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Monitoring Al Ain City urban growth dynamics Between 1972 and 2000 by integrating remote Sensing and GIS techniques

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A Thesis submitted to
the **United Arab Emirates University**
in partial fulfillment of the requirements for the Degree of
Master of Science in Remote Sensing and GIS

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Dedication

To my brother "Mohammed"
and my family
who have helped make my dream of achieving this Degree a reality

Acknowledgments

I would like to express my thanks and gratitude to Allah, the most beneficent and merciful who granted me the ability and willingness to start and complete this thesis.

I would like to express my thanks and gratitude to Dr. Salem Issa, my first supervisor, for his patience, constructive suggestions, criticisms and encouragement.

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ABSTRACT

We live in a world full of change as a result of either natural processes or human activities. This study focuses on evaluating and monitoring the urban changes of Al Ain city by quantifing and visualizing various aspects of that change between 1972 and 2000. The results of the actual study will serve for effective city planning and decision making process for better life quality of the residents of the city. Rapid changes of the land use and land cover especialy built up and impervious areas, make it necessary to invo [illegible] depict these changes and analyze its dynamics.

In this study remote sensing and Geographic Information Systems (GIS) were integrated to monitoring and mapping the urban growth of Al Ain city between 1972 and 2000. Landsat MSS, TM and ETM+ for the year 1972, 1990 and 2000 respectively were chosen to study and analyze the urban growth in Al Ain city. Remote sensing techniques have the ability to delineate land cover categories by means of classification process. A hybrid unsupervised-supervised classification approach was used for detecting the changes using multi-sensor, multi-temporal remotely sensed images. Prior knowledge of the study area, unsupervised classification outputs, information from previous researchs and the Anderson classification schema concluded to the application of a classification schema consisting of 6 classes: **urban, vegetation, sand and gravel, sand dune, lime stone, water bodies and shadow**

Changes in land cover between the successive [illegible] two techniques in a multi stage approach. Post classification comparison and GIS overlay are adopted with given attention to urban areas. The urban change detection is used to identify the pattern of urban growth. Using spatial metrics like Land consumption Rate and Land Absoprtion Coefficient waqs very helpful to analyze and

understand the urban growth pattern. Driving forces behined Al Ain urban growth along with associated impacts on the city were identified, discussed and analyzed. An attempt to predict future trends to help the municipality to plan for better future of the city was investigated. The outcomes from this study are a demonstration of the embedded powerfulness of remote sensing and GIS techniques for studying spatial and temporal changes of land use in general and urban areas in particular. These outcomes reveal that Al Ain city lived through a period of huge and rapid development after the foundation of the United Arab Emirates in 1971. The expansion of the city generally occurred at the expense of sand dune, gravel sand and limestone with a high density in areas close to the city centre.

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RS	Remote sensing
GIS	Geographic Information System
LULC	Land use Land Cover
Landsat MSS	Landsat Multi [illegible]
Landsat TM	Landsat Thematic Mapper
Landsat ETM+	Landsat Enhanced Thematic Mapper plus
LCR	Land Consumptio [illegible]
LAC	Land Absorption Coefficient
AGR	Annual Urban Growth Rate
AOI	Area Of Interest
PLAND_U	The percentage of built up land
UTM	Universal Transverse Mercator
ISODATA	Iterati [illegible]

Chapter One

INTRODUCTION

1.1 Background

Al Ain is an oasis town, often described as the "Garden City". Over the years, the city has emerged as a centre for agriculture, education and tourism (Dyck 1995; Barrault 2003). Moreover, its conditions, for example, its geographic location, geomorphology, water resources and climate have encouraged its development to become a modern city.

Structurally, Al Ain lies on the eastern side of a topographic and structural depression between the Arabian shield and the Oman Mountains. It is located on gravel and outwash plains, with a ridge formation running from north to south from Bida Bint Saud to Hafeet Mountain. The Al Jaww Plain is located to the east of Hafeet Mountain where it is drained by two main wadis - Al Ain and Al Toyawwa. The alluvium brought down by the wadis plays an important role in creating a fine soil texture which played a significant role in the history of plantation; the area where the city is built is composed of deposits of alluvial silts and sands. These are generally thicker to its north and east, while in the west, the deposit thins out with gravel close to the surface (Master plan 1986).

Historically, Al Ain has played a significant role in the Arabian Peninsula because of its geographic location. Beneficially, the city is located at the junction of two major trade routes, namely between Abu Dhabi in the west and the mountain pass to the Gulf of Oman in the east and Dubai in the north and the settlement south of Al Ain along the foothills of the Oman Mountains. Furthermore, its location on the edge of the Empty Quarter meant it became a significant oasis, trading centre and stopping point for caravans carrying merchandise across the Arabian Peninsula to India and Persia (Hell and Buckton 1998).

The physical nature of Al Ain as an oasis where natural water, fertile soil and relatively deep loamy soil were available helped it to emerge as a permanent agricultural settlement. Indeed, "the initial settlement of the city consisted of twelve plantation villages where fertile silts washed down from the mountains could be exploited with water drawn from the underground water table by means of the Aflaj" (Master Plan 1986). Historically, the main irrigation system was composed of the Aflaj, namely Hilli, Jimi, Qattara, Saa and Jahli, with each playing a worthy role in irrigating the palm trees. The city had a large number of aflaj, possibly exceeding 300. Many of these still exist, but most of them have now become historic sites (Helo 1983; Master plan 1998; Takhriti 2002).

The discovery of oil in the Abu Dhabi Emirate in 1959, the establishment of the nation in 1971 and the development of the Arabian Gulf countries led to the United Arab Emirates in general, and Al Ain city in particular, to experience rapid development in several sectors over a very short period of time. During his appointment as the representative ruler in the Al Ain Region from 1946 to 1966, H.H Sheikh Zayed bin Sultan Al Nahyan did not spare any effort to improve the local situation (Antoni 2002). His demonstration of wisdom began with settling disputes with neighboring states and drawing up the borders between Oman, the United Arab Emirates and Saudi Arabia following the claim to Buraimi by Saudi Arabia, and ended with his desire to build a modern city with unique specifications. As a result, Al Ain witnessed a period of rapid change and growth in the areas of agriculture, medical care and education.

Particular attention was paid to agriculture and the irrigation system by cleaning the aflaj and building the new Al Sarrouj Falaj. In addition, H.H Sheikh Zayed bin Sultan Al Nahyan changed water distribution practice, and introduced a water policy making water available to the public free of charge to increase farming lands (Barrault 2003). Previously, there had been two kinds of palm tree owners, the first had farms privileged with a large percentage of the aflaj water, and who irrigated their farms five times a month while the second, owners of small farms could only irrigate once a month. The less irrigated farms had to be sold to the wealthier owners during times of drought when they had been damaged due to the conditions (Arshani

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1980, Qamri 1983). These agricultural reclamations led to an increase in agricultural production and established Al Ain as a market centre for the w result, today, the city is considered the second capital of Abu Dhabi Emirate after Abu Dhabi city and its region plays an important role in food security because of its agricultural development. The first experimental farms were established in the city and the area now produces high quality local vegetables and fruits at competitive prices (Hellyer and Buckton 1998).

During that same period, medical care and education also witnessed great improvements. For instance, in November 1960, the Oasis Hospital played an important role in the provis be established in the region (Dyck 1995). The establishment of Al Nahyaniaa Primary School in 1955 followed by the Islamic Institute for Qu'ranic Studies in 1967 started Al Ain's educational transformation. These developments were the first steps in bringing Al Ain into a new cultural role in both the United Arab Emirates and the Gulf countries. As a source of knowledge, it hosts a number of universities and colleges, particularly the main national university, the United Arab Emirates University (UAEU), Abu Dhabi Private University, Al Ain Technology Private University and the Higher Colleges of Technology (Qanim and AlQaydi, 2001).

In spite of its modernization, the city s character and its harmonious relationship with the oases has survived to the present day. Significantly, historic buildings, original physical fabric and setting assist to preserve its integrity. In addition, social customs and traditions have been preserved and many continue to be respected through their regular practice, such as, wedding celebrations, Bedouin hospitality, falconry, and camel racing (Retrieved 02 April, 2009 from http://whc.unesco.org/en/tentativelists/5266/).

