIS and remote sensing. GIS and remote sensing are land related technologies and are therefore very useful in the formulation and implementation of the land related component of the sustainable development strategy. The different stages in the formulation and implementation of a sustainable regional development strategy can be generalised as determination of objectives, resource inventory, analyses of the existing situation, modelling and projection, development of planning options, selection of planning options, plan implementation, and plan evaluation, monitoring and feedback. GIS and remote sensing techniques are developed and operational to implement such a proposed strategy (Sudhira *et al.* 2003).

GIS, when integrated with remote sensing, can save time in collecting land use and environmental information. Remote sensing image are becoming an important source of spatial information for urban areas. Moreover, integrating GIS with high spatial resolution remotely sensed data found very useful in some countries for evaluating urban growth scenarios (Paulsson 1992). Remote sensing and GIS technologies offer tremendous advantage in carrying out land-use planning and management activities (Patkar and Kumar 2004).

Moreover, The integration of GIS with advanced urban models, such as cellular automata has enabled planners to make use of the data and geoprocessing functions of GIS to evaluate and develop different planning scenarios (Li and Yeh 2000)

Urban modelling can support and enhance urban planning processes and outputs generally and urban growth management specifically if necessary data and tools are available. For example, zoning plans or any other planning activities and regulations can be incorporated into modelling processes to produce future image based on certain planning parameters.
The relationship among remote sensing, as a high-resolution input, GIS, as a high-technology analytical tool, and urban modelling as a very-complicated programming environment, cannot be neglected if enhancing urban planning generally and urban growth management specifically is desired.

8.5.12 International cooperation

Urban growth, beside other problems in developing countries, needs a huge capacity of different resources to deal with it. These needed resources are beyond the capacity of most, if not all, developing countries. Indeed, financial resources come in the front of the queue, but there are also other resources such as information, technology, and experience. As we are supposed to live in one world or small village according to "Globalisation", any side effects of any problem in any site in the world may have its negative impacts in other sites in the world. There are many examples to mention to confirm this principle, such as economic deceleration, international immigration, and terrorism. Therefore, it is important to emphasise the role of international cooperation not only in managing urban growth problems only, but also in other problems as well.

This international cooperation should not be a one-way approach but it should be mutual where each part of the world can exchange something with the other parts. Developing countries are becoming the best sites for transcontinental and international enterprises because of many factors such as cheap labour. For example, if you check the label of any famous brand of sport wears and shoes such as Nike and Adidas, you will find these products are being manufactured in developing countries such as Indonesia and Vietnam and are being exported again to the developed countries. This small example shows that there is a way that developing countries can contribute in international integration. Therefore, it is important to develop innovative approaches and frameworks for international cooperation in the urban growth management. These approaches and frameworks should include new and improved forms of cooperation and coordination between and among countries, multilateral and bilateral assistance agencies, international financial institutions, international organizations, and bodies of the United Nations. These innovative approaches should not only promote international cooperation but also include new forms of partnerships and cooperation involving civil society organizations, the private sector and local authorities (UN-Habitat 1996).

The international community should support governments in their efforts to cope with the impacts of urban growth problems within a framework of enabling strategies by providing an international financial system that is encouraging to economic development, social development and environmental protection, as components of sustainable development to ensure that the benefits of global economic growth improve people's quality of life in all countries. In addition, the international cooperation must enable developing countries to attract and promote investment especially in housing. In the same context, it is important to link local authorities, the private sector and relevant organizations with global capital markets and to have access to financial markets to finance housing and infrastructure for sustainable human settlements programmes. Financial resources are important but are not the only needed support. Technology transfer, best practices dissemination, and experience exchange, especially in policy responses, are urgently needed to face the challenges of urban growth (UN-Habitat 1996).

8.6 Urban plan types

Before starting the discussion about urban plans assessment in Alexandria, it is instructive to refer to the types of urban plans to understand what type of plan has been used in the city. Urban plans can be categorized into two groups: traditional and new plans. Traditional plans include general, comprehensive, master, and zoning plans. New plans emerged to cover some of the shortcomings of traditional plans. These plans include structure, action, and strategic plans. In the following, a brief discussion for both kinds of plans will be introduced.

8.6.1 General Plan

A general plan is long-range and comprehensive planning by the government as a base for the whole land development policies within a specific geographical context (Eisner *et al.* 1993).

8.6.2 Comprehensive plan

> *"The comprehensive plan is a guide to orderly city development to promote the health, safety, welfare, and convenience of the people of a community. It organizes and coordinates the complex relationships between urban land uses and many civic activities. It charts a course for growth and change. It expresses the aims and ambitions of a community, delineating the form and character it seeks to achieve. It reflects the policies by which these goals may be reached. It is responsive to appropriate change and for maintaining its essential vitality and is subject to continual review. It directs the physical development of the community and its environs in relation to its social and economic well-being for the fulfilment of the rightful common destiny, according to a "master plan" based on "careful and comprehensive surveys and studies of present conditions and the prospects of future growth of the municipality, and embodying scientific teachings and creative experience." (Eisner et al. 1993:245)*

The comprehensive plan should be driven from a national general plan to manage urban growth and redistribute population to achieve healthy urban development. This comprehensive plan should consist of zoning plans, policies, and laws by which effective urban growth management can be achieved. It is important to produce a comprehensive plan to manage urban growth. A comprehensive plan is the basis for planning. Therefore, all zoning and other planning activities must be consistent with both the intent and the purpose of the comprehensive plan (Eisner *et al.* 1993).

8.6.3 Master Plan

A master plan is a state plan which rely on central government resources and public agencies. This type of plan is valid in case of the following conditions; slow growth, high incomes, and effective enforcement practices (Clarke 1994). Moreover, a master plan requires a long time (years to decades) and high cost in preparation. Specifically in the developing countries, this type of plan is inappropriate as urban growth is characterized by low-income population that swallowed governmental resources especially at the city level (Clarke 1994). Master plan making is a technocratic process rather than political process, which leads to rejected policies by politicians and community.

8.6.4 Zoning Plan

Zoning involves defining single or limited use for land parcels for housing, commercial, industrial and other land use activities using ordinances and codes(Clarke 1994). Zoning received many criticisms as it is reactive and timeless (Cullingworth 1997). Therefore, the traditional concept of zoning underwent some recent approaches such as mixed-use zoning, floating zoning, conditional or contract zoning and phased-zoning to overcome the limitations of the usual zoning. Mixed-use zoning means allowing integrated land use activities in the plan. Floating zoning means preparation of development performance standards for the area by zoning ordinances but these are not placed on the zoning map until the need evolves. Conditional or contract zoning means the city will provide permission to develop certain land (e.g., for commercial use) under the condition of developing other land for public benefit such as parks. Phased zoning means no development before permission is granted. Zoning techniques are important tools in land regulation but need to be flexible (Clarke 1994).

8.6.5 Structure plan

This plan emerged in UK in 1968 to tackle a wide range of social, economic and physical development providing more flexibility for local plans preparation. This plan can be effective if it is action-oriented with clear definition of the recommended sites for urban growth. However, this plan has two shortcomings: first, the conflict resulting from the separation of responsibilities between the country and local authorities. Second, the limited role of structure planning to land use issues which means marginality of new urban concerns such as economic decline and social deprivation (Clarke 1994).

8.6.6 Action plan

Action plan deals with problems at a local level encouraging public participation as a key element for success. This plan should be treated as a process of the whole planning activity not a product, to avoid the risk of creating uncoordinated projects which do not deal with the intended problems (Clarke 1994).

8.6.7 Strategic plan

This plan is a set of unified strategies for city development including all necessary elements such as land development, infrastructure, financial resources, therefore, this plan is considered as a participatory approach to integrated urban development to achieve growth management (Clarke 1994). Various countries adopted different urban plans such as general, comprehensive, master plans. However, the shortcomings of some of these plans show the need for new plans that address these inadequacies. Structure, action, and strategic plans were introduced as new forms of planning. Although, these new plans deal with the limitations of the traditional plans, these also have some shortcomings. In the following sections, urban planning in Alexandria will be assessed and evaluated.

8.7 Assessment of urban planning in Alexandria

As urban growth started to appear as a significant phenomenon in the beginning of the 20th century, the municipality of Alexandria in 1918 started to feel the negative impacts of that early urban growth. Therefore, it deputed Mr McLean to prepare a plan to improve the city generally and he finished it in 1921 (Abdel-hakeem 1958). One of the benefits of the McLean plan was drawing attention to the necessity of manage future urban growth according to a well-structured plan (Abdel-hakeem 1958). Since that time up till 1955, there was not any information about any official plan for Alexandria. However, Egyptian Keynote geographer Abdel-hakeem (1958) in his important book "*Madinet Alaskandrya*" or "Alexandria City" suggested a plan for the city. This plan contains many elements to manage urban growth in Alexandria. It is instructive to highlight some important elements of his suggested plan. His plan will be called here Alexandria Plan (1958).

8.7.1 Alexandria Plan (1958)

Abdel-hakeem (1958) expected that the urban development in the next fifty years from 1955 onward would continue towards the eastern and southeastern areas rather than the western and southern areas and this would consume the agricultural lands as we have learnt in chapters four and six. Therefore, he suggested the eastern and the southeastern administrative borders of the governorate in 1947 to be the control line of urban development (Figure 68), as the urban development did not reach these borders at that time. He suggested not offering any building permissions beyond this control line (Abdel-hakeem 1958).

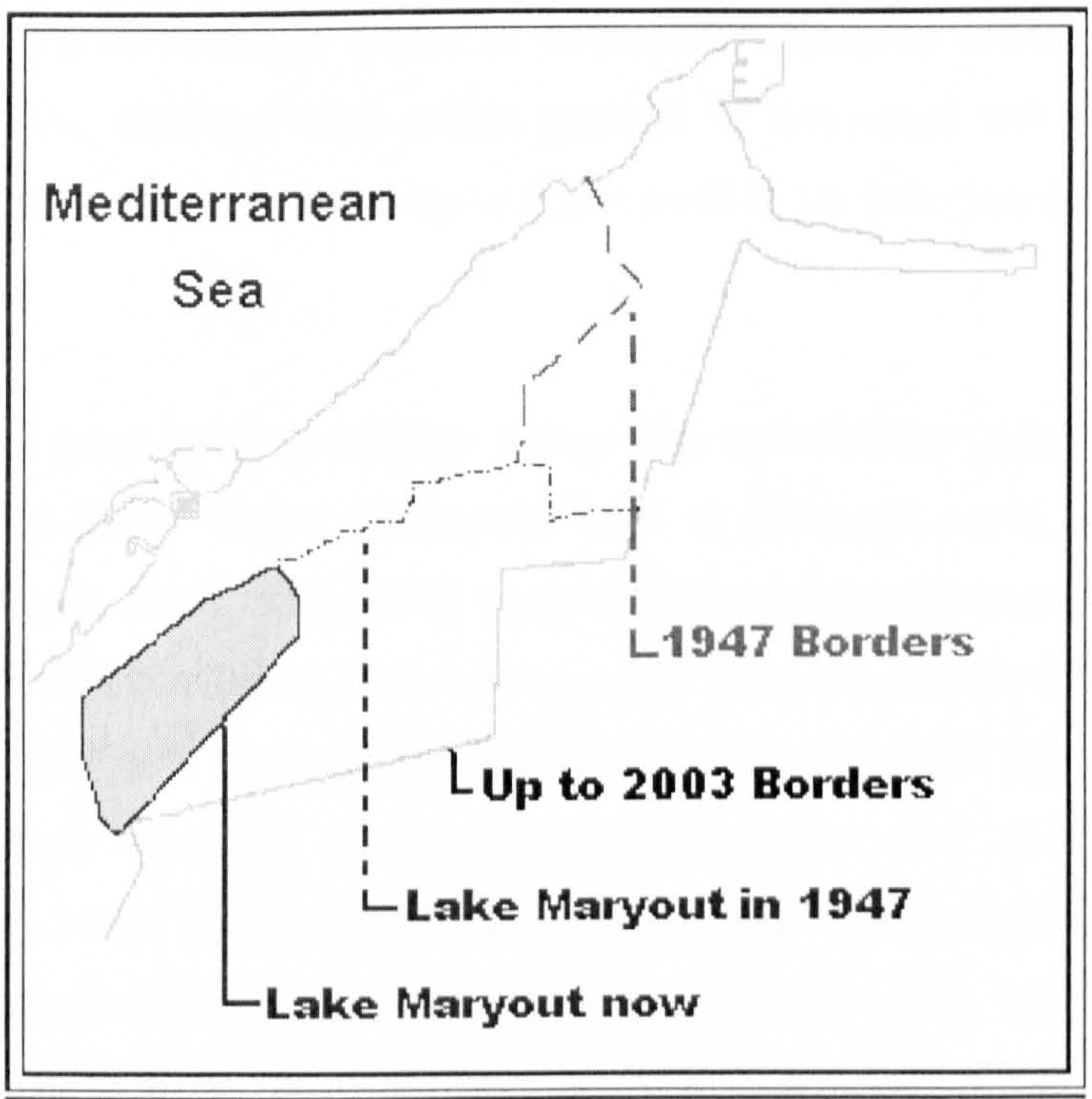


Figure 68 Alexandria eastern borders in 1947 and 2003

His expectations became true not only in the eastern and southeastern areas but also in the western and southern areas by the way that is presented in chapters four and six of this study. This can be explained in the light of his demographic projections where he expected the population of Alexandria would be 2.696 millions in 1997 while the total of population of Alexandria is

3.339 millions in 1996 (chapter three). In that case we understand why the urban growth extended also to the western and the south-eastern areas especially when we learn that urban development over the agricultural lands is prohibited by laws, even though, there are scattered informal urban development in these areas as well (Abdou-Azaz 1997).

Another important point should be noted here; the central government from that time onward did not only give the necessary attention to his cautions regarding to agricultural lands but also it ignored it by extending these borders more and more towards the east and the south east (chapter six) (Figure 68).

He suggested also dryness of the northern parts of Maryout Lake adjacent of Ghit-aleneb and El-Werdian areas to direct the expected urban development to the west. He claimed that urban growth in the west will not have any negative impacts as there is no agricultural land to be affected (Abdel-hakeem 1958).

He suggested also moving military areas and cemeteries outside the city as they occupy a large area of valuable land in different parts, mainly in the centre of the city. Then, part of the vacant lands can accommodate part of the urban growth and the other part can be used as green parks (Abdel-hakeem 1958) as the city is in severe conditions regarding to green areas. Per capita share of green lands in Alexandria is less than $1m^2$ (0.9) when it is recommended to be $21m^2$ per capita (Abdou-Azaz 1997). Again, his valuable recommendations did not find any listening ears. In this study, we renew these recommendations, as it will help partly in managing urban growth in the city.

8.7.2 Alexandria Comprehensive Plan till 2005 (ACP2005) (1984)

University of Alexandria (1984), through the comprehensive planning project, prepared a comprehensive plan for Alexandria till 2005 according to the commission of Alexandria governorate. This plan was prepared in five stages in a total period of 20 month (Alexandria 1984);

(a) Data collection and problems definition.
(b) Data Analysis.
(c) Results, alternatives analysis, and suggestions.
(d) Recommendations and results mapping.
(e) Final report preparation.

The plan suggested twenty years for implementation divided between four five-year plans started from 1985 and finish in 2005. The plan suggested also preparing a legal framework to implement its recommendations with emphasis on establishing a formal body to monitor and follow-up the tasks (Alexandria 1984). The final report was divided into 20 chapters covering the following areas; Strategy and basis of the comprehensive plan, Alexandria establishment and its physical growth, City morphology, Demographic and social studies, Physical planning, traffic and transport general plan, Ports and Airports, Housing, Infrastructure, Education, Culture, Health services, Social affairs, Industry, Agriculture, Tourism, Conservation of historical sites, Environmental issues, Economic and financial issues, and legal framework. A map contains the recommendations named comprehensive plan was produced at the end of the report amongst other figures and illustrations, (Figure 69).

Figure 69 illustrates the main recommendations for Alexandria urban development. As a year 2005 is approaching, a follow up study will be applied to assess Alexandria Comprehensive Plan 2005 (ACP2005). The final mapping outputs of our study along with the maps of the 2017 general plan and the personal experience of the city will be used in this assessment.

The comprehensive planning Strategy in Alexandria is based on many items. Regarding urban growth management, planning of the new Amrya city in the west and the northern coast development were the urban development alternatives to meet the potential population growth (4.75 millions in 2005 according to report projections). This is to keep the valuable agricultural lands in the southern and southeastern parts away from urban growth trajectories.

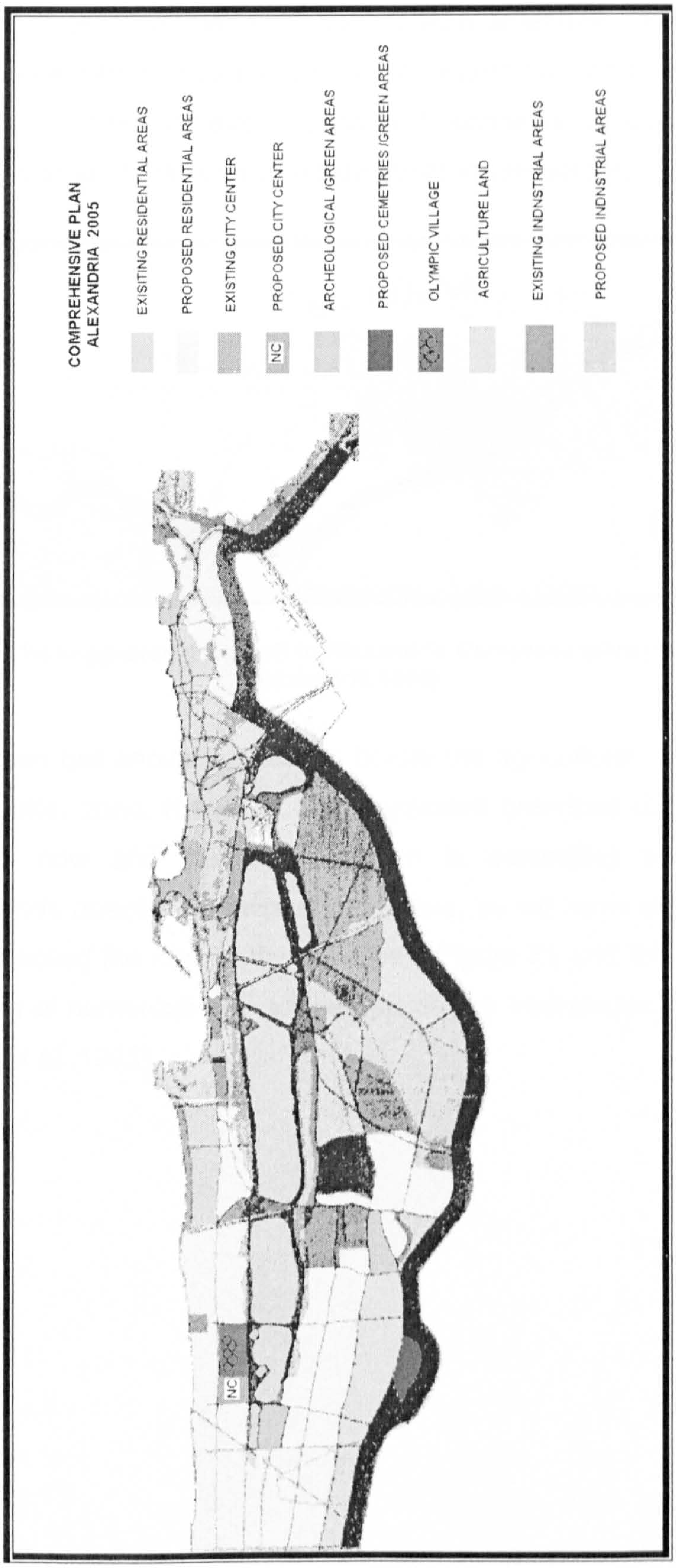


Figure 69 Alexandria Comprehensive Plan till 2005 (Alexandria 1984)

To bring this into practice, the report suggested a greenbelt (Figure 70) which agrees in general with the eastern and south eastern administrative borders in 1984 and this could not achieve its purpose to conserve agricultural lands as there is a huge area of these lands inside governorate borders (Figure 70).