Even though the urbanization of Al Ain city during the last three decades came primarily as a result of its geographic location, oil discovery, establishment of the nation, and the wise leadership of H.H Sheikh Zayed bin Sultan Al Nahyan. It cannot be denied that, additional driving forces contributed significantly to the urbanization process. The various political events in the Arab countries during the last six decades, for example, the 1973 War with Israel, Iraq-Iran War (1980-1988), Second Gulf War (1990-1991) and Arab-Israeli conflict since 1948 had an indirect positive impact for the United Arab Emirates. For example, in 1973-1974, the price of oil increased threefold, and consequently increasing oil revenue utilized for continuing economic development. Furthermore, and notably,

- workers from a number of countries and especially those suffering from poor political conditions migrated to the Gulf region due to the availability of work opportunities (Myer 1992; Shamsi 1996).
- in addition to the expansion of the work force, the enhancement of medical care lead to a reduction in infant mortality rates and longer life expectancy and hence contributed to population growth.
- the neighbourhood and open political boundaries between Al Ain and Buraimi District (Sultanate of Oman) until very recently contributed to the urbanization of the city; a substantial number of Omanis depend on Al Ain city for employment, work, study and shopping.
- economic development and increased per-capita income lead to more individual investment in different sectors such as industry, commerce and real estate.

Although the conversion of Al Ain from a number of small villages with very simple capabilities to a modern city offering all aspects of welfare, urbanization comes with both advantages and disadvantages. For instance, the growth in agricultural activities has seen the creation of a very large workforce whose contribution to population growth conflicts with the objective of reducing an expatriate workforce (Master plan 2006). On the other hand, urbanization is the result of a reclamation process that has seen the desert give way to a green garden. In this way, the nature of its urbanization differs from that of other countries where urban development came at the expense of green areas, for example, Indonesia (Dimyati et al 1996), Canada (Hathout 2002) and China (Weng 2002).

1.2 The Study Area

1.2.1 Location and size

Al Ain city is located in the Eastern region of the United Arab Emirates between 23° 45' and 24° 40' North and 54° 05' and 56° East with an average altitude of about 270 meters above sea level (Al Ain Town Planning and Survey Sector 2008).

Today, Al Ain is the fourth largest city in the United Arab Emirates and the second largest in the Emirate of Abu Dhabi, with a population of 421,948 (2005 estimate). It is located at 160 km east of Abu Dhabi city, and approximately 130 km southeast of Dubai. Al Ain is linked by a six-lane dual highway to Abu Dhabi City (Al Ain - Abu Dhabi Road) and Dubai (Al Ain – Dubai Road) and is approximately at a one and half hour drive from either city.

Why has Al Ain city been chosen as the study area? For varied reasons, including: -

(1) The site offers a discrete boundary for analysis (Al Ain Municipality Boundary). See Figure 1.1.

(2) The availability of high quality remote sensing imagery of this site in georeferenced format.

(3) Prior to the period of urban growth, the site contained a number of green oases, so it is an ideal example for observing the effect of urbanization on the oases.

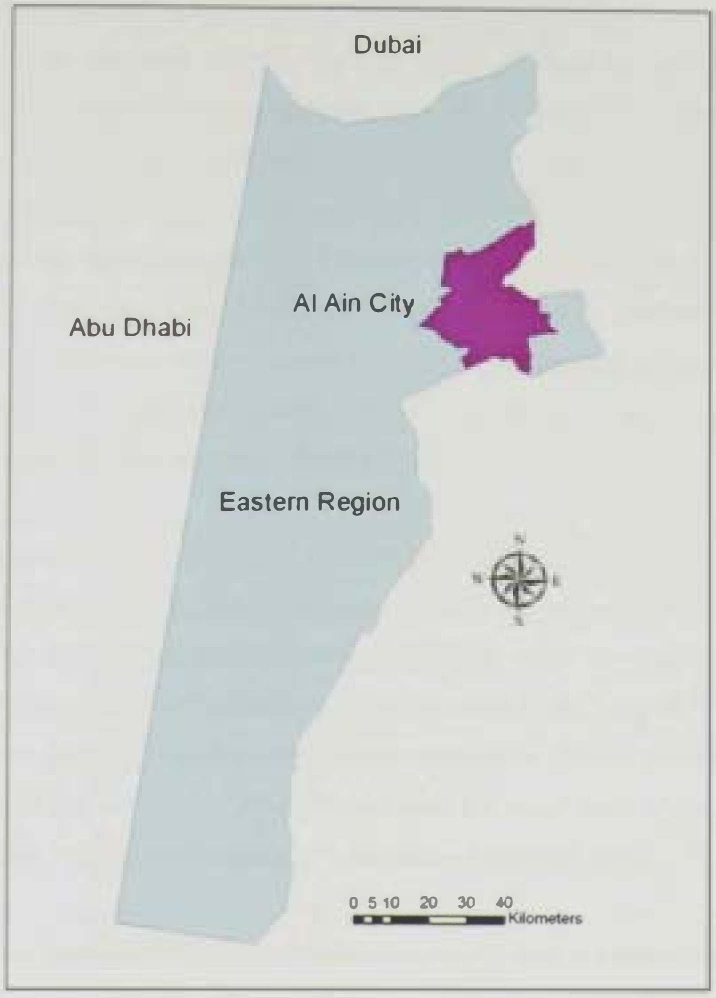


Figure 1.1: Study Area

Source: Al Ain Town Planning and Survey Sector

1.2.2 Physical Setting

Al Ain has a dramatic natural landscape surrounded by red sand dunes from the west and north, Hafeet Mountain on the south and rocky gravel plains to the east. The most attractive feature of Al Ain is that no buildings are more than three storeys high (22m) with the exception of some hotels, universities and hospitals (TPSS, 2009). Furthermore, there are many different factors affecting the climate of the city such as its location, distance from the sea (Continental), relief and pressure zone.

The location of the city inside the desert at some distance from the coast of the Arabian Gulf to the we [illegible] Gulf of Oman to the east, affects its climate. According to the classification of Koppen, Al Ain's climate is classified as arid desert (BW) (Qanim 1991, Qanim and AlQaydi 2001) where daytime temperature increases during the month of July to 40 degrees Celsius with little and sporadic rainfall. The rain usually falls in the w [illegible] Book 2000). The year 2000 climate data indicates that, the maximum temperature recorded in Al Ain w [illegible] o [illegible] s [illegible] 9 degrees Celsius. The total rainfall in the city wa [illegible] maximum recorded in the month of December.

In addition, the location of the desert city shelters it from high humidity. The average humidity in Al Ain city in the summer is 78% compared to 90% observed in cities lying on the Arabian Gulf or the Gulf of Oman. Also, the sand dunes barrier to the west and the mountain chains to the east protect the city from the affect of winds and sea breeze coming from the east and w [illegible] for making the city a favorite holiday destination for inhabitants of big coastal cities like Abu Dhabi and Dubai (Qamri 1983; Qanim and AlQaydi 2001).

Indeed, there is a correlation between climate and vegetation; climate affects the vegetation cover and the vegetation plays a significant role in mitigating the harsh climate conditions associated with dry lands. Plants in Al Ain are xerophytes (Qanim and Al-Qaydi 2001) that can adapt to and survive in dry conditions. The annual vegetation grows after rainfall events and survives only for a short period. Winter, where most of the rainfall events occur, extends from December to March. In addition to rainw [illegible] s [illegible] valleys (Qanim and Al-Qaydi 2001). In fact, it has several natural groundwater springs that feed the vegetation and oases (Qanim 1991). Beside groundwater, water used in the city for residential, industrial, agricultural and landscaping purposes comes from desalinated sea water, brackish groundwater and treated sewage effluence (Master plan 1998).

1.2.3 Socio-Economic

As the home-town of the ruling family of the nation, there was a strong desire to develop Al Ain into a modern garden city (Master Plan 1986). The development of the city is reflected in the population growth and the radical transformation in its urban space and has included investment programs involving roads, housing and utilities.

In the past, the Gulf societies were small and did not have the technical skills to undergo radical modernization. Indeed, the cities on the Gulf, in general, never achieved a high urban status prior to the discovery of the oil because their poor environmental settings compared to the neighbouring urban centres in Oman, Iraq, Iran and India (Ouf 2000).

Revenues from oil enabled the hiring of a large expatriate skilled and professional workforce that played a critical role in the urbanization process. This workforce contributed substantially to the population growth of the city (Khalaf and Al Kobaisi, 1999). In addition to the expatriate workforce, the United Arab Emirates University played a major role through the attraction of students from all over the country (Hellyer and Buckton 1998). The urban population in the city increased from 144,672 in 1985 to 179,640 in 1990 with a further increase to 218,510 in 1995 and 284,039 in 2005 (Statistical Year Book, 1989 and 1995; Al Ain Town Planning and Survey Sector 2008). During this period, the city also witnessed construction of new buildings, development in commercial and industrial activities, the use of modern methods and equipment for agriculture and irrigation. Alongside these, development of its infrastructure, such as roads, bridges, electricity, and sewage contributed to its notable expansion (Qamri 1983).

1.3 Scope of the Research

Numerous studies have been carried out worldwide using Remote Sensing (RS) and Geographic Information System (GIS) tools to detect urban expansion. However, previous studies of the development of Al Ain conducted by Qanim (1986), Al Ain Town Planning Department (Master Plan 1986), and Qanim and Al-Qaydi

(2001) were based on statistical indicators and field surveys. The only exception is an urban growth study by Yagoub (Yagoub 2004) that is based on a combination of statistical data, remote sensing and GIS to detect change for selected sites in the city using a post classification image difference approach.

The research presented in this dissertation is fundamentally different from previous studies in that it relies on the classification of the whole region of Al Ain using remotely sensed images from 3 time periods and then GIS to map change by tracing trajectories from urban to non-urban classes and to calculate a set of urban spatial metrics. Even though the study focuses on changes in the urban class, the classification and change detection maps created as part of the study encompass a wider range of classes that are available to researchers in a GIS format for use in a wider range of applications. For instance, data sets created as part of this research can subsequently be used to study the impact of urbanization on oases in Al Ain region.

The overall aim of this research is to portray the pattern of urbanization through the use of spatial metrics, such as, the Land Consumption Rate, Land Absorption Coefficient, Annual Urban Growth Rate, and the Percentage of Built-up Land in Al Ain city between 1972 and 2000. In addition, there is a desire to identify its driving forces along with their endemic impacts and future evolution.

1.4 Aim & Objectives

The research will also attempt to achieve the following specific objectives, to:

1. outline the urbanization process of Al Ain city using existing documents;
2. apply remote sensing and GIS techniques to estimate the urban growth rate during the study period;
3. map spatial distribution and direction of urbanization during the specified period by applying change detection techniques and GIS overlay analysis;
4. identify the driving forces of urban growth across the study period.
5. evaluate impacts of urban growth on other land use classes;
6. evaluate urbanization trends and predict a possible future evolution of the city.

Chapter Two

REMOTE SENSING AND GIS TECHNIQUES IN URBAN STUDIES

2.1 Background

Remote Sensing technology is essential for dealing with dynamic phenomena on the surface of the Earth such as urban growth. Devices orbiting the earth at high altitude image its surface and produce spatial data necessary to monitor and estimate urban growth effectively over time. Fortunately, during the past decades, this technology has witnessed remarkable development in the capability of providing repetitive data of the same area. Likewise, spatial, spectral, and temporal resolutions of satellite images have witnessed notable advancements. Spatial resolution, for instance, jumped from 80m in the early 1970s to less than 1m in the year 2000, while spectral resolution increased from around 4 bands in 1972 to more than 210 bands with the hyperspectral technology during the same period. Temporal resolution has seen shorter visiting time and even imaging on demand. In addition, substantial advances were made in the area of stereo-imaging and 3D mapping. The combination of all these factors has made the study of urban growth easier and more efficient. Moreover, RS technology is cost-effective compared to conventional methods of mapping and monitoring usually used in urban studies, which are time consuming and relatively highly expensive (Massasati 1991; Yagoub 2004; Opeyemi 2006; Saleh and Rawashdeh 2007; Jat *et al.*, 2007).

In addition to the use of RS to monitor the spatial and temporal variability of LULC (Jat *et al.*, 2007), GIS plays a key role in providing a framework for spatial analysis of remotely sensed data products and other sources of spatial data (Donnay *et al.*, 2001). The integration of RS and GIS can be carried out in one of three different ways: (1) RS can be used as a tool to gather data sets for use in GIS; (2) GIS data sets can be used as ancillary information to improve the products derived from RS and (3) RS and GIS data can be used together for modeling and analysis.

Urban growth is a phenomenon that has been and is still occurring in the majority of the cities of the world. Foody (2001) and Jensen (2005), found that its impacts are in the area of LULC change, which is considered a major component of global change with impact perhaps greater than climate change. Moreover, urbanization is responsible for some serious problems facing big cities today. Examples range from traffic congestion and urban sprawl as was the case in Atlanta city (Yang and Lo 2002) to urban heat island as in Zhujiang Delta, China (Weng 2001). Yang and Lo (2002) found that Atlanta city witnessed notable urban growth from 1973 to 1998, this growth came at the expense of forest, cropland and grassland. Indeed, many studies demonstrated that urban growth in most cities around the world led to the loss of agricultural area (Yeh and Li 1998; Stewart 2001; Yang and Lo 2002; Hathout 2002). In contrast, Dwivedi *et al.*, (2005), found that urban growth in parts of Ethiopia led to a decrease of barren land. Similarily, Yagoub (2004) found that desert land in the city of Al Ain in the UAE had decreased from 66,105 hectares in 1990 to 43,405 hectares in 2000 with vast desert areas being converted to agricultural farms.

Urban growth has its own driving forces and several authors reported that economic development, industrialization, population growth, migration, traffic infrastructure, topography and policy strategies are the major factors contributing to its progress (Masek *et al.*, 2000; Herold *et al.*, 2003a; Yagoub 2004; Mundia and Aniya 2005; Tian *et al.*, 2005; Xiao *et al.*, 2006). In contrast, there are several constraints that control its expansion rates and directions such as, mountains, water bodies, and political boundaries. Barredo and Demicheli (2003) found that Lagos city in Nigeria did not witness notable development on its south and west sides due to existing water bodies, which stood as constraints against its development in those directions. Furthermore, Mundia and Aniya (2005) found a number of negative factors that discouraged the expansion of Nairobi city in certain directions, such as, brown and black clay soils, the Nairobi National Park, as well as the safety zone and noise corridor surrounding the Nairobi International Airport. Similarly, Yagoub (2004) found that Al Ain Valley, Hafeet Mountain, high sand dunes and the conservation zones of the defense and zoo areas represent both natural and legal constraints to the expansion of Al Ain city to the south-east.

2.2 RS and GIS techniques in urban studies -with special focus on dryland cities

The driving forces and constraints of urban expansion can be analyzed after the monitoring and detection of change in a given area using change detection methods. For almost three decades, extensive research efforts have been directed towards urban change detection using RS imagery (Yang and Liu 2005).
In fact, the employment of RS and GIS techniques in urban studies is one of the topics that occupied a significant place in urban studies literature. The various topics covered in urban studies include, urban sprawl (Jothimani 1997; Yeh and Li 2001; Sutton 2003, Sudhira *et al.*, 2004, Jat *et al.*, 2007), urban expansion (Pathan *et al.*, 1993, Yeh and Li 1997; Dai *et al.*, 1996; Yeh and Li 1998; Chen *et al.*, 2000; Ji *et al.*, 2001; Weng 2001, Hathout 2002, Yagoub 2004; Forsythe 2005; Mundia and Aniya 2005; Xiao *et al.*, 2006, Zhao *et al.*, 2007; Saleh and Rawashdeh 2007) and urban modeling (Sui 1998; Ward *et al.*, 2000; Li and Yeh 2000; Allen and Lu 2003; Cheng 2003, Barredo and Demicheli 2003; Herold *et al.*, 2003a; Weber and Puissant 2003; Yang and Lo 2003; Oğuz 2004; Sudhira *et al.*, 2004; Jat *et al.*, 2007).

Special attention is given herein to urban studies of cities with conditions similar to those of Al Ain city such as, Seeb District in Oman; Al-Ahsa Oasis in Saudi Arabia; Doha in Qatar; Cairo in Egypt; Bombay in India; Amman, Ma'daba and Irbid cities in Jordan and Istanbul in Turkey. In the Gulf region, three case studies integrate RS and GIS techniques to study urban growth and detect change in three major cities: Seeb District in the Sultanate of Oman by Al-Awadhi and Azaz (2005); Al Ahsa Oasis in Saudi Arabia and Doha city in Qatar (Belaid 2006). The last two studies investige the effects of change on land use categories and predict the direction of growth. Their results revealed that, the built-up areas increased during the study period in all three cities, while the agricultual areas decreased in both Seeb District and Doha city and increased in Al Ahsa. On the other hand, Yagoub (2004) monitored the urban growth of Al Ain city over the last three decades using RS and GIS, by focusing on selected sites in the city, and found that its development was not at the expense of green areas which expanded over the same period due to the conservation of agricultural areas and desert reclamation.

In Cairo city, Yin *et al.*, (2005) focused on the spatial extent of urban land use rather than its internal variation. That study analyzed the relationship between the built-up surface and population distribution as indicators of urban expansion. The result revealed that built-up areas increased at the expense of desert and there was a strong correlation between built-up surfaces and population density.

Pathan *et al.* (1993) also studied the relationship between the population and urban growth in the Bombay Metropolitan Region during 1986-1989 in order to estimate the requirements of urban development until the year 2001. Their results indicated that, all zones investigated in the study witnessed an increase in built-up areas and population growth except for the central Business District (CBD), which may have been growing in a vertical direction.

Using RS and GIS to study the urban expansion in three Jordanian cities, Amman, Ma'daba and Irbid, detected the causes of uncontrolled urban growth (Saleh and Rawashdeh 2007). The authors found that the urban area in the three cities increased during the study period following major roads and fertile lands, whereas the addition of war-time Palestinian refugees and the internal migration of Jordanians has led to irregular, but massive urban growth.