Figure 70 The suggested greenbelt in Alexandria Comprehensive plan till 2005 (Alexandria 1984)

Thus, this green belt should be located before the agricultural lands leaving a reasonable buffer zone. However, this suggested greenbelt did not come to reality up to now and the urban growth is expanding consuming the agricultural lands despite the laws and decrees, as we have seen in chapter six. London applied the idea of the greenbelt, Figure 71 and this has resulted in the building of numerous new towns outside the boundaries of the London area (Eisner *et al.* 1993).

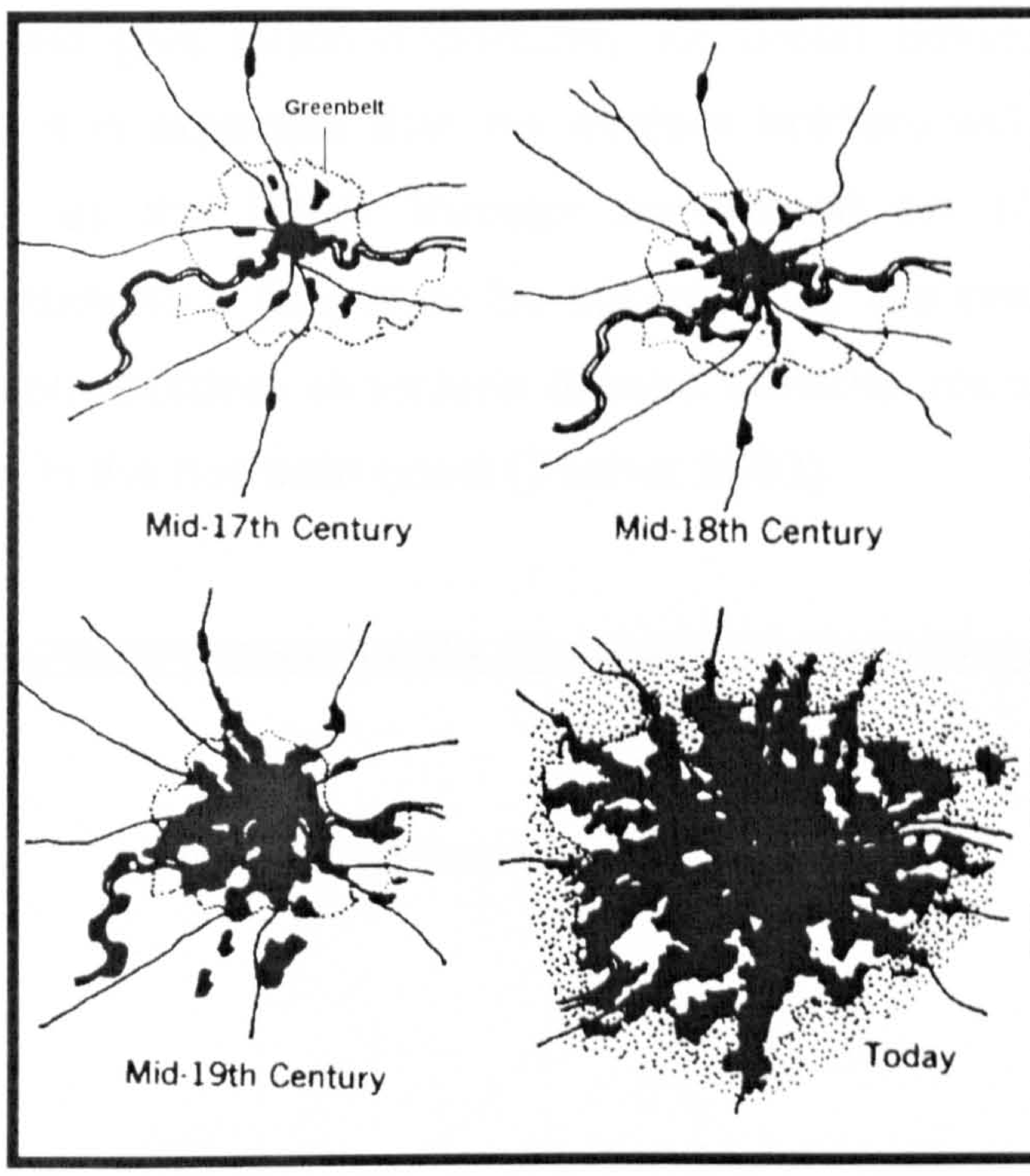


Figure 71 The impact of greenbelt on urban growth in London (Hartshorn *et al.* 1992)

Also, the report recommended two directions to assimilate the continuous urban growth,

- Re-plan Al-Amrya district in the southwest with full public utilities so that it can absorb part of population increase.

- Establish a new high-class suburb in King Maryout area in the southwestern part to be like Heliopolos and El-Maadi suburbs in Cairo. This area can accommodate about half a million inhabitants with different levels of housing (Alexandria 1984).

The comprehensive plan defined the coastal zone from El-Beetash to the sign of El-kilo 21 as a green area; in reality, this part became one of the mixed and extensive urban development sites in the governorate where you can find permanent and summer housing as well (chapters four and six).
In this context, it is important to refer to the extension of the governorate borders towards the western and the southwestern parts in 1991, according to the Presidential Decree (Figure 72). This extension was considered in 2017

Plan, and this will give much opportunity for urban development in these directions. Also, it is expected that the western borders will be expanded in the near future as the Prime Minister announced on 1/6/2003 that the government is studying a project to be approved by the president to extend Alexandria western borders to include Marina summer resort to unify urban planning system in the northern coast (Thabet 2003).

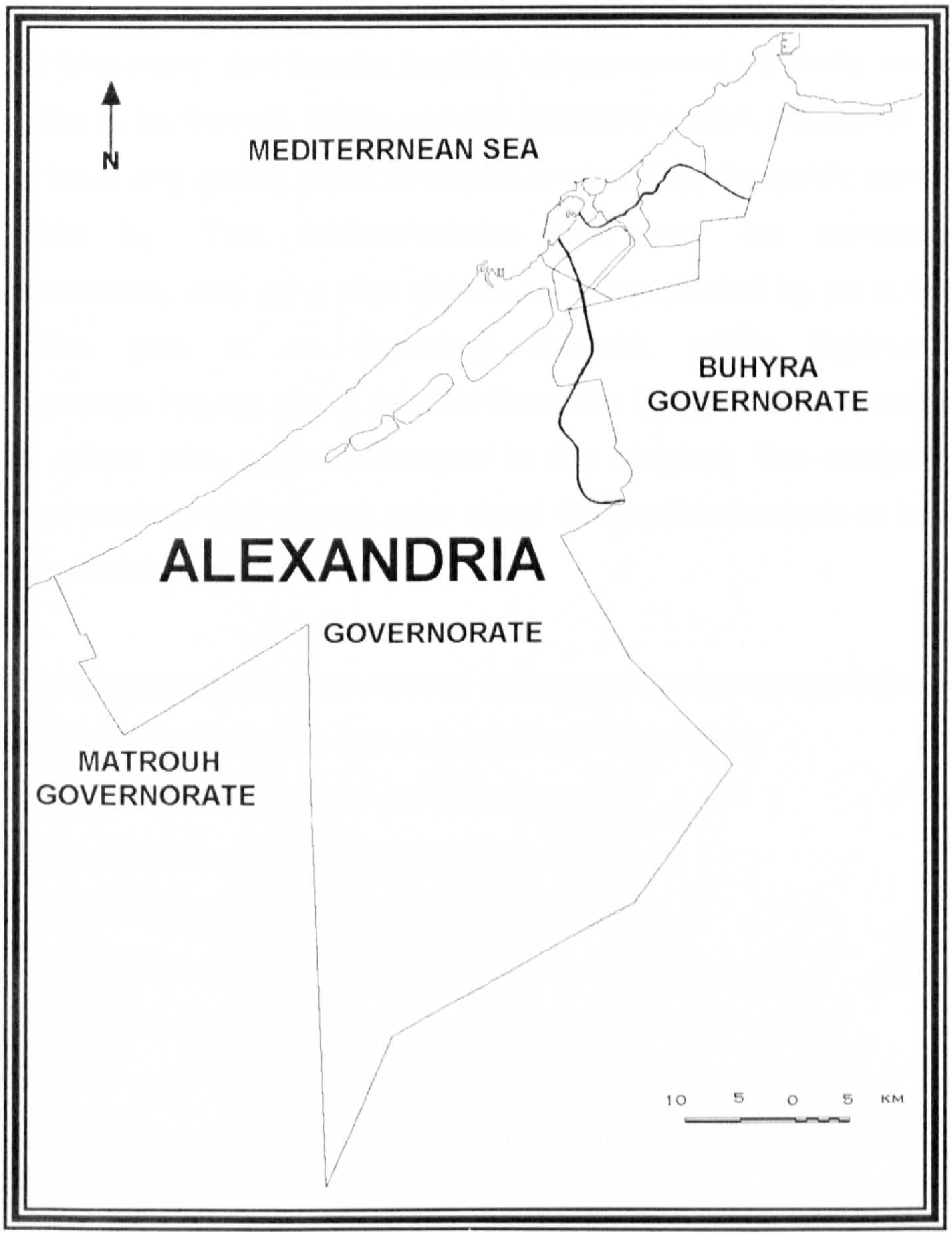


Figure 72 Alexandria borders until 2003

The report also suggested development of Maryout Lake, however, the lake did not see any organised efforts to develop it, but it witnessed only haphazard endeavours. Some parts were dried and parts of the lake in the west were used as fish farms as was shown before in the Change detection chapter. In brief, the lake became one of the environmental predicaments in the city; therefore, the need for an urban growth management programme, which contains a significant part about lake development, is necessary.

Finally, it is instructive to mention that the comprehensive plan was produced by Alexandria University for Alexandria governorate with some help from Liverpool University; that means there is no permanent authority responsible for this plan to implement, follow-up, and update the plan. Moreover, the plan does not have any zoning plans at district level so that the public can observe and abide by. This comprehensive plan can be considered as recommendations only as a plan should be accompanied by an action plan. The action plan is an important element, which represents the "Implementation Phase" with a detailed timetable for each task (lessons learnt from ***8.6 urban plan types*** subsection in this chapter). The comprehensive plan report certifies that when it talks about the legal framework to implement the comprehensive plan:

"It is prima facie to legalise the needed laws to put the comprehensive plan in implementation phase by the executive authorities such as;

1. *Definition of the lands for the different uses.*
2. *Road network planning and implementation.*
3. *Infrastructure planning and implementation.*
4. *Services planning and implementation.*
5. *Population density definition in the new and the old areas.*
6. *Built-up area density definition in the new and the old areas.*
7. *Setting the necessary laws to conserve the historical sites."(Alexandria 1984:199).*

8.7.3 General Planning of Alexandria City till 2017 (GPAC2017) (1997)

This plan was produced in 1997 by the General Organization for Physical Planning (GOPP), Ministry of Housing, Infrastructures, and New constructive societies. This plan was produced in three volumes:

1. Physical planning studies.
2. Demographic, services, and economic studies.
3. Infrastructures studies.

This plan is a strong sign of centralisation planning and can be considered as many steps backward in terms of decentralisation as Alexandrian planners were involved in the ACP2005 plan. Moreover, there was not any involvement of Alexandria governorate in this plan as all the members of the team were from the General Organization for Physical Planning (GOPP). Indeed, public participation is one of the important missing elements of this plan beside the absence of local governorate involvement, financial resources and legal framework elements as well (lessons learnt from ***8.5 recommended principles for managing urban growth*** subsection in this chapter). Thus, this plan can be considered as a general development plan rather than an urban development or comprehensive plan as the report summarised its recommendations within a *Comprehensive Development Strategy* framework. Moreover, it cannot be considered a general development plan (lessons learnt from ***8.6 urban plan types*** subsection in this chapter), as the development plan should involve many ministries and organisations; Ministry of Planning is the most important body between of these institutions as it is responsible for allocating the needed financial resources for any development task.

The main objectives of this comprehensive development plan regarding to urban development are:

1. Creation of a development axis in the western and southern parts to accommodate the potential urban growth where the population of Alexandria will be 4.604 millions in 2017 according to the probable alternative (GOPP 1997).

2. Conservation and pollution prevention of Maryout Lake.

3. Development of the northwestern coast hinterland by establishing permanent housing sites as the housing on the coast is mainly summer resorts, which are used for few months only.

8.8 Future development alternatives

It is important to not allow vertical and horizontal expansion of the main built-up area as a response to continuous urban growth as this is considered as a short-sighted response (El-Shakhs 1997) as it will lead to easy access to the existing overextended services and utilities.

> *"An alternative development process should attempt spatially to separate new urban development by green belts or reserves of open land, and create independent communities as an approach to expanding the urban land market. This approach would distinguish these communities from the core built-up area of the central city and reduce their dependence on its utilities and service systems." (El-Shakhs 1997:517)*

This approach means a typical "Urban Realms Model" which has been introduced in a Chapter Four to interpret the current situation of urban growth in Alexandria. As stated in chapter Four, Alexandria experiences currently much similarity to an urban realms model, so it is important to support this approach by covering the gap in services in the well-established areas and provide the necessary services in the potential "realms". GPAC-2017 adopted a similar concept where it suggests the so-called "Cluster Dispersal" as an alternative for future urban development (GOPP 1997). This concept is aimed at delimiting the growth of the old urban core and direct urban growth to the current and potential nuclei around the original city in the southern and south western areas to achieve the so called "Greater Alexandria Development" (GOPP 1997), (Figure 73).