Finally, in their study based on integration of RS and GIS, Maktav and Erbek (2005) used RS to investigate the impacts of urban growth on land use changes, particularly on agricultural land in the district of Buyukvekmece in suburban Istanbul. They used image differencing and image ratioing methods to detect change and an NDVI based index as an indicator of lack of vegetated areas. The results revealed that, urban growth was mainly driven by population migration leading to a decrease in agricultural areas.

2.3 Classification and mapping of urban areas

Determining a definition of urban areas is essential to monitoring urban growth. Urban definitions and urban classifications are two of several subjects that concerned individuals, governments, and the United Nations (UN). Although there are various definitions of urban, there is one element that is common to all these definitions: the existence of man-made structures related to the city (Massassati 1991). In this research, we define urban areas as man-made structures (e.g. buildings, roads, pavements) and vegetation covered area (e.g. oases, farms, parks, agricultural area inside the city). The argument behind merging built-up with vegetation to form urban areas is twofold: firstly in the study area it is found that built-up always led to the occurrence of new vegetation cover, as in the past, where oases and farms had been the most populated sites. Secondly, Al-Awadhi and Azaz (2005) used this same definition for their study on urban growth of Seeb District in Oman and obtained good results in their monitoring study.

RS is considered as a source of information used to characterize the LULC at local, regional and global scales (Townshend and Justice 2002; Lunetta and Lyons 2003). LULC can be extracted by classification based on statistical pattern recognition techniques applied to multispectral remote sensor data (Narumalani *et al.*, 2002). In general, classification methods are divided into two methods - supervised and unsupervised. The unsupervised classification allows spectral clusters to be identified with a high degree of objectivity (Yang and Lo 2002; Mundia and Aniya 2005), where the user does not require specifying information about the features contained in the images. The software identifies the homogenous pixels and puts them in one cluster. The ISODATA (Iterative Self-Organizing DATa Analysis) cluster algorithm is one of the most frequently used unsupervised classification algorithms used to identify a spectral cluster. Then the user combines unsupervised clustering and labels them (Jensen 2005; Mundia and Aniya 2005). On the other hand, supervised classification requires the user to define training sites with known land cover type, which are used to derive the spectral signatures of the land cover classes from specified locations in the image. Supervised classification algorithms are divided into parametric (e.g. Maximum likelihood) and nonparametric algorithms (e.g. Parallepiped and Minimum Distance). Parametric algorithms assume that the spectral response in each class follows a Gaussian distribution law (Serra *et al.*, 2003) whereas nonparametric algorithms make no such assumption (Jensen 2005).

Even though it requires prior knowledge of representative sites of the study area and of the land cover classes of interest, supervised classification remains the method of choice for land cover change studies where the conversion from and to a predefined set of classes is assessed (Rogan and Chen 2004). Among the different supervised classification algorithms, the maximum likelihood algorithm is the most widely used in land cover mapping (Murai1996) and in urban growth studies (e.g. Elnazir et al., 2004; Yilmaz et al., 2006 and Xiao et al., 2006).

A hybrid classifier combining an unsupervised classification approach with training areas is actually the supervised process leading or complimenting the unsupervised one (Lillesand and Kiefer 2000). It has proven more successful than the maximum likelihood classifier (Serra *et al.*, 2003). As a result, the hybrid classification was adopted in this study in order to classify the satellite images into different land use classes in the first step then grouping them into urban and non-urban areas.

2.4 Use of Spatial Metrics in urban studies

RS is an important source of data for spatial metric analysis (Barr and Barnsley, 2000). There are many simple indices computed from thematic maps used to quantify the pattern and structure of an urban environment (Herold *et al.*, 2003a). The adoption of these indices for landscape ecology has been identified as landscape metrics (Gustafson, 1998). Several landscape metrics were primarily used in ecological investigations, which then were extended to be used to improve the understanding of urban forms (Sudhira *et al.*, 2004). From the literature review (Gustafson 1998; McGarigal *et al.*, 2002), it was found that spatial metrics are commonly used to quantify the shape and pattern of quasi-natural vegetation in natural landscapes (Herold *et al.*, 2003a). However, there is not a confinement of these metrics to vegetation studies as, there has been an increasing interest in applying spatial metric techniques in an urban environment (Herold *et al.*, 2002). For instance, Sudhira *et al.*, (2004) computed Shannon's entropy, map density and patchiness to detect the urban sprawl phenomenon in Mangalore, Udupi region in Karnataka state, India. Yang and Liu (2005) used an imperviousness index which was found to be a useful alternative for quick and objective assessment of urban spatial growth, especially over large areas. Herold *et al.*, (2003a) calculated twenty two spatial metrics, e.g., percentage of landscape, patch density, edge density, mean patch size, largest patch index, in the urbanized area of the south-coast region in Santa Barbara County, California, to describe the spatial characteristics of land-cover objects within each land use region as derived from interpreted aerial photographs. Tian *et al.*, (2005) calculated urban land percentage and urban land expansion index for every one square kilometer cell throughout China using ArcGIS. Xiao *et al.*, (2006) evaluated the spatial distribution of urban expansion intensity by applying annual urban growth rate (AGR) used for evaluating urbanization speed of a unit area. Land Consumption Rate and Absorption Coefficient metrics were computed by Opeyemi (2006) to quantify and assess the amount of change in the built-up land in Ilorin, Nigeria.

The use of spatial metrics in the previous studies, in an urban environment demonstrated that spatial metrics -

- have been used for detailed analyses of the spatiotemporal patterns of urban change;
- offer enhanced description and representation of heterogeneous urban areas and provide a link between the physical landscape structure and urban form, functionality and process (Barnsley and Barr, 1997);
- are useful in providing the most important information for differentiating urban land uses;
- are considered an important tool for the analysis of urban mapping derived from RS data.
- play an efficient role in capturing the dynamics change of urban growth;
- are useful for the analysis of urban growth because they provide a comprehensive method for the description of process, the comparison between cities, and comparison with theory.

However, it should be noted that the spatial resolution, extent of the study area and level of detail in the landscape classification affect the absolute values of these metrics (Herold *et al.*, 2003a).

Although several spatial metrics were used in urban studies, only four of them are used in this study for their simplicity and ease of interpretation. They are: Land

Consumption Rate (LCR), Land Absorption Coefficient (LAC), Annual Urban Growth Rate (AGR), and the Percentage of Built-up Land (PLAND_U).

2.5 Change analysis techniques

Change detection "is the process of identifying differences in the state of an object or phenomenon by observing it at different times" (Lu *et al.*, 2004; Opeyemi 2006). The change detection can be seasonal, for example, snow coverage, flooding, agricultural practices, natural vegetation growth cycles or permanent, for example, urbanization, forest clear cutting or surface mining (Avery and Berlin 1992). In fact, several studies have applied change detection in order to monitor LULC and urban growth changes (Kwarteng and Chavez 1998; Yeh and Li 1998; Petit and Lambin 2001; Yang and Lo 2002; Zhang 2002). There exist different change detection algorithms using satellite digital images, such as, image differencing, visual analysis of multi-date images, vegetation index differencing, image difference, principle component analysis (PCA), Selective Principal Components Analysis, Direct multi-date classification and Post-classification analysis (Kwarteng and Chavez 1998; Mass 1999; Yagoub 2004) with each algorithm having its advantages and disadvantages (Jensen 2005).

In this study, a post-classification comparison change detection approach based on comparing two classified images with GIS overlay was adopted. This approach is commonly used in LULC change studies and offers a quantitative measure of change in individual classes suitable for examining LULC dynamics (Serra *et al.*, 2003; Lu *et al.*, 2004; Mundia and Aniya 2005). Moreover, it produces a detailed "from–to" change detection as it has the potential to detect the nature of urban LULC.

The following points summarize the main characteristics of the post-classification method (Jat *et al.*, 2007; Zhang 2002; Mas 1999): -

1. it is less affected by different vegetation phenology and soil moisture compared to the map algebra method;
2. it is less sensitive to registration errors and it is possible to integrate interpretive knowledge into the classification procedure;

3. images intended for post-classification change detection, do not require the performance of atmospheric corrections or normalizations.

4. also it is easy to implement in a GIS environment

However, the post-classification comparison method has the disadvantage of requiring separate classification of input data and compounding errors from both input classification maps.

2.6 GIS Overlay analysis

In recent decades, RS has been the most widely used source of data for change detection (Lu *et al.*, 2004). However, this has not prevented the occurrence of GIS-based change detection, which includes the integrated GIS and RS methods along with pure GIS methods alone.