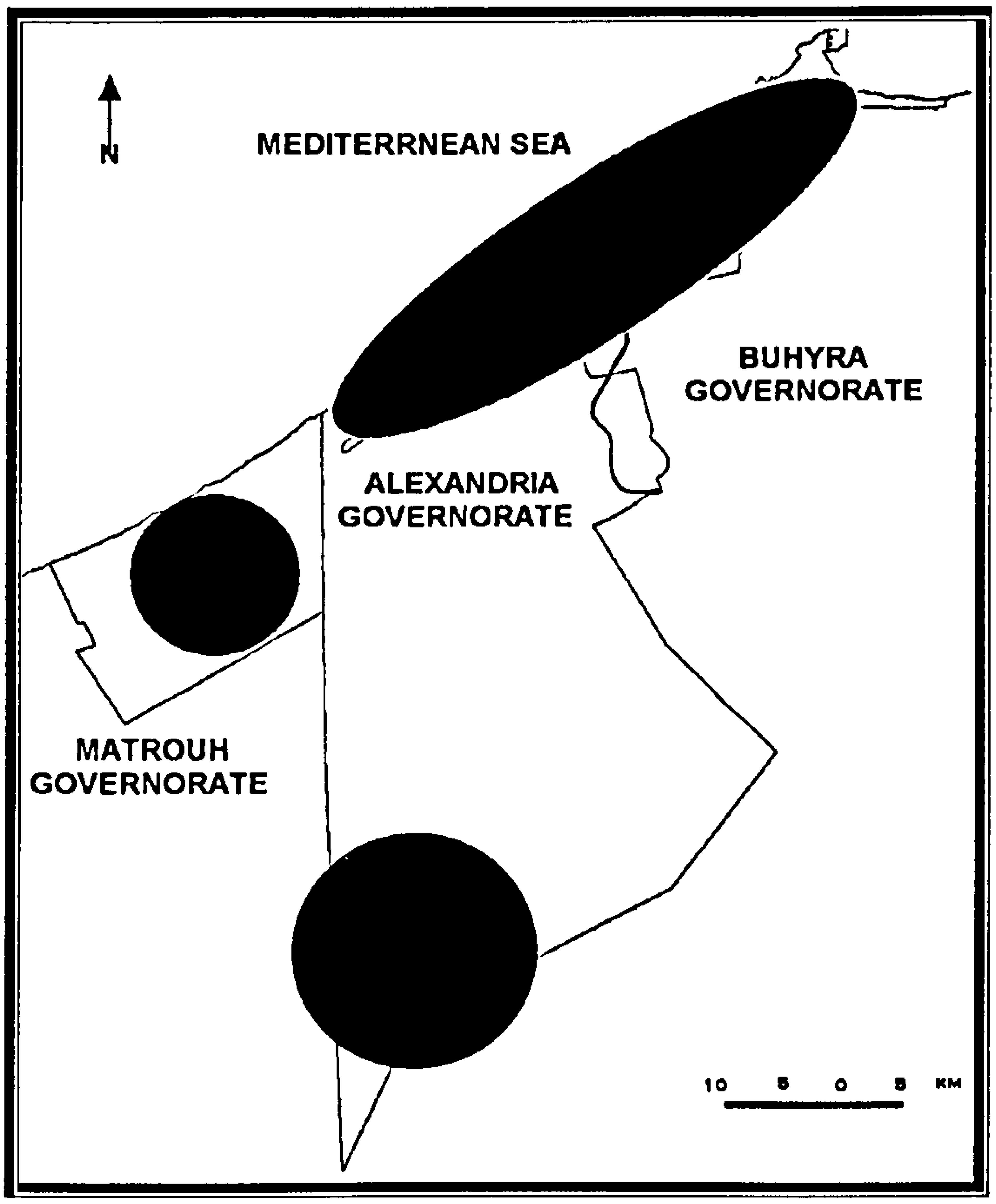


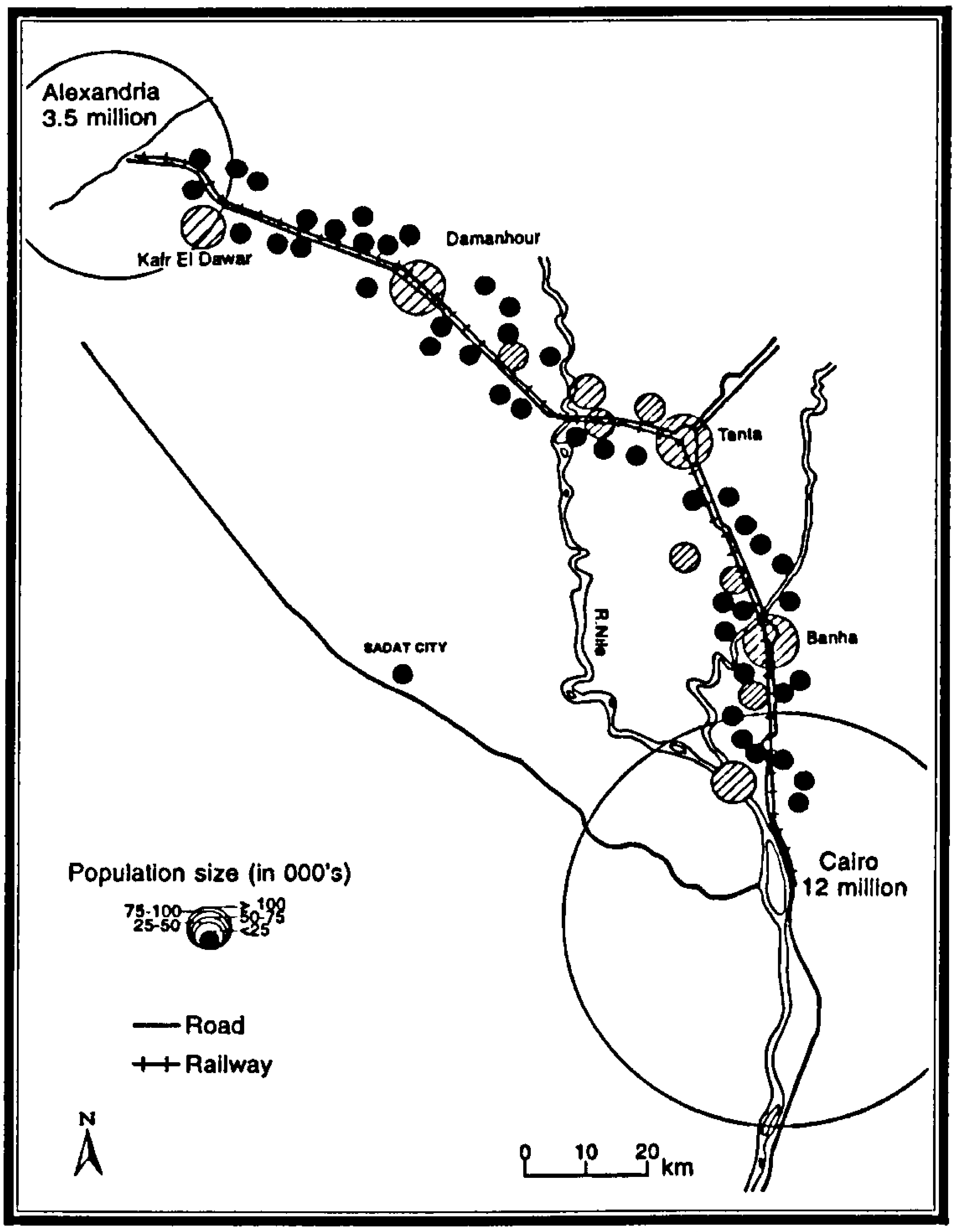
Figure 73 Cluster Dispersal development alternatives for Alexandria till 2017

Meanwhile, management of urban growth plan should be part of regional development policies meant to reduce growth pressures on the central city by promoting the development of a hierarchy of regional intermediate and small urban centres (El-Shakhs 1997) such as Al-Amrya, King Maryout, and Burg Al-Arb.

In addition to the previous development alternative, some planners expect an extensive urban corridor may appear along Agricultural Road between Alexandria and Cairo as (Yousry and Atta 1997:146-147) described ;

> *"Along the road from Cairo to Alexandria, which extends for 220 km, lie five large cities namely Banha, Tanta, Kafr El Zayat, Damanhour, and Kafr El-Dawar, and a number of medium and small towns and villages,* (Figure 74). *These urban centres are interrelated and affected heavily by the zone of influence of the two major poles of Cairo and Alexandria. They have experienced high rates of growth during recent decades*

both in population and in area. If these settlements continue to grow at the same rate, in a few years an extensive urban corridor may appear along this regional road and a new megalopolis area may emerge either along the whole corridor between Cairo and Alexandria or, at least, between Cairo and Tanta. Such a metropolitan area would house almost half of the Egyptian population."



**Sadat city was added to the map by the author*

Figure 74 Settlement size and distribution on the Cairo-Alexandria road (1994) (Rakodi 1997)

It is important also to mention here another development axis where there is an ongoing extensive agricultural development with other activities along the Desert Road between Alexandria and Cairo. Therefore, it might be called the "Green road" or "New agricultural road" instead of "Desert road". Some new cities such as Sadat city, 6th October City, and Nubaraya city are located on the Desert road and compete with each other and with old cities to attract development to this area as well. Therefore it is advisable to give particular attention to this potential growth as the previous experience indicates that the development of such urban regions is inevitable (El-Shakhs 1997).

8.9 Summary and Conclusion

Urban growth management is part of planning activity which itself is part of urban management. Different countries of both developing and developed worlds have adopted many strategies to tackle urban growth. Regardless of the failure or success of these strategies, it is important to admit that there is no single strategy that can be applied in all urban areas. Therefore, urban communities should learn from different experience and produce their own local initiatives.

Reviewing urban growth management principles reveals that this problem cannot be dealt with at a single level. Urban planning in Egypt needs much practice for *Decentralisation*. Urban growth management needs also effective urban governance by providing the necessary skills and abilities to intervene efficiently in the process of urban development. Public participation is the key-missing element in urban planning in Egypt and it should be initiated to secure the success of urban growth management. Any plans to manage urban growth will not be applied in the absence of a legal framework. This framework may not need new laws but it may require just simplification and clarification to be active. Effective land development policies are amongst the important elements of managing urban growth. There are many policies that can be applied to achieve that. Managing urban growth needs to give more attention to conservation and rehabilitation of historical place to preserve the identity of the city. All the plans for urban growth management require a great deal of financial resources. The search for more resources is a very critical issue. These resources need to be permanently based on a strong and stable economy. Management of urban growth needs to be part of national and regional development to avoid any potential pitfalls. Also, the urban development should be sustainable to save the environment. Better planning requires better access to information and data to give better chance to characterize the problems accurately which lead to better alternatives to solve it. Using GIS and remote sensing can enhance planning activities generally and urban growth planning especially as the integration between GIS and remote sensing have been found very useful in monitoring and modelling urban growth. These principles of urban growth management will not be achieved unless a great change occurs in the democratic practice (El-Shakhs 1997). Beside the need for democracy, there is another need for international cooperation as well, not only in financial resources but also in the experience and technology.

Reviewing available urban plans in Alexandria reveals some interesting findings. A key Egyptian geographer introduced many recommendations about 50 years ago and, if they were implemented, they might help the city nowadays. But these recommendations did not receive any attention, even when the Alexandria University prepared Alexandria Comprehensive Plan till 2005. This plan was not part of a general attitude to plan the city growth so we have not seen any signs of practical application of its recommendations. The most recent plan is the General Planning of Alexandria City till 2017 (1997), this plan is another mark of central planning which did not involve local authorities and people, and it did not include the financial resources, legal framework, and implementation plan as well. Thus, this plan cannot be considered as a general development plan or urban development or comprehensive plan as the report summarised its recommendations within a *Comprehensive Development Strategy* framework. It cannot be considered a general development plan, as the development plan should involve many ministries and organisations. However, this plan introduced the so-called "Cluster Dispersal" as an alternative for city development to control the growth of the old city and encourage people to move to the current and potential nucleuses. This concept agrees with the urban realms model that was presented and applied in chapter four. Finally, what do we need to manage urban growth in Alexandria? We need a locally based authority to be responsible for managing Alexandria's urban growth within a framework of national policy. It should be an integration and cooperation between the local and national authorities. This local authority should have the full capacity and resources to plan and implement urban growth management projects and recommendations with a great deal of public participation to secure the success of such potential plans.

In sum, this study introduces an approach to manage urban growth by monitoring and modelling urban expansion using conventional and innovative methods and data. The following chapter will highlight the most important findings and recommendations for the benefit of both policymaking and research.

9. CHAPTER NINE: FINDINGS, RECOMMENDATIONS, AND FUTURE RESEARCH

9.1 Introduction

The first part of this chapter underlines the key findings of this study, while the second part introduces the recommendations that emerged during the different phases of the research for the benefit of policy making and future similar studies. The last part outlines the propositions of further and future studies.

9.2 Findings

The findings of this study are grouped in two parts: general findings, satellite images, and GIS analysis. This section, in general, highlights the answers to the earlier research questions listed in chapter one.

9.2.1 General findings

- ***What are the demographic characteristics of urban growth in Alexandria? (1st research question)***

In spite of the continuous quantitative increase of the population of Egypt, there is a decreasing trend in urban population where the percentage of urban population became 43% in 1996 compared with 44% in 1986. In the same context, the percentage of urban governorates population became 18.68% in 1996 compared with 20.15% in 1986. This interesting finding may indicate the beginning of an "Urban decline" era in Egypt if this decrease will continue.

Alexandria had experienced fluctuating population growth for about twenty centuries during its long history from 200 B.C. up to 1828 A.D. The city started to see continuous urban growth from 1897 until present. This demographic growth is expected to continue up to the near future. The population of Alexandria was just 315,844 in 1897 and became 3,339,076 in 1996, and it is projected to be 5.4 million by 2015. Alexandria with this size consists of 5.6%, 13.2%, and 30.3% of total population, urban population, and urban governorates population respectively in Egypt in 1996.

Despite of this demographic size, there is a noticeable trend of demographic decrease in Alexandria. Annual growth rates of Alexandria were higher than the national rates for about seventy years from 1907 to 1976. Since 1976 up to 1996, this rate began to fall dramatically from 3.3% to 1.5%. Likewise, the percentage of Egypt's population in Alexandria dropped from 6.06% in 1986 to 5.6% in 1996. Part of this decrease is due to internal migration from Alexandria to Cairo. Another part moved to Gulf countries because of the difficulties in finding jobs in the city. Part of this demographic decrease is due to family planning programmes where the percentage of population under 15 fell from 34.4% in 1986 to 31.6% in 1996.

The old districts of the city turn their backs to both new comers from outside the city and new families from the city, and push them all towards other districts at city fringes. Population density in the city confirms this fact as population densities in the city agree with local migration rates. The density of the old core qisms such as El-Gomorok, Karmous, El-Manshya, El-Attareen, and Bab Sharky declined between 1976 and 1996. Meanwhile, other qisms in the city edges such as El-Montazah, El-Dekhyla, and Elamrya attracted the population of old core qisms and new comers as well. In the same context, the household size and crowding rates declined generally in all city areas between 1986 and 1996. However, the areas in the city edges keep relatively high values of crowding rates and household sizes.

- ***What are the physical characteristics of urban growth in Alexandria? (2nd research question)***
- ***What are the stages of urban growth in the city? (3rd research question)***
- ***What are the boundaries and the trend of this growth? (4th research question)***

The review of the urban expansion history in Alexandria indicates that the city had seen the first extension towards the east during the Roman Age, as the walls of the city could not stop its growth. The emperor Augustus established a new suburb called "Nicopolis" or "City of Victory" after his triumph over Cleopatra between Mustafa Kamel and Gleem beaches area now in the east of the city.

Alexandria experienced a long history of deterioration from the end of Roman era up until the French expedition departure in the beginning of the 19th century. Within the Arab era, the city contracted from the western and southern parts. The city length decreased by 41.1% from the east to the west, 13 % of the city width to the west, and 64.3 % of the city width to the east (compared with city area during the Greco-Roman era). This shrinkage was principally because the city became a provincial town, secondary to the new capital (Fustat). Another important factor led to the contraction of the city; the city witnessed "land decline" from the 6th century. The city kept these boundaries until the 15th century. Accordingly, the population of Alexandria shrank significantly. The estimations were between 3,000 and 15,000 inhabitants, and the plague was the main cause of depopulation.

In the first years of the 16th century, the Mamluks started to weaken and the city started to deteriorate. The Ottoman secured Alexandria in 1517 and the shape of the city changed. The Turks did not prefer the areas that were inside the 9th century walls. Instead, they moved north to the area that had been formed by silting-up on either side of the Hepastadium (the ancient bridge) and built the "new city" as it was named after the French expedition or the so-called "Turkish city" in other sources.

After this Middle Ages deterioration, in the middle of the 19^{th} century, the city expanded in two directions, to the north and the southeast. This early expansion was due to Mohammed Ali's development projects especially Mahmoudia canal and New Shipyard. These projects made the immigrants flock to the city from all over the country so that the population increased dramatically from 13,000 in 1821 to 60,000 in 1838, 180,000 in 1860, and 232,000 in 1880.

Up until the end of the 19^{th} century, the growth of the city started to take new directions to the south, the west, and the east. Railway networks between the city and other cities such as Cairo and Suez were the key factors of urban expansion until the beginning of the 20th century. The construction of the railway line between Alexandria and Cairo in 1854 can be considered as the true beginning of the second urban growth stage in Alexandria (Abdel-hakeem 1958). Moreover, the growth of El-Ramel suburb in the east was related to the construction of the railway between Alexandria and this suburb in 1863. Another railway was constructed in 1872 to link the city with Rosseta (Rashid now), which encouraged the population to move forward to the eastern areas. The city continued to expand along the southern, western, and eastern directions until the middle of the 20^{th} century. The eastern direction was the most important. Urban expansion stretched along the Corniche (coastal boulevard). New suburb (Semouha) emerged in the southwest overcoming a water obstacle (Al-Hadara Lake). Meanwhile, there was another trend to expand towards the southeastern areas as a response to the industrial development there.

Previous studies on Alexandria projected that urban expansion between 1955 and 1995 will continue towards the eastern and southeastern areas rather than the western and southern areas and this will consume the agricultural lands. These expectations came true not only in these directions but also in the western and southern areas ***(the consequences of urban growth in Alexandria, 9^{th} research question).***

This urban expansion in all available directions can be explained in the light of the underestimated demographic projections where the expected population of Alexandria in 1997 was 2.696 millions (Abdel-hakeem 1958) while the actual population was 3.339 millions in 1996. Another important finding should be noted here that urban growth in the south-eastern areas is taking the form of informal housing.

- ***To what extent did Alexandria experience urban growth in the last decades of the 20th century? (5^{th} research question)***

From the middle of the 20^{th} century up until the 1990s, the city expanded in four directions, the east, southeast, the west, and the southwest. The southeast expansion carries actual and potential risks to one of the most important natural resources; cultivated lands, as was shown by satellite images analysis in this study. Moreover, most, if not all, urban expansion in this direction is unplanned and informal. The built-up area increased seventy eight-fold in about ninety years during the 20th century from about 4 km^2 in 1905 to 310.02 km^2 in 1995. This huge urban expansion made the central government extends the governorate' borders first to the east in 1955 and, second, to the west and south in the 1990s to cope with this increasing urban growth.

Also, one of the important findings of this study is that the city tends to expand horizontally rather than vertically. The density trend between 1855 and 1993 emphasises this as a gradual decrease in the density can be detected. Generally, the density has decreased by 50% in about 150 years. In addition to that, the city experienced the largest horizontal expansion in the second half of the 20th century where every one per cent of population growth has led to 1.4 per cent of physical expansion. These figures show how great is the size of urban expansion in Alexandria especially in the modern and contemporary periods, and how important is to deal with this planning problem with the most effective policies to manage this growth and reduce its negative impacts.

- ***What are the shapes of urban growth in the city between the 19th and 20th centuries? (6th research question)***

Previous urban growth cannot be modelled using available traditional approaches for many reasons. However, many endeavours have been exerted to interpret urban growth using some theories or models. The application of urban models in Alexandria in its modern history was divided into three chronological stages. The first stage includes the 19th century as a whole. In this period, the city expanded taking a "Circular Development" shape. The second stage covers the first half of the 20th century, where the Multiple Nuclei Model can be applied to explain the urban growth in the city as Abdel-hakeem (1958) and El-Saaty and Hirabayashi (1959) applied it. The third stage began from the second half of the 20th century up to date and it is believed it will continue as a prominent pattern in Alexandria urban growth. The Urban Realms Model is the most appropriate model that can describe the contemporary situation of urban growth in the city. Seven urban realms can be identified from the east to the west: Montazah, East district, CBD, Qabary-Wardyan, Dekhila-Agamy, Amrya-king maryout, and Burg-Alarb.

9.2.2 Satellite images and GIS analysis findings

The general findings of this study are based on maps and socioeconomic data that represent one dimension of this study. Satellite image and GIS analysis introduce another dimension of this study. The satellite images used in this study were georeferenced with high accuracy providing a strong basis for further image analysis processes. The 1984 and 1993 images were rectified applying the first order transformation polynomial using between 39 and 43 GCPs from the reference maps of Alexandria of scale 1:50,000. The transformation matrix was computed and tested many times achieving an acceptable total RMSE of 0.26 pixel for the 1984 image and 0.25 pixel for the 1993 image. Both images were resampled using the nearest neighbour method.

Reference data source type has a great impact in decreasing RMSE of the rectified images and achieving high accuracy of land use/cover classification as the reference maps used in this study were produced from aerial photographs, which have their own high accuracy in presenting land features. This helped in achieving a very small RMSE and high accuracy classification and change detection as well.