Integrating GIS and remote sensing can be applied by the incorporation of imagery and GIS data, such as the overlay of GIS layers directly on image data and transfer the results of image processing into a GIS system for further analysis. Additionally, it allows access of ancillary data to help in the interpretation and analysis of remotely sensed data and offers the ability to directly update land use information in GIS. However, different data quality from various sources can degrade the results of LULC change detection in general (Lu *et al.*, 2004). Liu and Zhou (2005) adopted in their study the integration of RS, GIS, and multivariate mathematical models, where the LULC and spatio-temporal patterns were modelled by LULC change trajectories over a series of observation years. Yang and Lo (2002) used an unsupervised classification, GIS-based image spatial reclassification, and post-classification comparison with GIS overlay to map the spatial dynamics of urban LULC change in the Atlanta, Georgia, metropolitan area. Their results revealed that, this hybrid approach offered many advantages over traditional change detection methods in multi-source data analysis. They found the combination of post-classification comparison and GIS techniques has made possible the production of single-theme land use/cover change maps, which emphasize spatial dynamics. These successes were the reason for combining two techniques in a multi- stage approach post classification comparison and GIS overlay in this study.

2.7 Modelling urban change with GIS

Modeling of an urban development pattern is a pre-requisite for local urban planners to understand the complex urban growth process (Cheng and Masser, 2003). Urban growth modeling and prediction history essentially started in the 1950s, slowed down in the 1970s and 1980s, and then it saw a strong revival in the 1990s, benefiting from improvements in spatial data availability and advancements in computer technology and GIS (Allen and Lu, 2003).

A model is a simplified representation of the real world and its processes. It is a summary of data making general statements about the existence of phenomena and their operation. GIS modeling uses spatial analysis techniques in the production and modeling of spatial phenomena; it has two main objectives: to understand and to predict (Lo and Albert Yeung, 2002). The predictive model has provided a vision of the future, good or bad, that it is hoped will draw public attention along with an increase in environmental awareness. Indeed, urban modeling and growth prediction is the frontier of urban studies (Allen and Lu 2003). Several urban studies have seen the application of modelling, such as those of Sui 1998; Li and Yeh 2000; Lo´pez *et al.*, 2001; Allen and Lu 2003; Cheng and Masser 2003; Martin *et al.*, 2003; Yang and Liu 2005; Jat *et al.*, 2007 and Yuan 2008) as a result of its usefulness for planning managers and decision makers in guiding urban development correctly to minimize the impact on the important sites (Li and Yeh 2000).

Conversely urban modeling has its limitations in the quality and scope of the data needed for their parameterization, calibration and validation of application and performance. Likewise, it suffers from a lack of knowledge and understanding of the physical and socio-economic drivers that contribute to the pattern and dynamics of urban areas (Batty and Howes 2001; Longley and Mesev 2000; Herold *et al.*, 2003a). However, modelling was not in the scope of the actual study and may be the subject for future investigations in future studies. I think that researchers have to think in developing such models for the city of Al Ain to help in planning and predicting the future growth rates and directions of the city.

Chapter Three

RESEARCH METHODOLOGY

The following Flowchart summarises the methodology used in this study. However details are outlined in the next sections and subsections of this chapter.

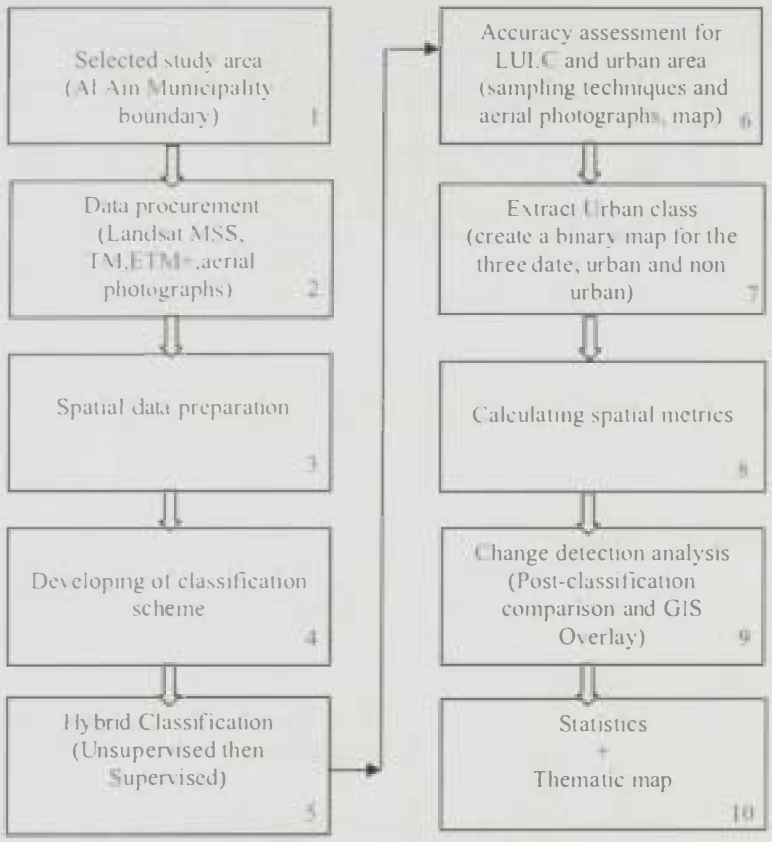


Figure 3.1. Methodology Flowchart

3.1 Spatial datasets, Software and Hardware.

A time series of Landsat satellite images spanning the period from 1972 to 2000 were used as a primary source for extracting the main land cover classes in the study area. Al Ain Municipality Boundary shapefile was used to generate an AOI (Area Of Intrest) and was implemented in ERDAS Imagine 8.7 to subset the study area from all images. Tabel 3.1 shows the list of primary as well as secondary data used in the research.

Table 3.1 List of primary and secondary data used

Data Type	Primary/Secondary	Date	Format	Resolution / Accuracy	Source
Landsat MSS	primary	29 January 1972	.img	57 meter	UAEU
Landsat TM	primary	28 august 1990	.img	28.5 meter	UAEU
Landsat ETM+	primary	23 March 2000	.img	15 & 30 meter	UAEU
Aerial photos	secondary	1976	Geotif	1:5000	Al Ain Town Planning and Surveying Sector (TPSS)
Aerial photos	secondary	1983	Geotif	1: 50,000	Al Ain Town Planning and Surveying Sector (TPSS)
Al Ain land use map	secondary	2000	.img	30meter	UAEU
IKONOS	secondary	2000 & 2006	.img	4 meter/ 1meter (data fusion)	UAEU /Al Ain Town Planning and Surveying Sector (TPSS)
Master Plan of Al Ain Region	secondary	1986- 2000 & 2000-2015	——	——	Al Ain Town Planning and Surveying Sector (TPSS)
Al Ain Administrative boundary map	primary	2008	shapfile	——	Al Ain Town Planning and Surveying Sector (TPSS)
Geology map	secondary	2009	JPEG	1:120,000	UAEU
Demographic data	secondary	1989 1995 2001 2005	——	——	Al Ain Town Planning and Surveying Sector (TPSS)/ UAEU

RS images covering the study area were procured from the United Arab Emirates University – GIS/RS Masters program and used as a primary data source to map all LULC classes in the study area, including the urban areas so as to exhibit physical growth in every decade period since early seveties to the late ninties. All images are rectified to a common Universal Transverse Mercator (UTM) coordinate system, zone 40 and the WGS 84 Datum.

Softwares used in this study include, ERDAS Imagine version 8.7 which was used for displaying, enhancing, processing and analysing the images; Arc GIS version 9.3 used for editing vector data, performing overlay analysis and laying out maps; Excel MS was used for calculating the metrics and creating the charts; finally MS Word processor used for writing and compiling the drafts. Furthermore, hardware used includs PC Pentium IV and HP DeskJet D1650 color printer. All lab works were executed in both the GIS/RS laboratories of the UAEU and the Al Ain Town Planning and Survey Sector (TPSS).

3.2 Data preparation.

Spatial data was the subject of the following preparation and pre-processing tasks: -

a. Upload and stack the different images (MSS_1972; TM_1990; ETM+_2000). Thermal bands are excluded.
b. Adjust vector files coordinates to fit with the UTM coordinate system.
c. Use of Al Ain Municipality boundary polygon shape file as an Area of Interest (AOI) to subset the raster data.

Geometric correction is an essential step for remote sensing data. It is a process of correcting the systematic and nonsystemic errors in the remote sensing system during the process of image acquisition (Jensen, 2005). Therefore Geometric correction of the 1976 aerial photography and the 1990 landuse map was performed by collecting ground control points (e.g. a road intersection) from existing IKONOS images; and registered to the UTM, zone 40 and WGS 1984 datum. Twenty-five, well distributed, ground control points (GCPs) and 11 check points were used to correct the 1976 aerial photography.(Figure 3.2) Likewise, twenty (GCPs) and 10 check points were used for correcting the 1990 landuse map. In both cases, a first order polynomial was used resulting in an RMS error of less than half a pixel.