- ***What is the most current state of land use in Alexandria as a base for monitoring growth and detecting urban change? (7th research question)***

According to the customised land use/cover classification scheme by the author, there are five classes namely; Coastal Plain and Desert, Water Bodies, Shallow water/Saline/Marsh, Green land, and Built-up area. Coastal Plain and Desert category dominated the study area by occupying 48.91% in 1984 and 45.36% in 1993. This means that this class lost 7.26% of its area between 1984 and 1993. The change in this class is due to the urban and agricultural developments projects. Water Bodies and Shallow water/Saline/Marsh classes occupied 27.78% in 1984 and 1993. Shallow water/Saline/Marsh class increased by 37.96% as parts of Maryout Lake were dried. Green land category decreased by about 6% from 15.41% in 1984 to 14.48% in 1993 ***(The consequences of urban growth in Alexandria, 9th research question)***. The green lands lost more than 6% of its area between 1984 and 1993, but this is not shown in the final balance as the green land gained a considerable area through land reform projects in the deserts. Most of the loss of green lands related to urban expansion. Built-up area class, the focus of this study, gained 56.71% where it was 7.9% in 1984 and become 12.38% in 1993. This increase was from green lands and Coastal Plain and Desert classes.

Land use/cover classification maps were produced with overall accuracy of 93.82% and 95.27% for 1984 and 1993 images correspondingly. Unsupervised classification using ISODATA clustering method was applied to perform the classification. This high accuracy in land use/cover classification presented a high-quality source for land use/cover change detection using post-classification comparison method. This study emphasises the importance of special customisation of land use/cover schemes especially for developing countries studies as this research underlines the fact of non-existence of a universally applied classification scheme. In this context, a user-defined classification scheme has been customised to comply with both data resolution and study area spatial and environmental characteristics.

- ***What are the changes of the land use/cover during the period of study? (8th research question)***

The land use/cover change detection study reveals several changes in the period of study (1984-1993). These changes can be grouped into two divisions: spatial changes and quantitative changes. Spatial changes represent either emerging of new features or changing in the existing features. New features such as new Dekhila Port, Sidi Krir power station, fish farms, recreation villages, and lands reform projects appeared in the west. Maryout Lake saw some changes as some areas of the lake were dried to meet the accelerated demand for land; other parts of the lake have been used as Salina to produce salt. Indeed, all the above-mentioned features are results of urban development, but can be considered as indirect results. The direct results of urban development can be detected easily as new features in the eastern parts of the city consuming a significant part of the valuable agricultural lands ***(the consequences of urban growth in Alexandria, 9th research question)***. Moreover, the city centre area witnessed a little change of its existing features due to replacement and renewal factors. Quantitatively, green lands lost 23.79 % of its area for the built-up area with annual loss rate of 0.67%, which means there is a risk of losing about 75% of green land in the period between years 2096 and 2191. These are very optimistic projections if compared by other studies which estimated that ***ALL*** coastal agricultural lands in the northern of Egypt will be lost to urbanisation and other activities by year 2061 (Salem *et al.* 1995). From a methodological point of view, land use/cover change analysis in Alexandria using post-classification comparison change detection method yielded high accuracy results because of the high-accuracy of classified satellite images that being used as inputs.

- ***What may be the future urban growth in Alexandria using modelling techniques?(10th research question)***

Modelling urban growth model using SLEUTH emphasises that if the current physical urban expansion rates continued, it is expected that urban growth will persist in the edges of the current urban extent. This can be detected easily in the western, the south, and the southeastern directions. Much development is expected to occur also around Al-Amrya area in the southwestern parts. The direction of urban growth to the southeastern parts means a serious threat to the cultivated lands, which already experience continuous loss.

The expected urban growth has many consequent probabilities. These follow the consequent urban growth phases (Spontaneous, New Spreading Centres, Edge Growth, and Road-Influenced Growth). The adjacent areas to the current built-up area have the highest probability to become urban, and the probability decreases through moving to the edges. Moreover, the model's output shows that urban growth can occur away from the current built-up area as an indication of the Road-Influenced Growth coefficient, and this may appear much more clearly, if detailed road maps were used in the model.

Moreover, modelling urban growth using the SLEUTH model has great potential especially when the necessary input data with the higher resolution and accuracy are accessible.

- ***What is the potential of using remote sensing and GIS in monitoring, detecting and modeling urban growth? (11th research question)***

This study demonstrates that GIS and remote sensing coupled with statistical analysis can assist immensely in monitoring and modelling spatial and temporal analysis of urban growth. In terms of modelling future urban growth, the study successfully defines the potential urban growth boundaries using the SLEUTH model. The possibilities of urban expansion were modelled up to 2055.

Moreover, this study emphasised the significance of using Landsat satellite images in monitoring urban land use/cover with its resolution, coverage, and accessibility. It should be noted here that these systems provide data that can monitor general changes only (macro scale). New sensors such as IKONOS provide more enhanced resolution that can benefit micro scale analysis of urban applications. In terms of remote sensing computer programmes, ERDAS imagine is a very functional tool in image processing and raster GIS analysis.

We have shown that digital data layers of terrain and elevation, land use/cover, and transportation can be combined using GIS in order to form new information products for decision support and urban management. The data can be used for mapping, infrastructure planning, emergency management, record keeping, and natural resource management, among other uses. They can also play a significant role in economic development as well. Remote sensing coupled with GIS can also provide a valuable information base for resource allocation and urban planning, including directing urban growth, locating buildings and services, and facilitating the operation of markets for land. Finally, GIS and remote sensing can be used in routine urban record keeping, allocation of services, and governance. This includes maintaining vital records, such as cadastral records of land ownership and property boundaries that serve both legal and administrative purposes.

- ***What is the current situation of urban growth management in Alexandria? (12th research question)***

It is important to admit here that there is no single strategy for growth management can be applied in all urban areas. Thus, every community needs to review, learn and innovate locally-based efforts. However, urban communities must learn from the precedent and current lessons of the powerful growth management strategies that are being employed in the United States, England,

and Europe bearing in mind that the contexts of these strategies are quite different even among the countries of named regions.

This study reveals the absence of a planning authority in Alexandria that is responsible for preparation, implementation, following-up, and updating urban plans. All previous plans were prepared outside the city by provisional efforts, thus these plans represent incomplete planning processes. In general, these plans did not have any zoning plans at district level so that the public can observe and abide by. These plans can be considered as recommendations not plans as the plans should be accompanied by an action plan. Action plan is an important element, which represents "Implementation Phase" with a detailed timetable for each task.

Moreover, the General Planning of Alexandria City until 2017 is a strong sign of centralisation planning and can be considered as many steps backward in terms of decentralisation as Alexandrian planners were involved in the ACP2005 plan. Moreover, there was no involvement of Alexandria governorate in this plan as all the members of the teamwork were from the General Organization for Physical Planning (GOPP). Indeed, public participation is one of the important missing elements of this plan beside the absence of local governorate involvement, financial resources and legal framework elements as well. Thus, this plan can be considered as a general development plan rather than urban development or comprehensive plan as the report summarised its recommendations within a Comprehensive Development Strategy framework. Nevertheless, it cannot be considered general development plan, as the development plan should involve many ministries and organisations, Ministry of Planning is the most important body between of these institutions as it is responsible for allocating the needed financial resources for any development task.

One of the positive issues is that there is a new dawn of public participation in Alexandria as the city now sees many of improvement projects based on the cooperation between the governorate, represented by its governor, Mr Al-Mahgoub, in one side, and Alexandria community and private sector representatives on the other side. The success of this initiative is well known not only in Egypt, but also at international level where some cities asked to benefit from this experience.

- ***What is the best practice to achieve a sustainable urban growth in the city?(13th research question)***

9.3 Recommendations

9.3.1 Policy recommendations

9.3.1.1 City level (Alexandria)

- To deal with urban growth problem in Alexandria from its roots, there is a need for a locally based planning authority that is responsible for all planning aspects in the city. Indeed, this suggested authority should be part of a national system to deal with urban growth problems not only in Alexandria but in all Egyptian urban centres as well. This suggested authority will solve the absence of a permanent planning authority problem in the cities.

- For the time being, the study appeals to the decision makers to issue and implement tough policies to direct urban growth towards suitable land for urban development, especially in the west and southwest of the city to protect the valuable agricultural lands. To preserve the environmental resources of the city, especially the agricultural lands, this study suggests a greenbelt to be planned in the south of the city. This suggested greenbelt should be located before the agricultural lands leaving a reasonable buffer zone. GIS can help in placing this greenbelt and locating the buffer zone considering all geographical and environmental factors. Meanwhile, as most urban development in the eastern parts is unplanned, there is a need also for planning solutions for this problem as well.

- In addition, it is important to prohibit vertical and horizontal expansion of the main built-up area as a response to continuous urban growth as this is considered as a shortsighted response as it will lead to easy access to the existing overextended services and utilities. Therefore, future urban development process should create independent communities as an approach to expanding the urban land. This approach would distinguish these communities from the core built-up area of the central city and reduce their dependence on its utilities and service systems (El-Shakhs 1997). To support this approach, it is important to cover the gap in services in the well-established areas and provide the necessary services in the potential development sites. Meanwhile, management of urban growth plans should be part of regional development policies meant to reduce growth pressures on the central city by promoting the development of a hierarchy of regional intermediate and small urban centres (El-Shakhs 1997) such as Al-Amrya, King Maryout, and Burg Al-Arab. In the same context, it is recommended to give particular attention to the potential axial growth along both the Agricultural and Desert roads between Alexandria and Cairo as the previous experience indicates that the development of such urban regions is inevitable (El-Shakhs 1997).

- Maryout Lake needs an appropriate decision about its future. Moreover, there is a serious need for an urban growth management programme, which contains a significant part about lake development. In this context, The Centre for Environment and Development for the Arab Region and Europe (CEDARE) is in the process of developing a Decision Support System for Lake Maryout to achieve sustainable development in such an environmentally sensitive area to analyse policy failures underlying unsustainable urban management systems. A national team has been formed consisting of government, municipal, consultants from different fields, NGOs and private sector representatives with public community to develop a shared vision of the capacity building process and to contribute actively to its implementation. This project aims at developing a software package to illustrate how an Information system and a Decision Support system could be applied in analysing and solving the complex environmental problems in a user-friendly environment. This system will allow decision makers to compose different scenarios and strategies for the different types of external development to the lake that may affect the current situation in the lake area and evaluate the results of the scenarios. The centre proposes that it would prepare a set of digital maps using GIS and satellite images at a later stage. Image processing techniques might be employed to classify land and urban patterns, among other things. Examples of the attribute data that can be used include demographic growth trends, physical and temporal changes, expected population in the planning horizon year of 2017, required serviced areas for future expansion, and conditions of the newly developed areas (CEDARE 2004). As we can see, the current study about Alexandria can contribute significantly in this project. Every effort will be made to contact the project manager to discuss this potential contribution.

- In this study, we renew the recommendations of Abdel-hakeem study (1958) about moving military areas and cemeteries outside the city as they occupy a huge area of valuable land in different parts mainly in the centre of the city. Then, part of the vacant lands can accommodate some of the urban growth and the other parts can be used as green parks as the city is in severe conditions regarding to green areas.

- The results of this study also recommend the review of future planning of the study area not from local prospect only but at national level as well because urban growth is a reflection of national policies, which lead to a demographic mobilisation from different parts of the country to urban centres.

- At the micro scale, subdivision and servicing of peripheral sites, and supply of land at low prices is one of the advocated strategies (Devas and Rakodi 1993). In addition, an important element in management of urban land is "concurrency" which means simply "No infrastructure, No occupancy permission". In other words, occupancy permits should never issued before completing the needed infrastructures i.e. roads, water, drainage lines, and solid waste disposal; and schools.... etc. This policy will not be successful in Egypt case unless it is accompanied by very tough regulations and procedures to prevent informal housing that does not need any occupancy permits.

- Moreover, before developing any peripheral lands, it is advised strongly to develop intermediate lands (land left inside the city) first to gain the most benefits of the existing infrastructure and services. This can be achieved by applying some incentive-based approaches such as tax exemptions, and low-interest loans to direct development into these areas.

- Successful urban growth management programme should include conservation and rehabilitation element for the important and historical places in any given city as this would maintain the cultural identity of the city, which makes it unique amongst other cities at both national and international levels.

- It is recommended that the city should have enough revenues through an effective land and property taxation system so that it can manage and control urban growth effectively. It is recommended for Alexandria and any other city suffering from urban growth challenge should have a categorised taxation system for land and property. The suggested system will have twofold objectives; the first is to increase the profits through a comprehensive taxation system, the second is to direct and control urban growth. This system may offer reduced rates where the urban growth needs to be directed and high rates where the urban growth requires being restricted. The zoning plan will contain the areas where urban growth is prohibited and another tax category may be applied according to the type of land use. In addition, GIS-based land registration system can enhance taxation system and land management in the same time. In this suggested system, the ownership of the land will be validated only when land ownership is registered in this system. Therefore, the monitoring of transactions will be up to date. This will provide a strong database to the decision makers to manage land development. In the same context, the potential owner of the land can check its status in this system to check tax rates applied to it before acquisition. In addition, this system can prevent speculation by providing automated high rates taxes when land is registered in case frequent transactions without real development detected by the system. An efficient registration system, regular assessment of property values and collection of taxes, and sufficient political support are essential requirements for system success.

- It is recommended to integrate environmental consideration into urban management and development through an integrated approach to manage natural resources as a whole. Also to achieve sustainable urban development, it should be an equitable access to urban resources as inequalities of purchasing the necessary elements of urban life such as food, energy, water, and land, lead to malnutrition, informal housing on even the most dangerous sites, and illegal access into electricity and water. These necessary elements of urban life must be incorporated into regional development planning for the cities and their hinterlands. To maintain these resources, there is a need for environmental audits. Increasing the environmental awareness of existing public authorities is likely to be much better than establishing new ones so long as the environmental impacts and sustainability are incorporated to all policies at the different levels of planning (Devas and Rakodi 1993).

9.3.1.2 National level (Egypt)

- In general, it is important to support governments at both local and national levels with the necessary skills and abilities in order to intervene effectively in the process of urban development as the previous experiences in cities in both developed and developing countries revealed that the cities may not have these skills (Devas and Rakodi 1993). In the same context, it is imperative to establish networks between and within existing organisations and institutions as that would facilitate information flows and enhance coordination throughout the process (El-Shakhs 1997).

- Partnership between government agencies, private sector, and community can lead to win-win outcomes that benefit all. National and local policies must be linked, coordinated and complementary. This governmental collaboration should contain a clear definition of roles to avoid conflict of interests.

- Urban growth management strategies must have the capacity and resources to be implemented. It should be noted also that urban growth strategies (when implemented) take a long time and huge investment to yield their fruits (between 10-25 years, e.g., London and Portland experiences respectively). Urban growth management strategies should be comprehensive in scale and can integrate with urban fringe and rural areas policies. Taxes can be used by different ways (grants, tax abatement, waiving of levies) as means of financial incentives.

- Integration between centralisation and decentralisation is one of the key principles in managing urban growth. The allocation of responsibilities for decision-making, operation and maintenance must balance the relative advantages of centralisation and decentralisation as the government at national level can ensure the achievement of national service standards whilst the local government can ensure an effective response to local needs and problems (Devas and Rakodi 1993).

- Public participation is the best way to obtain effective, responsible, and responsive government (Eisner et al. 1993). This involvement or participation should have the necessary power to contribute effectively in urban management processes.

- Urban management may not need new or additional laws, as the existing laws are not being applied appropriately because of overlapping and contradictory characteristics; simplification and clarification are likely to be the solution. Nevertheless, if there is any need for new laws to manage urban growth, these laws should be equitable, flexible, participative and easily manageable, simple, efficient, administratively fair and environmentally conscious (Devas and Rakodi 1993).

- Improving access to urban land markets is one of the critical factors of urban growth management that would have two advantages; the first is improving the housing situation and economic prospects. Second is directing urban growth to the appropriate land which will protect the valuable land (Payne 1999), leading to sustainable urban growth. Therefore, the government as a key player is recommended to cooperate with the other actors to implement an appropriate partnership. This appropriate partnership requires several changes in the orientation of the current land delivery systems, which includes:
    - Establishing suitable financial means to minimise risk and maximise profits for all concerned parties,
    - Widening the scope of planning systems to involve all markets in the system,
    - Enhancing the institutional framework (Soliman 1999).

- Moreover, it is important to make significant efforts in improving the economy at both national and local levels to provide a strong base for urban growth management by adopting the following recommendations:
    - Supporting the capacity of local authorities to attract investments especially in urban development projects,
    - Promoting increased savings and facilitate their use in housing activities,
    - Improving national and local tax collection capabilities and expenditure control to control costs and enhance profits, and
    - Application of full-cost recovery for urban services, with the exception of public safety services.
- The key factor of managing urban growth is not just trying to solve the problem locally in the affected area(s), but the solution should adopt an integrated approach that can deal with the problem in a broader view at national, regional, and local levels and also between urban and rural areas.

- It is recommended also to develop rural areas especially in Upper Egypt to reduce internal migration and this should be applied at national, regional and local levels. Some attention should be given also to the capitals of rural governorates so that it can encourage their people to stay instead of moving to central urban areas. Creating opportunities and providing needed services in the rural areas would increase rural productivity and this may lead to reducing the flow of migrants and even open the way to the migrants from over populated urban governorates.

- The central government should support the local urban governorates to establish sustainable urban land-use patterns and planning by preparing legal frameworks to assist the development and implementation of public plans and policies for sustainable urban development and rehabilitation, land utilization, housing and the improved management of urban growth.

This should be accompanied by developing fiscal incentives and land-use control measures, including land-use planning solutions for more reasonable and sustainable use of limited land resources. In addition, it is important to endorse the integration of land-use and transport planning to encourage development patterns that reduce the demand for transport. These activities should be addressed in the global context of comprehensive and environmentally sound land-use strategies at the local level taking into account the environmental impact to mitigate present and prevent future population and development pressures on urban and rural areas. The most important issue needs to be addressed is urban monitoring and reporting activities based on appropriate indicators for the environmental, social and economic performance of cities (UN-Habitat 1996). This requires developing integrated land information and mapping systems using hi-technology approaches such as GIS and Remote Sensing.