Figure 3.2 : An example of GCPs distribution of 1976 aerial photograph.

3.3 Image classification.

Notably, there is no single classification system that can be used for all types of imagery and all different scales. Up to the present, the Anderson classification system also referred to as the U.S.Geological Survey (USGS) classification scheme continues to be the most successful scheme compatible with RS data. Most available schemes are in fact a kind of new versions being modified from this first scheme e.g., Opeyemi (2006).

Mundia and Aniya (2005) found that some considerations should be attentioned during the design of a classification scheme, including :- (1) The major LULC categories within the study area; (2) Differences in spatial resolution of the sensors; (3) The need to consistently discriminate LULC classes irrespective of the seasonal differences. Therefore, in this study, and based on: prior knowledge of the study area, unsupervised classification output of the three dates, findings of previous studies and the Anderson classification scheme, the following six classes were adopted to represent most land cover types present (Table 3.2).

1. Urban (built-up including roads and buildings).
2. Vegetation (oases, farms, parks).
3. Sand and gravel (dark soils).
4. Sand dunes(bright sand).
5. Limestone.
6. Water bodies and shadow.

Table 3.2: Land cover classification scheme

Code	Description	Sample
1	Urban (built-up including: roads and building)	
2	Vegetation (oasis, farms, parks)	
3	Sand and gravel (dark soils)	
4	Sand dunes (bright sand)	
5	Limestone	
6	Water bodies and shadow	

Indeed, the number of classes is the most important parameter when applying an unsupervised classification where an increased number of classes may give better results, but will consume time and effort when cluster labeling is underway (Yang and Lo 2002; Mundia and Aniya 2005). To obtain the optimum number of classes, different iterations has to be empirically tested until we reach the optimum number that gives the best discrimination possible among classes. Yang and Lo (2002) and Mundia and Aniya (2005) found that, the number of maximum iterations and the convergence value also has an effect on classification. The laters achieved better results for differentiation between the vegetation mixed with other types of land cover by applying these criteria. They found 40 classes to be the optimum number for TM, ETM+ and MSS data while 80 was the maximum number of iterations allowing the clustering to stop naturally upon reaching the convergence threshold of 0.990.

In this study, we started arbitrarily with smaller numbers of classes to be incremented after each iteration. The problem of discrimination between oases, dark sands or shadow soon became obvious, therefore 67, 80 and 60 iterations with a convergence value of 0.990 for all images were found most suitable for MSS, TM and ETM+ respectively. Resampling the images to a finer resolution was carried out in some studies in order to solve mixed pixels concerns (Fung 1992; Lodhi *et al.*, 1998; Serra *et al.*, 2003). Resampling the Landsat MSS to 30m was carried out using bilinear interpolation then nearest neighbour to achieve better classification accuracy. Unfortunately, this did not give better results. Consequently, we did not adopt resampling method and the Landsat MSS image with 57m spatial resoulution was used. Labeling of classes based upon the original image in a false color composite and clustered map were displayed together using geolink and swipe tool in ERDAS Imagine. In addition, aerial photographs from 1976 and 1998 were used so as to label the pixels in the correct classes.

Supervised classification was the second step in our image classification scheme. Signatures resulted from the unsupervised classification process were merged and recoded in ERDAS Imagine, to keep optimum number of the main six land cover classes in the study area; then we used the maximum likelihood algorithm with training sites carefully selected from the unsupervised classification results to run the supervised classification. Furthermore, classified images were filtered using a 3 x 3 majority filter to remove speckles and to smooth the resulting images and decrease analytical errors (Yang and Lo 2002).

3.4 Extracting Urban areas from satellite images (MSS 1972, TM 1990 and ETM+ 2000).

The second main focus of this study is on urban areas, so in order to analyse urban change, a bit map is produced including only two land cover classes: Urban and non-Urban. This same approach was applied by Southworth *et al.*, (2002) to address the relationship between the trajectories of forest-cover change and the biophysical and social characteristics of the landscape in the mountains of Western Honduras.

Extraction of the urban area from the three LULC maps of 1972, 1990 and 2000 first required conversion of them to binary maps by merging urban/built-up and vegetation classes in all three maps to Urban. Vegetation is merged with built-up areas because vegetation occurred within built-up areas as a man made feature associated with this desert city's urban areas. Such features include gardens, grasses, parks and tree plantations along roads network. While the other classes were recoded as non-Urban except for the class of water-body and shadow in the first 1972 image. Here the water-body and shadow classes were merged into the non-Urban class because of the largest percentage of shadow occurred in places that were not urban, for example, Hafeet Mountain. (Figure 3.2). However, in 1990 and 2000 LULC maps, this class was merged into Urban because it is mainly caused by built-up and man made features, e.g., buildings and newly constructed roads (Table 3.3).

Table 3.3: Recoding of the LULC classes into Urban and non-Urban.

Class	1972
Built up	Urban
Vegetation	
Sand dunes	Non-Urban
Sand & Gravel	
Limestone	
Water body & shadow	

Class	1990 and 2000
Built up	Urban
Vegetation	
Water body and shadow	
Sand & Gravel	Non-Urban
Limestone	
Sand dunes	

Certain classes were over-estimated e.g vegetation while others were underestimated when running the accuracy assessment. For example, in the 1972 classified image, sand and gravel were classified as urban areas because they are usually used for construction of urban areas such as: buildings, roads, pavements and other urban features being brought from the surrounding environment, (Yang and Liu 2005; Zhang 2002). Furthermore, this explained the occurrence of urban pixels on Hafeet Mountain and other parts of the study area which was absurd! This problem was resolved manually (by working on the vector polygons!) by the removal of the pixels that were judged as non urban using the researcher knowledge of the study area and the existence of reference maps.

In the 1990 classified image, there were some buildings under construction, such as, the Al Ain International Airport and Al Towayya District, which were split into urban in some cases and non-urban, as sand and gravel, limestone and sand dune, in others. Likewise, in the 2000 classified image, water bodies and shadows were classified as non-urban areas while they were formed in the built-up areas which should be eliminated to avoid overlapping with the existing built-up and then added (merged) to form one urban class (Figure 3.3 a, b, and c).

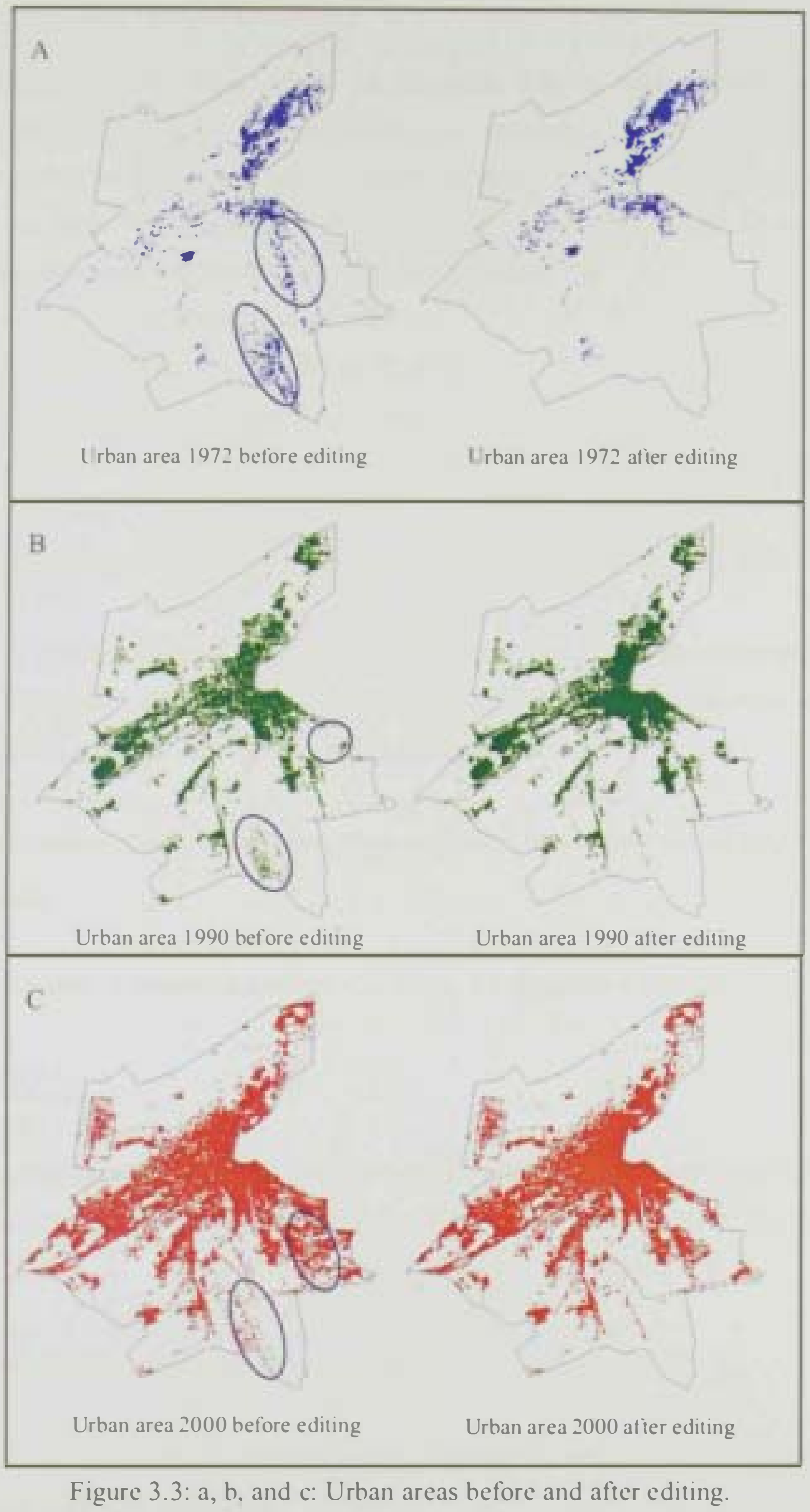


Figure 3.3: a, b, and c: Urban areas before and after editing.

3.5 Selecting spatial metrics.

Spatial metrics have played an important role in urban studies as was mentioned in the chapter 2. Consequently, the application of a number of spatial metrics is used to analyze and understand the urban growth pattern and dynamics to help in the prediction and planning of the future evolution of the city. As such, the following spatial metrics are applied: -

- Land Consumption Rate (LCR)
- Land Absorption Coefficient (LAC)
- Annual Urban Growth Rate (AGR)
- The Percentage of built up land (PLAND_U)

Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC)

L.C.R is a measure of compactness which indicates a progressive spatial expansion of a city. While, L.A.C is considered as a measure of change in consumption of new urban land by each unit increase in urban population.

The Land consumption rate and absorption coefficient formula are shown below -

$$L.C.R = \frac{A}{P}$$

A = areal extent of the city in hectares P = population (per capita)

$$L.A.C = \frac{A2 - A1}{P2 - P1}$$

A1 and A2 are the areal extents in hectares for the early and later years, whilst P1 and P2 are population (per capita) for the early and later years respectively (Yeates and Garner, 1976).

- **Annual Urban Growth Rate (AGR)**

Annual Urban Growth Rate (AGR) is used to evaluate the urbanization speed of a unit area. AGR is defined as follows:-

$$AGR = \frac{UA_{n+i} - UA_i}{nTA_{n+i}} \times 100\%$$

where TAn + i is the total land area of the target unit to be calculated at the time point of i + n; UAn + i and UAi the urban area or built-up area in the target unit at time i +n and i, respectively, and n is the interval of the calculating period in years (Xiao *et al.*, 2006).

- **The Percentage of built- up land (PLAND_U)**

The Percentage of built-up land (PLAND_U) was applied by Tian *et al.*, 2005 and Herold *et al.*, 2003b. In general, PLAND equals the sum of the areas (hectare) of a specific land cover divided by total landscape area (hectare), multiplied by 100

$$(PLAND\_U) = \frac{UL}{TL} \times 100\%$$

3.6 Urban change analysis techniques.

A combination of two techniques (hybrid) in a multi- stage approach post classification comparison and GIS overlay is implemented in this study. Starting with the post-classification comparison approach that is used based on comparing separately the produced classified landuse/cover maps (1972, 1990, 2000) in order to identify the change in the landuse/cover classes and provide descriptive information about the nature of change that occurred in different dates (Mundia and Aniya 2005). Besides detecting change by applying a post-classification comparison algorithm, GIS overlay was adopted with attention given to urban areas. After all binary maps were generated for the three dates, urban change trajectories were further investigated and analyzed by integrating the three vector maps in ArcGIS software. The binary maps were produced by converting the raster classified maps to vector format using conversion tools in ArcToolbox "from Raster to polygon" in order to conduct a Polygon-Polygon-Polygon overlay analysis between the three dates. All urban change trajectories were produced and mapped using SQL statements. A total of eight trajectories have been identified (Table 3.4 and Figure 3.4).

Table 3.4: Urban-non urban trajectory between the three dates: 1972–1990–2000.

Case	1972	1990	2000
1	U	U	U
2	U	N	N
3	U	N	U
4	U	U	N
5	N	N	U
6	N	U	N
7	N	U	U
8	N	N	N

U = Urban
N = non-Urban

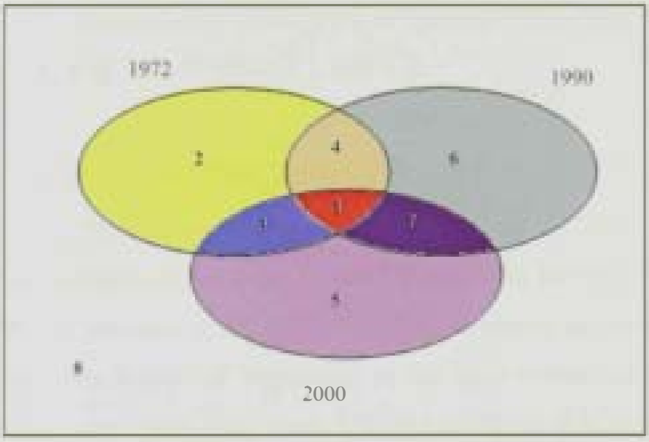


Figure 3.4: Instances of urban change trajectories from 1972 - 2000.

Chapter Four

LULC MAPS FOR THE YEARS 1972, 1990 AND 2000

4.1 LULC map of the year 1972

The 1972 LULC map, similarly to the other two dates, was produced by applying a hybrid classification approach including unsupervised and supervised classification schemes (§ 3). Accuracy assessment of the results gave acceptable values; for instance, the overall accuracy of the 1972 LULC map was 74.81% (Table 4.5). Figure 4.1 and table 4.1 shows that: sand dunes, sand and gravel, and limestone were the dominant land cover types as they occupied more than 90% of the study area; whereas urban areas, including built-up and vegetation, occupied less than 10%. The contribution of vegetation to urban areas constitutes 70%, while the built-up areas occupied the remaining 30% (Figures 4.1 and 4.2).

4.2 LULC map of the year 1990

In 1990, the study area showed great change in most LULC classes compared to the 1972. For example, urban areas jumped from 6,720 hectares in 1972 to 14,472 hectares in 1990, an increase of 115% in 19 years, as shown in Table 4.1. During the same period, the contribution of vegetation to the total urban area dropped to only 48% while built-up areas jumped to reach 52% exceeding that of vegetation, as can be seen in Figure 4.2. On the other hand, sand dunes, limestone, sand and gravel witnessed net decrease during the same period especially for sand dunes and sand and gravel classes; in particular, sand dunes decreased from 26,221 hectares in 1972 to 22,838 hectares in 1990, a decrease of 13% in 19 years (Table 4.1).

4.3 LULC map of the year 2000

The largest increase in urban areas of Al Ain city however was noticed on the 2000 classified map. Indeed, the urban area increased sharply by the year 2000 to occupy more than a quarter of the city. It is notable from the three maps in figure 4.1 that the non-urban areas witnessed a net decrease over the period of study from 90% in 1972 to 80% in 1990 and to 70% in 2000. Figure 4.2 also indicates that the contribution of vegetation to urban areas rises again to reach 51% of total urban areas while built-up areas occupied the remaining 49%. The total area, in hectares, occupied by each of the LULC classes in the classified maps are summarized in Table 4.1.