- It is recommended to have a fully accurate and up-to-date information and data about urban growth problem(s) to deal with it effectively. This will be achieved by developing, upgrading and maintaining information technology infrastructure and encouraging their use by all levels of key actors, i.e., government, public institutions, civil society organizations and community-based organizations. This should be accompanied also by the necessary training for all key parties. These reforms will not be effective without supporting policies that make information technology available and more accessible to the public. These reforms also must provide free flow of, and access to, information in the areas of public policy, decision-making, resource allocation and social development to increase the knowledge and strengthen the information base for all interested parties in general. Specifically, these reforms must promote research on economic, social and environmental aspects related to urbanization and its problems, focusing on research priorities identified based on national requirements. Meanwhile, it is important to adopt efficient and sustainable methodologies developed by systematically incorporating research results and by compiling, analysing and updating data for urban areas. This also includes dissemination of research indicators and mainstreaming their results in policy-making at all levels and ensuring a two-way flow of information between producers and users of information (UN-Habitat 1996). In the same context, using GIS can provide rapid and easy access to large volumes of data. Using GIS functions in decision making in planning can provide facilities to store, manipulate, update, combine, query, and display required information in many formats such as maps, diagrams, and tables. Moreover, integrating GIS with high resolution remotely sensed data has been found very useful in some countries for evaluating urban growth scenarios (Paulsson 1992).

- International cooperation is one of the most important factors that can help in problem-solving in the world. Urban growth, besides other problems in developing countries, needs a huge capacity of different resources to deal with it. These needed resources are out of the capacity of most, if not all, developing countries. Indeed, financial resources come in the front of the queue, but also, there are other resources such as information, technology, and experience.

9.3.2 Technical recommendations

9.3.2.1 Data collection

- One of the most important and critical issues of this study and other similar studies is data. The data issue in this study has multi-dimensional aspects; data access, data resolution, data accuracy, and data format. For data access, many efforts need to be done at different scales. At the national level in developing countries, it is important to raise the awareness of data easy-access, as this is the only way for precise problem diagnosis and solving. This study faced a significant delay of more than two years in obtaining the required data resources. National security checks and financial issues are the main reasons of this delay. Some data sources were not available as well. At international level, it is recommended to facilitate access to developing countries data especially innovative sources such as satellite images.

- Data resolution is another important feature. Data has two resolutions: spatial and temporal resolutions. Spatial resolution is related to the geographical coverage of the area of interest, while temporal resolution is related to the time coverage. This study faced serious difficulties regarding data resolution as most of the data used, especially maps, is not completely consistent in terms of spatial and temporal resolutions. In the same context, data accuracy and data format are another two crucial elements especially with the growing demand for electronic data format for using with GIS platforms.

- Data accuracy is linked with tools used in data production. In addition, most of the data used in this study was in hard-copy format, which restricted the full integration into GIS especially in the modelling phase. Moreover, the final outputs of modelling urban growth in the city have been affected by data limitations especially for roads and slope inputs: as those inputs are very general with a small resolution. Therefore, for all the above-mentioned limitations it is recommended to update the maps with its different scales using modern tools and technologies such as GIS and remote sensing. This recommended updating will have significant impacts in the resolution, accuracy, and format of maps.

9.3.2.2 Data analysis

- When georeferencing, it is recommended to distribute ground control points (GCPs) appropriately to cover most if not the whole of the image especially image edges to reduce image distortion. This suggestion is linked directly with the number of GCPs, which should be enough to achieve this aim. This includes the other considerations of selecting GCPs, e.g. road intersections. It is also recommended to re-distribute GCPs and increase their number to check the possibility of RMSE reduction.

- Moreover, it is recommended to use a high accuracy data as reference sources for image georeferencing and land use-cover classification, as this will secure a small size of RMSE in rectification and high accuracy of classification.

- For land use/cover classification using satellite images, it is recommended to develop user-defined classification systems according to the nature of study area and data type. This study recommends also using Post-classification change detection method to yield good results especially if there are not any anniversary satellite images available to perform change detection. Indeed, this is linked directly with the production of highly accurate classified images to achieve high accuracy in change detection.

- Modelling physical urban growth using the SLEUTH model is recommended especially when the necessary input data with the recommended resolution and accuracy are accessible. The model succeeded in predicting urban growth in the city with the available data sources, and produced the potential urban growth in the city. Moreover, using this model in the current study provided a strong base for the future research using data with high resolution and accuracy.

- Using the SLEUTH model in this study was meant mainly to check the possibility of applying this model outside the contexts of USA and Europe, and the model proved its portability. Therefore, the model will be subject to further investigations when better data are available.

9.4 Future research

- The future research agenda will be linked with the Egyptian Remote Sensing projects where the government is intending to launch its own satellite system in the near future (the end of 2004 as the Minister of Higher Education announced recently). Urban applications will be an essential part of the proposed applications of this new system. Remote sensing urban applications, in general, have a very small share amongst other applications at international level and it is difficult to find any share at national level. Therefore, my research agenda will focus on urban applications and be linked with these new developments.

- There is an obvious need for an urban-oriented land-use classification system (Jensen 1996). Participation in preparing urban land use/cover classification system for developing countries generally and the Middle East area especially will be one of the priorities on my future research agenda. This proposed system should serve the different applications of remote sensing from the available systems.

- The urban modelling issue generally will be also one of the main themes of further studies in the journey of searching for the model that can simulate urban growth avoiding the limitations of SLEUTH and other urban models. Using SLEUTH model in this study was meant mainly to check the possibility of applying this model outside the contexts of US and Europe, and the model proved its portability. Therefore, the model will be subject to further investigations when better data are available. In addition, future work may try to develop a model that can consider most of urban growth factors, especially socioeconomic factors, so that it can introduce a relatively accurate future picture. This potential model also may use GIS as a core component for modelling starting from data preparation, passing through programming using its own capabilities rather than using another programming languages, and finishing with final outputs production. Overcoming these limitations and achieving these ambitious goals can offer a great chance to change the future of urban models. Precise projection of urban growth using modelling techniques can enhance the processes of urban growth management.

- Transport modelling is one of the important issues that are linked directly with urban growth modelling. Transport means especially roads are the fundamentals of urban growth in general. Therefore, future studies will endeavour to give more attention to this important factor of urban expansion.

- Urban growth also is not a stand-alone phenomenon that can occur without the interaction with some other important factors. Economic development is one of the crucial factors of urban growth. Slow economic rates may hinder urban growth and vice versa. Future studies also may include economic development as one of the key issues in urban growth.

- As it was mentioned elsewhere in this study, the idea behind studying urban growth was developed along the course of my MA thesis about urban poverty in Alexandria. Therefore, future studies will try to make efforts to link urban growth implications with urban poverty and informal housing.

- In the same context, one of the future studies will focus on the implications and impacts of urban growth on the environment. This suggested study will discuss sustainable urban development as a way of managing future urban growth effectively and efficiently.

- In addition, urban decline – as it was found in this study – at city and national level, requires more in-depth investigations to follow its roots and implications. Urban decline or urban decrease – if continued – may change the projection approaches of urban growth in Egypt. Therefore, my research agenda will try also to study this phenomenon. Linked with this new development, is the decrease in the importance of internal migration as a branch of population increase in Alexandria. This also requires detailed investigations to understand the factors behind this to predict urban growth accurately as well.

- Finally yet importantly, one of the future studies may focus on the situation of the city in the globalisation era. Large cities like Alexandria experience this new development that will have various impacts. Open market policies will change the economic structure of the cities. This may incite or inhibit urban growth consequently. This also will have its own environmental impacts as well. Therefore, there is a need for such study as well.

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Appendices

Appendix (1)

The scenario file of the model, there are some changes in the file to enable the model reading the new inputs files and write the output files in the new predefined directories.

```
growth.c 122 *********************************************
# FILE: 'scenario file' for SLEUTH land cover transition model
#       (UGM  v3.0)
#       Comments start with #
#
#   I. Path Name Variables
#  II. Running Status (Echo)
# III. Output ASCII Files
#  IV. Log File Preferences
#   V. Working Grids
#  VI. Random Number Seed
# VII. Monte Carlo Iteration
#VIII. Coefficients
#      A. Coefficients and Growth Types
#      B. Modes and Coefficient Settings
#  IX. Prediction Date Range
#   X. Input Images
#  XI. Output Images
# XII. Colortable Settings
#      A. Date_Color
#      B. Non-Landuse Colortable
#      C. Land Cover Colortable
#      D. Growth Type Images
#      E. Deltatron Images
#XIII. Self Modification Parameters
```


```
# FILE: 'scenario file' for SLEUTH land cover transition model
#       (UGM  v3.0)
#       Comments start with #
#
#   I. Path Name Variables
#  II. Running Status (Echo)
# III. Output ASCII Files
#  IV. Log File Preferences
#   V. Working Grids
#  VI. Random Number Seed
# VII. Monte Carlo Iteration
#VIII. Coefficients
#      A. Coefficients and Growth Types
#      B. Modes and Coefficient Settings
#  IX. Prediction Date Range
#   X. Input Images
#  XI. Output Images
```

```
# XII. Colortable Settings
#     A. Date_Color
#     B. Non-Landuse Colortable
#     C. Land Cover Colortable
#     D. Growth Type Images
#     E. Deltatron Images
#XIII. Self Modification Parameters
# I.PATH NAME VARIABLES
#   INPUT_DIR: relative or absolute path where input image files and
#             (if modeling land cover) 'landuse.classes' file are
#             located.
#   OUTPUT_DIR: relative or absolute path where all output files will
#              be located.
#   WHIRLGIF_BINARY: relative path to 'whirlgif' gif animation program.
#                   These must be compiled before execution.

INPUT_DIR= /home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/
OUTPUT_DIR=/home/ucs/040/n8721108/UG-My-Outputs/
WHIRLGIF_BINARY=/home/ucs/040/n8721108/UG/UGM3.0beta/Whirlgif/whirlgif/


# II. RUNNING STATUS (ECHO)
# Status of model run, monte carlo iteration, and year will be #  printed to the screen
during model execution.

ECHO(YES/NO)=yes

# III. Output Files INDICATE TYPES OF ASCII DATA FILES TO BE WRITTEN TO OUTPUT_
DIRECTORY. #
#   COEFF_FILE: contains coefficient values for every run, monte carlo
#              iteration and year.
#   AVG_FILE: contains measured values of simulated data averaged over
#            monte carlo iterations for every run and control year.
#   STD_DEV_FILE: contains standard diviation of averaged values
#                in the AVG_FILE.
#   MEMORY_MAP: logs memory map to file 'memory.log'
#   LOGGING: will create a 'LOG_#' file where # signifies the processor
#           number that created the file if running code in parallel.
#           Otherwise, # will be 0. Contents of the LOG file may be
#           described below.

WRITE_COEFF_FILE(YES/NO)=yes
WRITE_AVG_FILE(YES/NO)=yes
WRITE_STD_DEV_FILE(YES/NO)=yes
WRITE_MEMORY_MAP(YES/NO)=no
LOGGING(YES/NO)=YES

# IV. Log File Preferences
# INDICATE CONTENT OF LOG_# FILE (IF LOGGING == ON).
#   LANDCLASS_SUMMARY: (if landuse is being modeled) summary of input
#                     from 'landuse.classes' file
#   SLOPE_WEIGHTS(YES/NO): annual slope weight values as effected
#                         by slope_coeff
```

READS(YES/NO)= notes if a file is read in
WRITES(YES/NO)= notes if a file is written
COLORTABLES(YES/NO)= rgb lookup tables for all colortables generated
PROCESSING_STATUS(0:off/1:low verbosity/2:high verbosity)= ????
TRANSITION_MATRIX(YES/NO)= pixel count and annual probability of
land class transitions
URBANIZATION_ATTEMPTS(YES/NO)= number of times an attempt to urbanize
a pixel occurred
INITIAL_COEFFICIENTS(YES/NO)= initial coefficient values for
each monte carlo
BASE_STATISTICS(YES/NO)= measurements of urban control year data
DEBUG(YES/NO)= data dump of igrid object and grid pointers
TIMINGS(0:off/1:low verbosity/2:high verbosity)= time spent within
each module. If running in parallel, LOG_0 will contain timing for
complete job.

LOG_LANDCLASS_SUMMARY(YES/NO)=yes
LOG_SLOPE_WEIGHTS(YES/NO)=no
LOG_READS(YES/NO)=no
LOG_WRITES(YES/NO)=no
LOG_COLORTABLES(YES/NO)=NO
LOG_PROCESSING_STATUS(0:off/1:low verbosity/2:high verbosity)=1
LOG_TRANSITION_MATRIX(YES/NO)=yes LOG_URBANIZATION_ATTEMPTS(YES/NO)=no
LOG_INITIAL_COEFFICIENTS(YES/NO)=no
LOG_BASE_STATISTICS(YES/NO)=yes
LOG_DEBUG(YES/NO)= no
LOG_TIMINGS(0:off/1:low verbosity/2:high verbosity)=1

V. WORKING GRIDS
The number of working grids needed from memory during model execution is

designated up front. This number may change depending upon modes. If # NUM_WORKING_GRIDS needs to be increased, the execution will be exited # and an error message will be written to the screen and to 'ERROR_LOG' # in the OUTPUT_DIRECTORY. If the number may be decreased an optimal # number will be written to the end of the LOG_0 file.

NUM_WORKING_GRIDS=5

VI. RANDOM NUMBER SEED
This number initializes the random number generator. This seed will be # used to initialize each model run.

RANDOM_SEED=47392074

VII. MONTE CARLO ITERATIONS
Each model run may be completed in a monte carlo fashion.
For CALIBRATION or TEST mode measurements of simulated data will be # taken for years of known data, and averaged over the number of monte # carlo iterations. These averages are written to the AVG_FILE, and # the associated standard diviation is written to the STD_DEV_FILE. # The averaged values are compared to the known data, and a Pearson # correlation coefficient measure is calculated and written to the

```
control_stats.log file. The input per run may be associated across #  files using the
'index' number in the files' first column. #

MONTE_CARLO_ITERATIONS=5

# VIII. COEFFICIENTS
# The coefficients effect how the growth rules are applied to the data. # For additional
information see our publications and PROJECT # GIGALOPOLIS web site
(www.ncgia.ucsb.edu/project/gig/).
#  A. COEFFICIENTS AND GROWTH TYPES
#     DIFFUSION: effects SPONTANEOUS GROWTH and search distance along the
#              road network as part of ROAD INFLUENCED GROWTH.
#     BREED: NEW SPREADING CENTER probability and effects number of ROAD
#           INFLUENCED GROWTH attempts.
#     SPREAD: the probabilty of ORGANIC GROWTH from established urban
#           pixels occuring.
#
#     SLOPE_RESISTANCE: effects the influence of slope to urbanization. As
#                 value increases, the ability to urbanize
#                 ever steepening slopes decreases.
#     ROAD_GRAVITY: effects the outward distance from a selected pixel for
#               which a road pixel will be searched for as part of
#               ROAD INFLUENCED GROWTH.
#
#  B. MODES AND COEFFICIENT SETTINGS
#     TEST: TEST mode will perform a single run through the historical
#         data using the CALIBRATION_*_START values to initialize
#         growth, complete the MONTE_CARLO_ITERATIONS, and then conclude
#         execution. GIF images of the simulated urban growth will be
#         written to the OUTPUT_DIRECTORY.
#     CALIBRATE: CALIBRATE will perform monte carlo runs through the
#             historical data using every combination of the
#             coefficient values indicated. The CALIBRATION_*_START
#             coefficient values will initialize the first run. A
#             coefficient will then be increased by its _STEP value,
#             and another run performed. This will be repeated for all
#             possible permutations of given ranges and increments.
#     PREDICTION: PREDICTION will perform a single run, in monte carlo
#              fashion, using the PREDICTION_*_BEST_FIT values
#              for initialization.

CALIBRATION_DIFFUSION_START= 0
CALIBRATION_DIFFUSION_STEP=  25
CALIBRATION_DIFFUSION_STOP=  100

CALIBRATION_BREED_START=    0
CALIBRATION_BREED_STEP=    25
CALIBRATION_BREED_STOP=    100

CALIBRATION_SPREAD_START=   0
CALIBRATION_SPREAD_STEP=    25
CALIBRATION_SPREAD_STOP=    100
```

```
CALIBRATION_SLOPE_START=    0
CALIBRATION_SLOPE_STEP=    25
CALIBRATION_SLOPE_STOP=    100

CALIBRATION_ROAD_START=    0
CALIBRATION_ROAD_STEP=    25
CALIBRATION_ROAD_STOP=    100

PREDICTION_DIFFUSION_BEST_FIT= 20
PREDICTION_BREED_BEST_FIT= 20
PREDICTION_SPREAD_BEST_FIT= 20
PREDICTION_SLOPE_BEST_FIT= 20
PREDICTION_ROAD_BEST_FIT= 20

# IX. PREDICTION DATE RANGE
# The urban and road images used to initialize growth during
# prediction are those with dates equal to, or greater than,
# the PREDICTION_START_DATE. If the PREDICTION_START_DATE is greater # than any
of the urban dates, the last urban file on the list will be # used. Similarly, if the
PREDICTION_START_DATE is greater # than any of the road dates, the last road file on
the list will be # used. The prediction run will terminate at PREDICTION_STOP_DATE. #

PREDICTION_START_DATE=1995
PREDICTION_STOP_DATE=2015

# X. INPUT IMAGES
# The model expects grayscale, GIF image files with file name
# format as described below. For more information see our
# PROJECT GIGALOPOLIS web site (www.ncgia.ucsb.edu/project/gig/).
#
# IF LAND COVER IS NOT BEING MODELED: Remove or comment out
# the LANDUSE_DATA data input flags below.
#
#    < >  = user selected fields
#   [< >] = optional fields
#
# Urban data GIFs
#  format:  <location>.urban.<date>.[<user info>].gif

URBAN_DATA= demo200.urban.1955.gif
URBAN_DATA= demo200.urban.1995.gif

# Road data GIFs
#  format:  <location>.roads.<date>.[<user info>].gif

ROAD_DATA= demo200.roads.1955.gif
ROAD_DATA= demo200.roads.1995.gif

# Landuse data GIFs
#  format:  <location>.landuse.<date>.[<user info>].gif
#

# Excluded data GIF
```

```
# format: <location>.excluded.[<user info>].gif
#

EXCLUDED_DATA= demo200.excluded.gif


# Slope data GIF
# format: <location>.slope.[<user info>].gif
#

SLOPE_DATA= demo200.slope.gif

#
# Background data GIF
# format: <location>.hillshade.[<user info>].gif
#

BACKGROUND_DATA= demo200.hillshade.gif

# XI. OUTPUT IMAGES
#   WRITE_COLOR_KEY_IMAGES: Creates image maps of each colortable.
#                     File name format: 'key_[type]_COLORMAP'
#                     where [type] represents the colortable.
#   ECHO_IMAGE_FILES: Creates GIF of each input file used in that job.
# File names format: 'echo_of_[input_filename]'
# where [input_filename] represents the input name.
#   ANIMATION: if whirlgif has been compiled, and the WHIRLGIF_BINARY
#           path has been defined, animated gifs begining with the
#           file name 'animated' will be created in PREDICT and
#           CALIBRATE mode.

WRITE_COLOR_KEY_IMAGES(YES/NO)=yes
ECHO_IMAGE_FILES(YES/NO)=yes
ANIMATION(YES/NO)= yes

# XII. COLORTABLE SETTINGS
#  A. DATE COLOR SETTING
#    The date will automatically be placed in the lower left corner
#    of output images. DATE_COLOR may be designated in with red, green,
#    and blue values (format: <red_value, green_value, blue_value> )
#    or with hexadecimal begining with '0X' (format: <0X######> ).
#default DATE_COLOR= 0XFFFFFF white

DATE_COLOR=    0XFFFFFF #white

# B. URBAN (NON-LANDUSE) COLORTABLE SETTINGS
#    1. URBAN MODE OUTPUTS
#       TEST mode: Annual images of simulated urban growth will be
#                created using SEED_COLOR to indicate urbanized areas.

#       CALIBRATE mode: Images will not be created.
#       PREDICT mode: Annual probability images of simulated urban
#                  growth will be created using the PROBABILITY
```

```
#                    _COLORTABLE. The initializing urban data will be
#                    indicated by SEED_COLOR.
#
#    2. COLORTABLE SETTINGS
#       SEED_COLOR: initializing and extrapolated historic urban extent

#       WATER_COLOR: BACKGROUND_DATA is used as a backdrop for

#                    simulated urban growth. If pixels in this file
#                    contain the value zero (0), they will be filled
#                    with the color value in WATER_COLOR. In this way,
#                    major water bodies in a study area may be included
#                    in output images.

SEED_COLOR= 0XFFFF00 #yellow
SEED_COLOR=  255, 255, 0 #yellow
WATER_COLOR=  0X0000FF # blue

#    3. PROBABILITY COLORTABLE FOR URBAN GROWTH
#      For PREDICTION, annual probability images of urban growth
#      will be created using the monte carlo iterations. In these
#      images, the higher the value the more likely urbanizaion is.
#      In order to interpret these 'continuous' values more easily
#      they may be color classified by range.
#
#      If 'hex' is not present then the range is transparent.
#      The transparent range must be the first on the list.
#      The max number of entries is 100.
#        PROBABILITY_COLOR: a color value in hexadecimal that indicates
#                           a probability range.
#          low/upper: indicate the boundaries of the range.
#
#              low,  upper,   hex,  (Optional Name)
PROBABILITY_COLOR=  0,    50,         , #transparent
PROBABILITY_COLOR=  50,   60, 0X005A00, #0, 90,0 dark green
PROBABILITY_COLOR=  60,   70, 0X008200, #0,130,0
PROBABILITY_COLOR=  70,   80, 0X00AA00, #0,170,0
PROBABILITY_COLOR=  80,   90, 0X00D200, #0,210,0
PROBABILITY_COLOR=  90,   95, 0X00FF00, #0,255,0 light green
PROBABILITY_COLOR=  95,  100, 0X8B0000, #dark red

# C. LAND COVER COLORTABLE
# Land cover input images should be in grayscale GIF image format. #  The 'pix' value
indicates a land class grayscale pixel value in #  the image. If desired, the model will
create color classified #  land cover output. The output colortable is designated by the #
'hex/rgb' values.
#   pix: input land class pixel value
#   name: text string indicating land class
#   flag: special case land classes
#        URB - urban class (area is included in urban input data
#             and will not be transitioned by deltatron)
#        UNC - unclass (no data areas in image)
#        EXC - excluded (land class will be ignored by deltatron)
```

```
#   hex/rgb: hexidecimal or rgb (red, green, blue) output colors
#
#           pix, name,     flag,   hex/rgb, #comment
# LANDUSE_CLASS= 0,  Unclass , UNC    , 0X000000
# LANDUSE_CLASS= 1,  Urban   , URB    , 0X8b2323 #dark red
# LANDUSE_CLASS= 2,  Agric   ,        , 0Xffec8b #pale yellow
# LANDUSE_CLASS= 3,  Range   ,        , 0Xee9a49 #tan
# LANDUSE_CLASS= 4,  Forest  ,        , 0X006400
# LANDUSE_CLASS= 5,  Water   , EXC    , 0X104e8b
# LANDUSE_CLASS= 6,  Wetland ,        , 0X483d8b
# LANDUSE_CLASS= 7,  Barren  ,        , 0Xeec591
# LANDUSE_CLASS= 8,  Tundra  ,        , 0X323232
# LANDUSE_CLASS= 9,  Ice&Sno ,        , 0XFFFFFF

# D. GROWTH TYPE IMAGE OUTPUT CONTROL AND COLORTABLE
#
# From here you can control the output of the Z grid
# (urban growth) just after it is returned from the spr_spread() #  function. In this way it
is possible to see the different types #  of growth that have occured. # #
VIEW_GROWTH_TYPES(YES/NO) provides an on/off #  toggle to control whether the
images are generated. # #  GROWTH_TYPE_PRINT_WINDOW provides a print window #
to control the amount of images created. #  format:
<start_run>,<end_run>,<start_monte_carlo>,
#        <end_monte_carlo>,<start_year>,<end_year>
# for example:
# GROWTH_TYPE_PRINT_WINDOW=run1,run2,mc1,mc2,year1,year2
# so images are only created when
# run1<= current run <=run2 AND
# mc1 <= current monte carlo <= mc2 AND
# year1 <= currrent year <= year2
#
# 0 == first

VIEW_GROWTH_TYPES(YES/NO)=yes
GROWTH_TYPE_PRINT_WINDOW=0,1,0,1,1995,2020
PHASE0G_GROWTH_COLOR=  0xff0000 # seed urban area
PHASE1G_GROWTH_COLOR=  0X00ff00 # diffusion growth
PHASE2G_GROWTH_COLOR=  0X0000ff # NOT USED PHASE3G_GROWTH_COLOR=
0Xffff00 # breed growth PHASE4G_GROWTH_COLOR=  0Xffffff # spread growth
PHASE5G_GROWTH_COLOR=  0X00ffff # road influenced growth

#*************************************************************
#
# E. DELTATRON AGING SECTION
#
# From here you can control the output of the deltatron grid
# just before they are aged
#
# VIEW_DELTATRON_AGING(YES/NO) provides an on/off
# toggle to control whether the images are generated.
#
# DELTATRON_PRINT_WINDOW provides a print window
# to control the amount of images created.
```

```
# format:  <start_run>,<end_run>,<start_monte_carlo>,
#          <end_monte_carlo>,<start_year>,<end_year>
# for example:
# DELTATRON_PRINT_WINDOW=run1,run2,mc1,mc2,year1,year2
# so images are only created when
# run1<= current run <=run2 AND
# mc1 <= current monte carlo <= mc2 AND
# year1 <= currrent year <= year2
#
# 0 == first

VIEW_DELTATRON_AGING(YES/NO)=NO
DELTATRON_PRINT_WINDOW=0,0,0,0,1955,2020
DELTATRON_COLOR=  0x000000 # index 0 No or dead deltatron DELTATRON_COLOR=
0X00FF00 # index 1 age = 1 year DELTATRON_COLOR=  0X00D200 # index 2 age = 2
year DELTATRON_COLOR=  0X00AA00 # index 3 age = 3 year DELTATRON_COLOR=
0X008200 # index 4 age = 4 year DELTATRON_COLOR=  0X005A00 # index 5 age = 5
year

# XI.SELF-MODIFICATION PARAMETERS
#   SLEUTH is a self-modifying cellular automata. For more information
#   see our PROJECT GIGALOPOLIS web site
#   (www.ncgia.ucsb.edu/project/gig/)
#   and publications (and/or grep 'self modification' in code).

ROAD_GRAV_SENSITIVITY=0.01
SLOPE_SENSITIVITY=0.1
CRITICAL_LOW=0.97
CRITICAL_HIGH=1.03
CRITICAL_LOW=0.0
CRITICAL_HIGH=10000000000000.0
CRITICAL_SLOPE=15.0
BOOM=1.1
BUST=0.9
```

Appendix (2)

Phase test of the model using our data. The model has worked well with the data of the current study.

```
seat1 [sparc] 16% cd Scenarios
seat1 [sparc] 17% ../grow test scenario.demo200


**************************************************************************
****
**************************************************************************
****
**                                                        **
**                    SLUETH                                **
**              (URBAN GROWTH MODEL)                              **
**                 Beta Version 3.0                           **
**            Release Date: December4, 2000                          **
**                                                        **
**                                                        **
** Notice: This is a beta version. It has been formally released    **
** by the U.S. Environmental Protection Agency (EPA) and should       **
** not be construed to represent Agency policy. This model is being   **
** circulated for comments on its technical merit and potential for  **
** policy implications.                                         **
**                                                        **
** The U.S. Environmental Protection Agency through its Office      **
** of Research and Development Interagency Agreement #DW14938148-01-2  **
** with the United States Geological Survey partially funded and     **
** collaborated in the model described here. Implementation and      **
** redesign of the model code was conducted under contract #68W70055   **
** to Lockheed Martin Technical Services. The model has not been     **
** subjected to Agency review . Mention of trade names or           **
** commercial products does not constitute an endorsement or         **
** recommendation for use.                                       **
**                                                        **
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**                                                  **
**********************************************************************
****
**********************************************************************
****


growth.c 122 *******************************************
growth.c 130 Monte Carlo = 1 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
```

```
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995
growth.c 122 *********************************************
growth.c 130 Monte Carlo = 2 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 3 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 4 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 5 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995
seat1 [sparc] 18%
```

Appendix (3)

The model outputs from test phase.

```
seat1 [sparc] 27% cd UG-My-Outputs
seat1 [sparc] 28% ls -l | more
total 7368
-rw-------   1 n8721108 ntcqw      466 Jun 23 16:43 avg.log
-rw-------   1 n8721108 ntcqw    12465 Jun 23 16:42 coeff.log
-rw-------   1 n8721108 ntcqw      327 Jun 23 16:43 control_stats.log
-rw-------   1 n8721108 ntcqw    80581 Jun 23 16:35 demo200_urban_1956.gif
-rw-------   1 n8721108 ntcqw    80707 Jun 23 16:36 demo200_urban_1957.gif
-rw-------   1 n8721108 ntcqw    81029 Jun 23 16:36 demo200_urban_1958.gif
-rw-------   1 n8721108 ntcqw    81119 Jun 23 16:36 demo200_urban_1959.gif
-rw-------   1 n8721108 ntcqw    81261 Jun 23 16:36 demo200_urban_1960.gif
-rw-------   1 n8721108 ntcqw    81422 Jun 23 16:37 demo200_urban_1961.gif
-rw-------   1 n8721108 ntcqw    81556 Jun 23 16:37 demo200_urban_1962.gif
-rw-------   1 n8721108 ntcqw    81647 Jun 23 16:37 demo200_urban_1963.gif
-rw-------   1 n8721108 ntcqw    81854 Jun 23 16:37 demo200_urban_1964.gif
-rw-------   1 n8721108 ntcqw    81991 Jun 23 16:37 demo200_urban_1965.gif
-rw-------   1 n8721108 ntcqw    82068 Jun 23 16:37 demo200_urban_1966.gif
-rw-------   1 n8721108 ntcqw    82135 Jun 23 16:38 demo200_urban_1967.gif
-rw-------   1 n8721108 ntcqw    82413 Jun 23 16:38 demo200_urban_1968.gif
-rw-------   1 n8721108 ntcqw    82514 Jun 23 16:38 demo200_urban_1969.gif
-rw-------   1 n8721108 ntcqw    82632 Jun 23 16:38 demo200_urban_1970.gif
-rw-------   1 n8721108 ntcqw    82796 Jun 23 16:38 demo200_urban_1971.gif
-rw-------   1 n8721108 ntcqw    82950 Jun 23 16:38 demo200_urban_1972.gif
-rw-------   1 n8721108 ntcqw    83061 Jun 23 16:38 demo200_urban_1973.gif
-rw-------   1 n8721108 ntcqw    83266 Jun 23 16:39 demo200_urban_1974.gif
-rw-------   1 n8721108 ntcqw    83300 Jun 23 16:39 demo200_urban_1975.gif
-rw-------   1 n8721108 ntcqw    83455 Jun 23 16:39 demo200_urban_1976.gif
-rw-------   1 n8721108 ntcqw    83579 Jun 23 16:39 demo200_urban_1977.gif
-rw-------   1 n8721108 ntcqw    83732 Jun 23 16:39 demo200_urban_1978.gif
-rw-------   1 n8721108 ntcqw    83848 Jun 23 16:39 demo200_urban_1979.gif
-rw-------   1 n8721108 ntcqw    83956 Jun 23 16:40 demo200_urban_1980.gif
-rw-------   1 n8721108 ntcqw    84040 Jun 23 16:40 demo200_urban_1981.gif
-rw-------   1 n8721108 ntcqw    84106 Jun 23 16:40 demo200_urban_1982.gif
-rw-------   1 n8721108 ntcqw    84275 Jun 23 16:40 demo200_urban_1983.gif
-rw-------   1 n8721108 ntcqw    84441 Jun 23 16:40 demo200_urban_1984.gif
-rw-------   1 n8721108 ntcqw    84490 Jun 23 16:40 demo200_urban_1985.gif
-rw-------   1 n8721108 ntcqw    84518 Jun 23 16:41 demo200_urban_1986.gif
-rw-------   1 n8721108 ntcqw    84744 Jun 23 16:41 demo200_urban_1987.gif
-rw-------   1 n8721108 ntcqw    84747 Jun 23 16:41 demo200_urban_1988.gif
-rw-------   1 n8721108 ntcqw    84756 Jun 23 16:41 demo200_urban_1989.gif
-rw-------   1 n8721108 ntcqw    84888 Jun 23 16:41 demo200_urban_1990.gif
-rw-------   1 n8721108 ntcqw    84974 Jun 23 16:41 demo200_urban_1991.gif
-rw-------   1 n8721108 ntcqw    85037 Jun 23 16:41 demo200_urban_1992.gif
-rw-------   1 n8721108 ntcqw    85114 Jun 23 16:42 demo200_urban_1993.gif
-rw-------   1 n8721108 ntcqw    85248 Jun 23 16:42 demo200_urban_1994.gif
-rw-------   1 n8721108 ntcqw    85355 Jun 23 16:42 demo200_urban_1995.gif
-rw-------   1 n8721108 ntcqw     9613 Jun 23 16:13 echo_of_demo200.excluded.gif
-rw-------   1 n8721108 ntcqw    79785 Jun 23 16:14 echo_of_demo200.hillshade.gif
-rw-------   1 n8721108 ntcqw   16189 Jun 23 16:1 echo_of_demo200.roads.1955.gif
```

```
-rw-------   1 n8721108 ntcqw  18930 Jun 23 16:1 echo_of_demo200.roads.1995.gif
-rw-------   1 n8721108 ntcqw   144212 Jun 23 16:14 echo_of_demo200.slope.gif
-rw-------   1 n8721108 ntcqw  5597 Jun 23 16:1 echo_of_demo200.urban.1955.gif
-rw-------   1 n8721108 ntcqw  8512 Jun 23 16:12 echo_of_demo200.urban.1995.gif
-rw-------   1 n8721108 ntcqw 17446 Jun 23 16:12 key_DELTATRON_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    17446 Jun 23 16:12 key_GROWTH_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    17446 Jun 23 16:12 key_LANDUSE_COLORMAP.gif
-rw-------   1 n8721108 ntcqw 17446 Jun 23 16:12 key_PROBABILITY_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    16841 Jun 23 16:43 LOG_0
-rw-------   1 n8721108 ntcqw       20 Jun 23 16:15 restart_file.data0
-rw-------   1 n8721108 ntcqw      466 Jun 23 16:43 std_dev.log
-rw-------   1 n8721108 ntcqw     7602 Jun 23 16:19 z_growth_types_0_0_1995.gif
-rw-------   1 n8721108 ntcqw    7676 Jun 23 16:24 z_growth_types_0_1_1995.gif
```

Appendix (4)

The log file of the test phase. This file was used to check the validity of used data.

```
**************************************************************************
****
**************************************************************************
****
**                                                          **
**                       SLUETH                                **
**                  (URBAN GROWTH MODEL)                               **
**                   Beta Version 3.0                         **
**             Release Date: December4, 2000                          **
**                                                          **
**                                                          **
**  Notice:  This is a beta version.  It has been formally released     **
**  by the U.S. Environmental Protection Agency (EPA) and should         **
**  not be construed to represent Agency policy. This model is being    **
**  circulated for comments on its technical merit and potential for    **
**  policy implications.                                        **
**                                                          **
**  The U.S. Environmental Protection Agency through its Office          **
**  of Research and Development Interagency Agreement #DW14938148-01-2   **
**  with the United States Geological Survey partially funded and        **
**  collaborated in the model described here. Implementation and         **
**  redesign of the model code was conducted under contract #68W70055    **
**  to Lockheed Martin Technical Services.  The model has not been       **
**  subjected to Agency review .  Mention of trade names or              **
**  commercial products does not constitute an endorsement or            **
**  recommendation for use.                                        **
**                                                          **
**  Contributors:                                                   **
**                                                          **
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**  (Project Officer, coordination, parallelization, technical          **
**  assistance, review and testing)                                  **
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**                                                          **
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**                                                          **
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```

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** Santa Barbara, CA 93117                                   **
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**                                                   **
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** Research Triangle Park, NC 27711                          **
** (Implementation, model redesign, parallelization, and coding)      **
**                                                   **
****************************************************************************
****
****************************************************************************
****
```

DATE OF RUN: Mon Jun 23 16:11:14 2003

USER: n8721108
HOST: finan
HOSTTYPE: sun
OSTYPE: sparc
Type of architecture: 32 bit

Number of CPUs 1

PWD: /home/ucs/040/n8721108/UG/UGM3.0beta/Scenarios
Scenario File: scenario.demo200
Type of Processing: TESTING
scenario.filename = scenario.demo200
scenario.input_dir = /home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/
scenario.output_dir = /home/ucs/040/n8721108/UG-My-Outputs/
scenario.whirlgif_binary = /home/ucs/040/n8721108/UG/UGM3.0beta/Whirlgif/whirlgif/
scenario.urban_data_file[0] = demo200.urban.1955.gif scenario.urban_data_file[1] = demo200.urban.1995.gif scenario.road_data_file[0] = demo200.roads.1955.gif scenario.road_data_file[1] = demo200.roads.1995.gif scenario.excluded_data_file = demo200.excluded.gif scenario.slope_data_file = demo200.slope.gif scenario.background_data_file = demo200.hillshade.gif scenario.echo = 1 scenario.logging = 1 scenario.log_processing_status = 1 scenario.random_seed = 47392074 scenario.num_working_grids = 5 scenario.monte_carlo_iterations = 5 scenario.start.diffusion = 0 scenario.stop.diffusion = 100 scenario.step.diffusion = 25 scenario.best_fit.diffusion = 20 scenario.start.breed = 0 scenario.stop.breed = 100 scenario.step.breed = 25 scenario.best_fit.breed = 20 scenario.start.spread = 0 scenario.stop.spread = 100 scenario.step.spread = 25 scenario.best_fit.spread = 20 scenario.start.slope_resistance = 0 scenario.stop.slope_resistance = 100 scenario.step.slope_resistance = 25 scenario.best_fit.slope_resistance = 20 scenario.start.road_gravity = 0 scenario.stop.road_gravity = 100 scenario.step.road_gravity = 25 scenario.best_fit.road_gravity = 20 scenario.prediction_start_date = 1995 scenario.prediction_stop_date = 2015 scenario.date_color = ffffff scenario.seed_color = ffff00 scenario.water_color = ff scenario.probability_color[0].lower_bound = 0 scenario.probability_color[0].upper_bound = 50 scenario.probability_color[0].color = 0 scenario.rd_grav_sensitivity = 0.010000 scenario.slope_sensitivity = 0.100000 scenario.critical_low = 0.000000 scenario.critical_high = 10000000000000.000000 scenario.critical_slope = 15.000000 scenario.boom = 1.100000 scenario.bust = 0.900000 scenario.log_base_stats = 1 scenario.log_debug = 0 scenario.log_urbanization_attempts = 0 scenario.log_coeff = 0 scenario.log_timings = 1 scenario.write_avg_file = 1 scenario.write_std_dev_file = 1 scenario.log_memory_map = 0 scenario.log_landclass_summary = 1 scenario.log_slope_weights = 0 scenario.log_reads = 0 scenario.log_writes = 0 scenario.log_colortables = 0 scenario.log_processing_status = 1 scenario.log_trans_matrix = 1 scenario.view_growth_types = 1 scenario.growth_type_window.run1 = 0 scenario.growth_type_window.run2 = 1 scenario.growth_type_window.monte_carlo1 = 0 scenario.growth_type_window.monte_carlo2 = 1 scenario.growth_type_window.year1 = 1995 scenario.growth_type_window.year2 = 2020 scenario.phase0g_growth_color = ff0000 scenario.phase1g_growth_color = ff00 scenario.phase2g_growth_color = ff scenario.phase3g_growth_color = ffff00 scenario.phase4g_growth_color = ffffff scenario.phase5g_growth_color = ffff scenario.view_deltatron_aging = 0 scenario.deltatron_aging_window.run1 = 0 scenario.deltatron_aging_window.run2 = 0 scenario.deltatron_aging_window.monte_carlo1 = 0 scenario.deltatron_aging_window.monte_carlo2 = 0 scenario.deltatron_aging_window.year1 = 1955 scenario.deltatron_aging_window.year2 = 2020 scenario.deltatron_color[0] = 0 scenario.deltatron_color[1] = 65280 scenario.deltatron_color[2] = 53760 scenario.deltatron_color[3] = 43520 scenario.deltatron_color[4] = 33280 scenario.deltatron_color[5] = 23040 coeff_obj.c 1237 start_coeff.diffusion = 0 coeff_obj.c 1238 start_coeff.spread = 0 coeff_obj.c 1239 start_coeff.breed = 0 coeff_obj.c 1240 start_coeff.slope_resistance = 0 coeff_obj.c

1241 start_coeff.road_gravity = 0 coeff_obj.c 1258 stop_coeff.diffusion = 100 coeff_obj.c 1259 stop_coeff.spread = 100 coeff_obj.c 1260 stop_coeff.breed = 100 coeff_obj.c 1261 stop_coeff.slope_resistance = 100 coeff_obj.c 1262 stop_coeff.road_gravity = 100 coeff_obj.c 1216 step_coeff.diffusion = 25 coeff_obj.c 1217 step_coeff.spread = 25 coeff_obj.c 1218 step_coeff.breed = 25 coeff_obj.c 1219 step_coeff.slope_resistance = 25 coeff_obj.c 1220 step_coeff.road_gravity = 25 coeff_obj.c 1279 best_fit_coeff.diffusion = 20 coeff_obj.c 1280 best_fit_coeff.spread = 20 coeff_obj.c 1281 best_fit_coeff.breed = 20 coeff_obj.c 1282 best_fit_coeff.slope_resistance = 20 coeff_obj.c 1283 best_fit_coeff.road_gravity = 20 memory_obj.c 717 Allocated 176133892 bytes of memory 730420 igrid_array[0].ptr 10515636 igrid_array[1].ptr 20300852 igrid_array[2].ptr 30086068 igrid_array[3].ptr 39871284 igrid_array[4].ptr 49656500 igrid_array[5].ptr 59441716 igrid_array[6].ptr pgrid_array[0].ptr = 69226932 pgrid_array[1].ptr = 79012148 pgrid_array[2].ptr = 88797364 pgrid_array[3].ptr = 98582580 pgrid_array[4].ptr = 108367796 pgrid_array[5].ptr = 118153012 wgrid_array[0].ptr = 127938228 wgrid_array[1].ptr = 137723444 wgrid_array[2].ptr = 147508660 wgrid_array[3].ptr = 157293876 wgrid_array[4].ptr = 167079092 mem_check_array[0].ptr = 730416 mem_check_array[1].ptr = 10515632 mem_check_array[2].ptr = 20300848 mem_check_array[3].ptr = 30086064 mem_check_array[4].ptr = 39871280 mem_check_array[5].ptr = 49656496 mem_check_array[6].ptr = 59441712 mem_check_array[7].ptr = 69226928 mem_check_array[8].ptr = 79012144 mem_check_array[9].ptr = 88797360 mem_check_array[10].ptr = 98582576 mem_check_array[11].ptr = 108367792 mem_check_array[12].ptr = 118153008 mem_check_array[13].ptr = 127938224 mem_check_array[14].ptr = 137723440 mem_check_array[15].ptr = 147508656 mem_check_array[16].ptr = 157293872 mem_check_array[17].ptr = 167079088 mem_check_array[18].ptr = 176864304 memory_obj.c 463 MEMORY CHECK at main.c main 324 MEMORY CHECK OK

****

****

VALIDATING INPUT GRIDS

Validating urban input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.urban.1955.gif

Index Count PercentOfImage
0 2402197 98.20%
128 44106 1.80%

Validating urban input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.urban.1995.gif

Index Count PercentOfImage
0 2332159 95.33%
128 114144 4.67%

Validating road input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.roads.1955.gif

Index Count PercentOfImage
0 2272979 92.91%
85 12011 0.49%
170 139782 5.71%

```
255  21531     0.88%

Validating road input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.roads.1995.gif

Index Count PercentOfImage
  0  2242089     91.65%
128  183482      7.50%
255  20732     0.85%

Validating slope input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.slope.gif

Validating excluded input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.excluded.gif

Validating background input grid:
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.hillshade.gif

Validation OK
**********************************************************
**********************************************************


*********************************INPUT GIFs*********************************

  Urban GIFs
     rowXcol cb bpp path
     rowXcol cb bpp min max path
   2263X1081  8  8   0 128
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.urban.1955.gif
   2263X1081  8  8   0 128
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.urban.1995.gif
  Road GIFs
     rowXcol cb bpp path
   2263X1081  8  8   0 255
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.roads.1955.gif
   2263X1081  8  8   0 255
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.roads.1995.gif
  Landuse GIFs
     rowXcol cb bpp path
  Excluded GIF
     rowXcol cb bpp path
   2263X1081  8  8   0 128
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.excluded.gif
  Slope GIF
     rowXcol cb bpp path
   2263X1081  8  8   0 255
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.slope.gif
  Background GIF
     rowXcol cb bpp path
   2263X1081  8  8  202 243
/home/ucs/040/n8721108/UG/UGM3.0beta/Input/demo200/demo200.hillshade.gif
```

```
cb = # of color bits
bpp = # bits per pixel
Verifying Data Input Files
igrid_obj.c 1618 Data Input Files: OK

*************************LOG OF BASE STATISTICS FOR URBAN INPUT
DATA*********************
 Year     Area     Edges   Clusters      Pop      Mean Center        Radius   Avg Slope
MeanClusterSize
 1955  44106.00  2296.00      3.00   44106.00  (  856.92,  240.35)    118.49
24.71     14671.000
 1995  114144.00  4403.00      2.00   114144.00  (  681.74,  480.79)    190.61
24.51     56999.000


growth.c 671 Run=   0 of 3125 MC=0 of 5
growth.c 671 Run=   0 of 3125 MC=1 of 5   0.006% complete; Elapsed=0000:00:03:27 ;
ETC=0037:13:25:04
growth.c 671 Run=   0 of 3125 MC=2 of 5   0.013% complete; Elapsed=0000:00:06:06 ;
ETC=0033:03:54:18
growth.c 671 Run=   0 of 3125 MC=3 of 5   0.019% complete; Elapsed=0000:00:08:56 ;
ETC=0032:08:36:05
growth.c 671 Run=   0 of 3125 MC=4 of 5   0.026% complete; Elapsed=0000:00:11:34 ;
ETC=0031:09:12:51

******************************LOG OF TIMINGS
************************************
      Routine #Calls   Avg Time   Total Time
                      (millisec)  (millisec)
    spr_spread  200     1317.70     263540.00 = 0000:00:04:23
   spr_phase1n3  200       2.45        490.00 = 0000:00:00:00
    spr_phase4  200      500.20     100040.00 = 0000:00:01:40
    spr_phase5  200      111.75      22350.00 = 0000:00:00:22
  gdif_WriteGIF   49     2067.55     101310.00 = 0000:00:01:41
   gdif_ReadGIF    7     3082.86      21580.00 = 0000:00:00:21
delta_deltatron    0        0.00          0.00 = 0000:00:00:00
  delta_phase1     0        0.00          0.00 = 0000:00:00:00
  delta_phase2     0        0.00          0.00 = 0000:00:00:00
    grw_growth     5   182488.00     912440.00 = 0000:00:15:12
    drv_driver     1   914010.00     914010.00 = 0000:00:15:14
          main     2   481815.00     963630.00 = 0000:00:16:03
Number of CPUS = 1
Minmum number of Free working grids=1
For max efficiency of memory usage reduce NUM_WORKING_GRIDS by 1
```

Appendix (5)

Calibration requires many (often thousands) of single simulations of land cover change. Therefore, output requirements can greatly add to the total application time. The following is an example from the calibration phase.

```
rowth.c 122 ********************************************
growth.c 126 Run = 121 of 3125 (    3.9 percent complete)
growth.c 130 Monte Carlo = 1 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 ********************************************
growth.c 126 Run = 121 of 3125 (    3.9 percent complete)
growth.c 130 Monte Carlo = 2 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 ********************************************
growth.c 126 Run = 121 of 3125 (    3.9 percent complete)
growth.c 130 Monte Carlo = 3 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 ********************************************
growth.c 126 Run = 121 of 3125 (    3.9 percent complete)
growth.c 130 Monte Carlo = 4 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 ********************************************
growth.c 126 Run = 121 of 3125 (    3.9 percent complete)
```

```
growth.c 130 Monte Carlo = 5 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *******************************************
growth.c 126 Run = 122 of 3125 (     3.9 percent complete)
growth.c 130 Monte Carlo = 1 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *******************************************
growth.c 126 Run = 122 of 3125 (     3.9 percent complete)
growth.c 130 Monte Carlo = 2 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *******************************************
growth.c 126 Run = 122 of 3125 (     3.9 percent complete)
growth.c 130 Monte Carlo = 3 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
 1956 1957 1958 1959
 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989
 1990 1991 1992 1993 1994 1995

growth.c 122 *******************************************
growth.c 126 Run = 122 of 3125 (     3.9 percent complete)
growth.c 130 Monte Carlo = 4 of 5
growth.c 133 proc_GetCurrentYear=1955
growth.c 135 proc_GetStopYear=1995
```

Appendix (6)

Prediction mode was tested initially using the years ranging between 1995 and 2015 to estimate the running time. The first run lasted about 30 minutes. The following shows the processes of this phase.

```
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** Denver, CO 80225-0046
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**
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**
** Raytheon Corporation (contract with USGS #8701)
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** Sioux Falls, SD 57198
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**
**
**
** Tommy E. Cathey
**
** Lockheed Martin Technical Services
**
** National Environmental Supercomputing Center
**
** United States Environmental Protection Agency
**
** Research Triangle Park, NC 27711
**
** (Implementation, model redesign, parallelization, and coding)
**
**
**
```

```
*****************************************************************************
*
***
*****************************************************************************
*
***

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 1 of 5
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2015
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 2 of 5
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2015
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 3 of 5
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2015
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 4 of 5
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2015
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015

growth.c 122 *********************************************
growth.c 130 Monte Carlo = 5 of 5
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2015
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015
whirlgif Rev 3.04 (c) 1997-1999 by Hans Dinsen-Hansen
            (c) 1995-1996 by Kevin Kadow
            (c) 1990-1993 by Mark Podlipec
Processed 61 files.
```

Appendix (7)

This prediction run was implemented using a larger date range (1995-2055) to give much more indication of the future urban growth; the Monte Carlo iterations were increased to 100, and the generated coefficients of the area of study were used in this run. Here is a part of the log file of this run.

```
growth.c 122 *******************************************
growth.c 130 Monte Carlo = 93 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 94 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 95 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 96 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
```

```
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 97 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 98 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 99 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055

growth.c 122 *******************************************
growth.c 130 Monte Carlo = 100 of 100
growth.c 133 proc_GetCurrentYear=1995
growth.c 135 proc_GetStopYear=2055
 1996 1997 1998 1999
 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029
 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039
 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049
 2050 2051 2052 2053 2054 2055
whirlgif Rev 3.04 (c) 1997-1999 by Hans Dinsen-Hansen
              (c) 1995-1996 by Kevin Kadow
```

```
        (c) 1990-1993 by Mark Podlipec
Processed 61 files.
finan [sparc] 168%
```

Appendix (8)

This appendix shows the final output files and images from the last running of the prediction mode.

```
finan [sparc] 23% pwd
/home/ucs/040/n8721108/UG-My-OutputsP-SM
finan [sparc] 24% ls -l | more
total 41504
-rw-------   1 n8721108 ntcqw     15987 Nov  6 12:42 LOG_0
-rw-------   1 n8721108 ntcqw   6821555 Nov  6 12:42 animated_urban.gif
-rw-------   1 n8721108 ntcqw     14336 Nov  6 12:42 avg.log
-rw-------   1 n8721108 ntcqw     18665 Nov  6 12:42 coeff.log
-rw-------   1 n8721108 ntcqw    265257 Nov  6 12:42 cumulate_urban.gif
-rw-------   1 n8721108 ntcqw    189636 Nov  6 12:42 demo200_cumcolor_urban_2
055.gif
-rw-------   1 n8721108 ntcqw     81789 Nov  6 12:18 demo200_urban_1996.gif
-rw-------   1 n8721108 ntcqw     82713 Nov  6 12:19 demo200_urban_1997.gif
-rw-------   1 n8721108 ntcqw     83266 Nov  6 12:19 demo200_urban_1998.gif
-rw-------   1 n8721108 ntcqw     83614 Nov  6 12:19 demo200_urban_1999.gif
-rw-------   1 n8721108 ntcqw     83921 Nov  6 12:19 demo200_urban_2000.gif
-rw-------   1 n8721108 ntcqw     84105 Nov  6 12:20 demo200_urban_2001.gif
-rw-------   1 n8721108 ntcqw     84317 Nov  6 12:20 demo200_urban_2002.gif
-rw-------   1 n8721108 ntcqw     84414 Nov  6 12:20 demo200_urban_2003.gif
-rw-------   1 n8721108 ntcqw     84662 Nov  6 12:20 demo200_urban_2004.gif
-rw-------   1 n8721108 ntcqw     84865 Nov  6 12:20 demo200_urban_2005.gif
-rw-------   1 n8721108 ntcqw     84826 Nov  6 12:21 demo200_urban_2006.gif
-rw-------   1 n8721108 ntcqw     85016 Nov  6 12:21 demo200_urban_2007.gif
-rw-------   1 n8721108 ntcqw     85193 Nov  6 12:21 demo200_urban_2008.gif
-rw-------   1 n8721108 ntcqw     85193 Nov  6 12:22 demo200_urban_2009.gif
-rw-------   1 n8721108 ntcqw     85329 Nov  6 12:22 demo200_urban_2010.gif
-rw-------   1 n8721108 ntcqw     85409 Nov  6 12:22 demo200_urban_2011.gif
-rw-------   1 n8721108 ntcqw     85608 Nov  6 12:23 demo200_urban_2012.gif
-rw-------   1 n8721108 ntcqw     85786 Nov  6 12:23 demo200_urban_2013.gif
-rw-------   1 n8721108 ntcqw     86006 Nov  6 12:23 demo200_urban_2014.gif
-rw-------   1 n8721108 ntcqw     86418 Nov  6 12:24 demo200_urban_2015.gif
-rw-------   1 n8721108 ntcqw     86584 Nov  6 12:24 demo200_urban_2016.gif
-rw-------   1 n8721108 ntcqw     86952 Nov  6 12:25 demo200_urban_2017.gif
-rw-------   1 n8721108 ntcqw     87406 Nov  6 12:25 demo200_urban_2018.gif
-rw-------   1 n8721108 ntcqw     88077 Nov  6 12:25 demo200_urban_2019.gif
-rw-------   1 n8721108 ntcqw     88622 Nov  6 12:26 demo200_urban_2020.gif
-rw-------   1 n8721108 ntcqw     89358 Nov  6 12:26 demo200_urban_2021.gif
-rw-------   1 n8721108 ntcqw     90224 Nov  6 12:27 demo200_urban_2022.gif
-rw-------   1 n8721108 ntcqw     91116 Nov  6 12:27 demo200_urban_2023.gif
-rw-------   1 n8721108 ntcqw     92131 Nov  6 12:28 demo200_urban_2024.gif
-rw-------   1 n8721108 ntcqw     92992 Nov  6 12:28 demo200_urban_2025.gif
-rw-------   1 n8721108 ntcqw     94260 Nov  6 12:28 demo200_urban_2026.gif
-rw-------   1 n8721108 ntcqw     95836 Nov  6 12:29 demo200_urban_2027.gif
```

```
-rw-------   1 n8721108 ntcqw    97355 Nov  6 12:29 demo200_urban_2028.gif
-rw-------   1 n8721108 ntcqw    99147 Nov  6 12:30 demo200_urban_2029.gif
-rw-------   1 n8721108 ntcqw   101102 Nov  6 12:30 demo200_urban_2030.gif
-rw-------   1 n8721108 ntcqw   103401 Nov  6 12:31 demo200_urban_2031.gif
-rw-------   1 n8721108 ntcqw   105923 Nov  6 12:31 demo200_urban_2032.gif
-rw-------   1 n8721108 ntcqw   108428 Nov  6 12:31 demo200_urban_2033.gif
-rw-------   1 n8721108 ntcqw   111264 Nov  6 12:32 demo200_urban_2034.gif
-rw-------   1 n8721108 ntcqw   114053 Nov  6 12:32 demo200_urban_2035.gif
-rw-------   1 n8721108 ntcqw   117210 Nov  6 12:33 demo200_urban_2036.gif
-rw-------   1 n8721108 ntcqw   120695 Nov  6 12:33 demo200_urban_2037.gif
-rw-------   1 n8721108 ntcqw   123768 Nov  6 12:34 demo200_urban_2038.gif
-rw-------   1 n8721108 ntcqw   127487 Nov  6 12:34 demo200_urban_2039.gif
-rw-------   1 n8721108 ntcqw   131545 Nov  6 12:34 demo200_urban_2040.gif
-rw-------   1 n8721108 ntcqw   135300 Nov  6 12:35 demo200_urban_2041.gif
-rw-------   1 n8721108 ntcqw   139272 Nov  6 12:35 demo200_urban_2042.gif
-rw-------   1 n8721108 ntcqw   143029 Nov  6 12:36 demo200_urban_2043.gif
-rw-------   1 n8721108 ntcqw   146886 Nov  6 12:36 demo200_urban_2044.gif
-rw-------   1 n8721108 ntcqw   150856 Nov  6 12:37 demo200_urban_2045.gif
-rw-------   1 n8721108 ntcqw   154898 Nov  6 12:37 demo200_urban_2046.gif
-rw-------   1 n8721108 ntcqw   158915 Nov  6 12:38 demo200_urban_2047.gif
-rw-------   1 n8721108 ntcqw   162780 Nov  6 12:38 demo200_urban_2048.gif
-rw-------   1 n8721108 ntcqw   166821 Nov  6 12:39 demo200_urban_2049.gif
-rw-------   1 n8721108 ntcqw   170805 Nov  6 12:39 demo200_urban_2050.gif
-rw-------   1 n8721108 ntcqw   174938 Nov  6 12:40 demo200_urban_2051.gif
-rw-------   1 n8721108 ntcqw   178430 Nov  6 12:40 demo200_urban_2052.gif
-rw-------   1 n8721108 ntcqw   182283 Nov  6 12:40 demo200_urban_2053.gif
-rw-------   1 n8721108 ntcqw   186069 Nov  6 12:41 demo200_urban_2054.gif
-rw-------   1 n8721108 ntcqw   189636 Nov  6 12:41 demo200_urban_2055.gif
-rw-------   1 n8721108 ntcqw     9613 Nov  6 10:54 echo_of_demo200.excluded.gif
-rw-------   1 n8721108 ntcqw    79785 Nov  6 10:54 echo_of_demo200.hillshade.gif
-rw-------   1 n8721108 ntcqw    18930 Nov  6 10:54 echo_of_demo200.roads.1995.gif
-rw-------   1 n8721108 ntcqw   144212 Nov  6 10:54 echo_of_demo200.slope.gif
-rw-------   1 n8721108 ntcqw     8512 Nov  6 10:54 echo_of_demo200.urban.1995.gif
-rw-------   1 n8721108 ntcqw    17446 Nov  6 10:54 key_DELTATRON_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    17446 Nov  6 10:54 key_GROWTH_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    17446 Nov  6 10:54 key_LANDUSE_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    17446 Nov  6 10:54 key_PROBABILITY_COLORMAP.gif
-rw-------   1 n8721108 ntcqw    14213 Nov  6 12:42 std_dev.log
-rw-------   1 n8721108 ntcqw     9905 Nov  6 10:54 z_growth_types_0_0_1996.gif
-rw-------   1 n8721108 ntcqw    10859 Nov  6 10:55 z_growth_types_0_0_1997.gif
-rw-------   1 n8721108 ntcqw    11652 Nov  6 10:55 z_growth_types_0_0_1998.gif
-rw-------   1 n8721108 ntcqw    13096 Nov  6 10:55 z_growth_types_0_0_1999.gif
-rw-------   1 n8721108 ntcqw    13970 Nov  6 10:55 z_growth_types_0_0_2000.gif
-rw-------   1 n8721108 ntcqw    14852 Nov  6 10:55 z_growth_types_0_0_2001.gif
-rw-------   1 n8721108 ntcqw    15644 Nov  6 10:55 z_growth_types_0_0_2002.gif
-rw-------   1 n8721108 ntcqw    16442 Nov  6 10:56 z_growth_types_0_0_2003.gif
-rw-------   1 n8721108 ntcqw    17601 Nov  6 10:56 z_growth_types_0_0_2004.gif
-rw-------   1 n8721108 ntcqw    18983 Nov  6 10:56 z_growth_types_0_0_2005.gif
-rw-------   1 n8721108 ntcqw    20173 Nov  6 10:56 z_growth_types_0_0_2006.gif
-rw-------   1 n8721108 ntcqw    21279 Nov  6 10:56 z_growth_types_0_0_2007.gif
-rw-------   1 n8721108 ntcqw    22405 Nov  6 10:57 z_growth_types_0_0_2008.gif
-rw-------   1 n8721108 ntcqw    24052 Nov  6 10:57 z_growth_types_0_0_2009.gif
-rw-------   1 n8721108 ntcqw    25498 Nov  6 10:57 z_growth_types_0_0_2010.gif
```

```
-rw-------   1 n8721108 ntcqw    26781 Nov  6 10:58 z_growth_types_0_0_2011.gif
-rw-------   1 n8721108 ntcqw    28340 Nov  6 10:58 z_growth_types_0_0_2012.gif
-rw-------   1 n8721108 ntcqw    29898 Nov  6 10:58 z_growth_types_0_0_2013.gif
-rw-------   1 n8721108 ntcqw    31409 Nov  6 10:59 z_growth_types_0_0_2014.gif
-rw-------   1 n8721108 ntcqw    32919 Nov  6 10:59 z_growth_types_0_0_2015.gif
-rw-------   1 n8721108 ntcqw    34873 Nov  6 10:59 z_growth_types_0_0_2016.gif
-rw-------   1 n8721108 ntcqw    36520 Nov  6 11:00 z_growth_types_0_0_2017.gif
-rw-------   1 n8721108 ntcqw    38149 Nov  6 11:00 z_growth_types_0_0_2018.gif
-rw-------   1 n8721108 ntcqw    39989 Nov  6 11:00 z_growth_types_0_0_2019.gif
-rw-------   1 n8721108 ntcqw    41782 Nov  6 11:01 z_growth_types_0_0_2020.gif
-rw-------   1 n8721108 ntcqw    43490 Nov  6 11:01 z_growth_types_0_0_2021.gif
-rw-------   1 n8721108 ntcqw    45376 Nov  6 11:02 z_growth_types_0_0_2022.gif
-rw-------   1 n8721108 ntcqw    47216 Nov  6 11:02 z_growth_types_0_0_2023.gif
-rw-------   1 n8721108 ntcqw    48847 Nov  6 11:02 z_growth_types_0_0_2024.gif
-rw-------   1 n8721108 ntcqw    50926 Nov  6 11:03 z_growth_types_0_0_2025.gif
-rw-------   1 n8721108 ntcqw    52811 Nov  6 11:03 z_growth_types_0_0_2026.gif
-rw-------   1 n8721108 ntcqw    54632 Nov  6 11:04 z_growth_types_0_0_2027.gif
-rw-------   1 n8721108 ntcqw    56512 Nov  6 11:04 z_growth_types_0_0_2028.gif
-rw-------   1 n8721108 ntcqw    58198 Nov  6 11:04 z_growth_types_0_0_2029.gif
-rw-------   1 n8721108 ntcqw    60030 Nov  6 11:05 z_growth_types_0_0_2030.gif
-rw-------   1 n8721108 ntcqw    61907 Nov  6 11:05 z_growth_types_0_0_2031.gif
-rw-------   1 n8721108 ntcqw    63725 Nov  6 11:06 z_growth_types_0_0_2032.gif
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-rw-------   1 n8721108 ntcqw    72471 Nov  6 11:08 z_growth_types_0_0_2037.gif
-rw-------   1 n8721108 ntcqw    74336 Nov  6 11:08 z_growth_types_0_0_2038.gif
-rw-------   1 n8721108 ntcqw    75939 Nov  6 11:08 z_growth_types_0_0_2039.gif
-rw-------   1 n8721108 ntcqw    77655 Nov  6 11:09 z_growth_types_0_0_2040.gif
-rw-------   1 n8721108 ntcqw    79222 Nov  6 11:09 z_growth_types_0_0_2041.gif
-rw-------   1 n8721108 ntcqw    80767 Nov  6 11:10 z_growth_types_0_0_2042.gif
-rw-------   1 n8721108 ntcqw    82241 Nov  6 11:10 z_growth_types_0_0_2043.gif
-rw-------   1 n8721108 ntcqw    83960 Nov  6 11:10 z_growth_types_0_0_2044.gif
-rw-------   1 n8721108 ntcqw    85653 Nov  6 11:11 z_growth_types_0_0_2045.gif
-rw-------   1 n8721108 ntcqw    86942 Nov  6 11:11 z_growth_types_0_0_2046.gif
-rw-------   1 n8721108 ntcqw    88588 Nov  6 11:12 z_growth_types_0_0_2047.gif
-rw-------   1 n8721108 ntcqw    89931 Nov  6 11:12 z_growth_types_0_0_2048.gif
-rw-------   1 n8721108 ntcqw    91450 Nov  6 11:13 z_growth_types_0_0_2049.gif
-rw-------   1 n8721108 ntcqw    92668 Nov  6 11:13 z_growth_types_0_0_2050.gif
-rw-------   1 n8721108 ntcqw    94058 Nov  6 11:13 z_growth_types_0_0_2051.gif
-rw-------   1 n8721108 ntcqw    95269 Nov  6 11:14 z_growth_types_0_0_2052.gif
-rw-------   1 n8721108 ntcqw    96583 Nov  6 11:14 z_growth_types_0_0_2053.gif
-rw-------   1 n8721108 ntcqw    97747 Nov  6 11:15 z_growth_types_0_0_2054.gif
-rw-------   1 n8721108 ntcqw    98877 Nov  6 11:15 z_growth_types_0_0_2055.gif
-rw-------   1 n8721108 ntcqw     9990 Nov  6 11:15 z_growth_types_0_1_1996.gif
-rw-------   1 n8721108 ntcqw    11052 Nov  6 11:15 z_growth_types_0_1_1997.gif
-rw-------   1 n8721108 ntcqw    12363 Nov  6 11:16 z_growth_types_0_1_1998.gif
-rw-------   1 n8721108 ntcqw    13546 Nov  6 11:16 z_growth_types_0_1_1999.gif
-rw-------   1 n8721108 ntcqw    14450 Nov  6 11:16 z_growth_types_0_1_2000.gif
-rw-------   1 n8721108 ntcqw    15227 Nov  6 11:16 z_growth_types_0_1_2001.gif
-rw-------   1 n8721108 ntcqw    16128 Nov  6 11:16 z_growth_types_0_1_2002.gif
-rw-------   1 n8721108 ntcqw    16972 Nov  6 11:17 z_growth_types_0_1_2003.gif
```

```
-rw-------  1 n8721108 ntcqw   18496 Nov  6 11:17 z_growth_types_0_1_2004.gif
-rw-------  1 n8721108 ntcqw   19632 Nov  6 11:17 z_growth_types_0_1_2005.gif
-rw-------  1 n8721108 ntcqw   20852 Nov  6 11:17 z_growth_types_0_1_2006.gif
-rw-------  1 n8721108 ntcqw   22083 Nov  6 11:18 z_growth_types_0_1_2007.gif
-rw-------  1 n8721108 ntcqw   23541 Nov  6 11:18 z_growth_types_0_1_2008.gif
-rw-------  1 n8721108 ntcqw   25095 Nov  6 11:18 z_growth_types_0_1_2009.gif
-rw-------  1 n8721108 ntcqw   26580 Nov  6 11:19 z_growth_types_0_1_2010.gif
-rw-------  1 n8721108 ntcqw   28076 Nov  6 11:19 z_growth_types_0_1_2011.gif
-rw-------  1 n8721108 ntcqw   29869 Nov  6 11:19 z_growth_types_0_1_2012.gif
-rw-------  1 n8721108 ntcqw   31397 Nov  6 11:20 z_growth_types_0_1_2013.gif
-rw-------  1 n8721108 ntcqw   32905 Nov  6 11:20 z_growth_types_0_1_2014.gif
-rw-------  1 n8721108 ntcqw   34802 Nov  6 11:20 z_growth_types_0_1_2015.gif
-rw-------  1 n8721108 ntcqw   36602 Nov  6 11:21 z_growth_types_0_1_2016.gif
-rw-------  1 n8721108 ntcqw   38246 Nov  6 11:21 z_growth_types_0_1_2017.gif
-rw-------  1 n8721108 ntcqw   40184 Nov  6 11:21 z_growth_types_0_1_2018.gif
-rw-------  1 n8721108 ntcqw   41827 Nov  6 11:22 z_growth_types_0_1_2019.gif
-rw-------  1 n8721108 ntcqw   43563 Nov  6 11:22 z_growth_types_0_1_2020.gif
-rw-------  1 n8721108 ntcqw   45383 Nov  6 11:23 z_growth_types_0_1_2021.gif
-rw-------  1 n8721108 ntcqw   47318 Nov  6 11:23 z_growth_types_0_1_2022.gif
-rw-------  1 n8721108 ntcqw   49053 Nov  6 11:23 z_growth_types_0_1_2023.gif
-rw-------  1 n8721108 ntcqw   51056 Nov  6 11:24 z_growth_types_0_1_2024.gif
-rw-------  1 n8721108 ntcqw   52990 Nov  6 11:24 z_growth_types_0_1_2025.gif
-rw-------  1 n8721108 ntcqw   54809 Nov  6 11:25 z_growth_types_0_1_2026.gif
-rw-------  1 n8721108 ntcqw   56782 Nov  6 11:25 z_growth_types_0_1_2027.gif
-rw-------  1 n8721108 ntcqw   58658 Nov  6 11:25 z_growth_types_0_1_2028.gif
-rw-------  1 n8721108 ntcqw   60415 Nov  6 11:26 z_growth_types_0_1_2029.gif
-rw-------  1 n8721108 ntcqw   62302 Nov  6 11:26 z_growth_types_0_1_2030.gif
-rw-------  1 n8721108 ntcqw   64109 Nov  6 11:27 z_growth_types_0_1_2031.gif
-rw-------  1 n8721108 ntcqw   66009 Nov  6 11:27 z_growth_types_0_1_2032.gif
-rw-------  1 n8721108 ntcqw   67854 Nov  6 11:28 z_growth_types_0_1_2033.gif
-rw-------  1 n8721108 ntcqw   69680 Nov  6 11:28 z_growth_types_0_1_2034.gif
-rw-------  1 n8721108 ntcqw   71284 Nov  6 11:28 z_growth_types_0_1_2035.gif
-rw-------  1 n8721108 ntcqw   73253 Nov  6 11:29 z_growth_types_0_1_2036.gif
-rw-------  1 n8721108 ntcqw   75023 Nov  6 11:29 z_growth_types_0_1_2037.gif
-rw-------  1 n8721108 ntcqw   76544 Nov  6 11:30 z_growth_types_0_1_2038.gif
-rw-------  1 n8721108 ntcqw   78446 Nov  6 11:30 z_growth_types_0_1_2039.gif
-rw-------  1 n8721108 ntcqw   79816 Nov  6 11:31 z_growth_types_0_1_2040.gif
-rw-------  1 n8721108 ntcqw   81337 Nov  6 11:31 z_growth_types_0_1_2041.gif
-rw-------  1 n8721108 ntcqw   82924 Nov  6 11:31 z_growth_types_0_1_2042.gif
-rw-------  1 n8721108 ntcqw   84530 Nov  6 11:32 z_growth_types_0_1_2043.gif
-rw-------  1 n8721108 ntcqw   85997 Nov  6 11:32 z_growth_types_0_1_2044.gif
-rw-------  1 n8721108 ntcqw   87142 Nov  6 11:33 z_growth_types_0_1_2045.gif
-rw-------  1 n8721108 ntcqw   88434 Nov  6 11:33 z_growth_types_0_1_2046.gif
-rw-------  1 n8721108 ntcqw   89961 Nov  6 11:34 z_growth_types_0_1_2047.gif
-rw-------  1 n8721108 ntcqw   91296 Nov  6 11:34 z_growth_types_0_1_2048.gif
-rw-------  1 n8721108 ntcqw   92489 Nov  6 11:35 z_growth_types_0_1_2049.gif
-rw-------  1 n8721108 ntcqw   93831 Nov  6 11:35 z_growth_types_0_1_2050.gif
-rw-------  1 n8721108 ntcqw   94995 Nov  6 11:36 z_growth_types_0_1_2051.gif
-rw-------  1 n8721108 ntcqw   96351 Nov  6 11:36 z_growth_types_0_1_2052.gif
-rw-------  1 n8721108 ntcqw   97448 Nov  6 11:36 z_growth_types_0_1_2053.gif
-rw-------  1 n8721108 ntcqw   98268 Nov  6 11:37 z_growth_types_0_1_2054.gif
-rw-------  1 n8721108 ntcqw   99460 Nov  6 11:37 z_growth_types_0_1_2055.gif
```