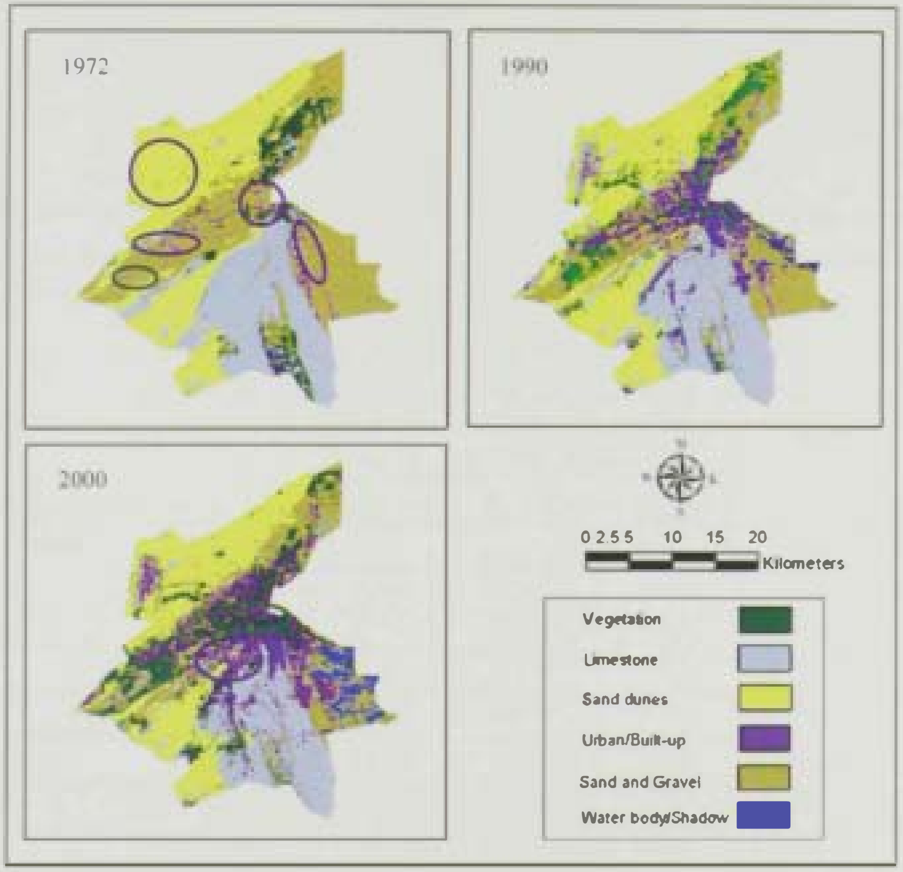


Figure 4.1: Al Ain LULC maps in 1972, 1990 and 2000

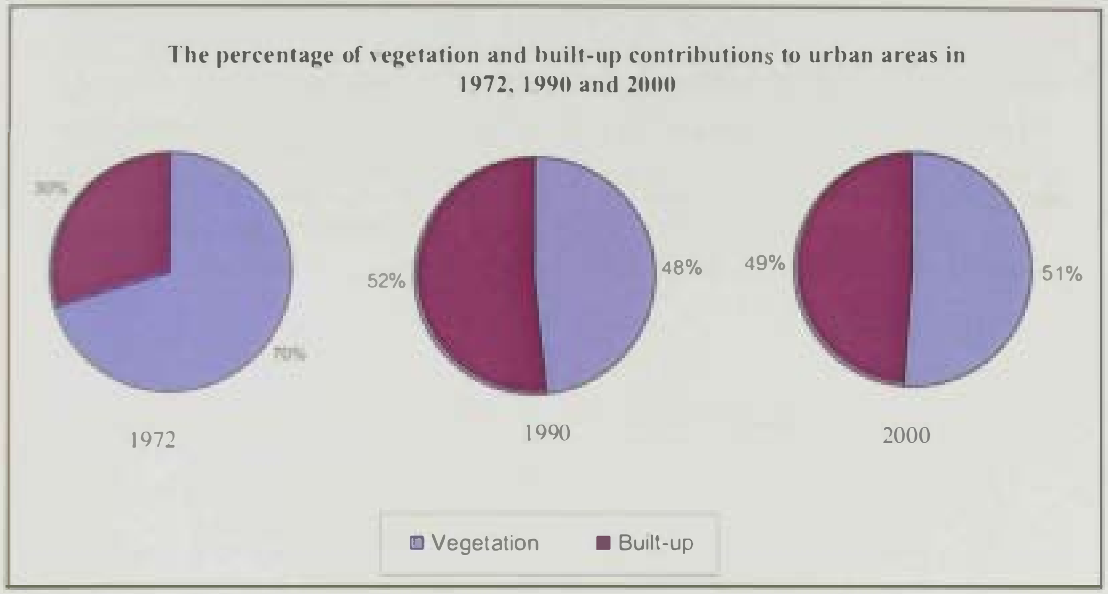


Figure 4.2: Percentages of vegetation and built-up contributions to urban areas in 1972, 1990 and 2000

Table 4.1: Areas (in hectare) and percentage of land cover classes during the study period

LULC classes	1972		1990		2000	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Vegetation	4728	6.14	6994	9.08	10335	13.42
Built-up	1992	2.59	7478	9.71	9844	12.78
Sand and gravel	25413	33.00	20857	27.09	18614	24.17
Sand dunes	26221	34.05	22838	29.66	20983	27.25
Limestone	18183	23.61	17618	22.88	14422	18.73
Water body/ Shadow	462	0.60	1215	1.58	[illegible]	3.64
Total	77000	100.00	77000	100.00	77000	100.00

4.4 Extracting Al Ain urban areas for the years 1972, 1990 and 2000.

As explained in chapter 3, urban areas were extracted by producing binary maps from the LULC maps by using the 'Recode Function' in ERDAS Imagine 8.7. A value of 1 is assigned to classes that fall in the urban category and 0 is assigned to all other classes. The results of this operation are presented in figures 4.3.

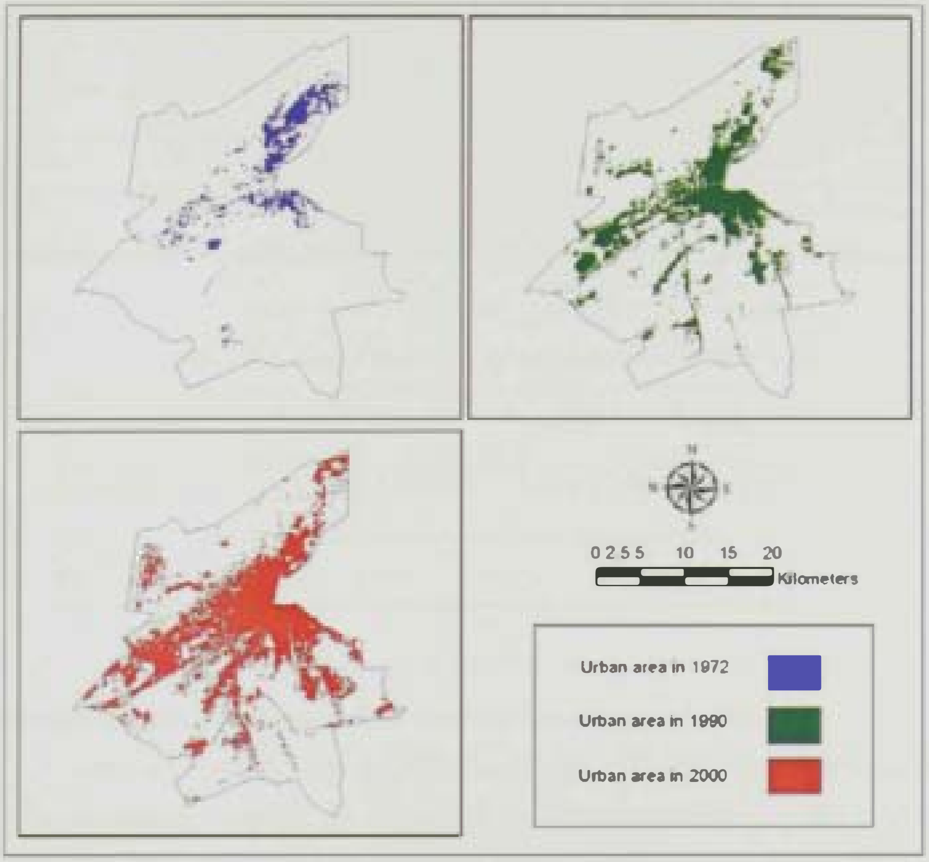


Figure 4.3: Al Ain urban areas in 1972, 1990 and 2000.

4.5 Calculating spatial metrics.

The set of spatial metrics discussed in chapter 3 requires knowledge of the population count in the study domain along with its total area and the area of the urban fraction. Population counts for representative time periods were obtained from external sources and are summarized in table 4.2. The needed areas were calculated from the classified maps and presented in table 4.3.

Table 4.2: Population data of Al Ain city for the years 1972, 1990 and 2000

Year	Population	Source
1975	50,700	Master plan for the Region of Al Ain 1986
1990	179,640	Statistical Yearbook 1995
2001	264,000	2001 survey (corrected for under enumeration)

Table 4.3: Areas (hectare) of urban and total study area

Area (ha)	1972	1990	2000
Urban area	4,107.00	13,965.00	21,160.00
Total Study area	77,000.00		

Calculating Land Consumption Rate and Land Absorption Coefficient

Land consumption rate (LCR) was calculated by dividing the area in hectare by the population count in the study area for the corresponding year. It should be noted here that population counts were not available for the same years as the classified maps. Counts from the closest year available were used, that is, 1975 was used for the year 1972; the 1995 statistical year book of the government of Abu Dhabi was used for the year 1990, and the 2001 survey was used for the year 2000. The total area of the study area was found to be 770 km^2 (TPSS, 2008), and was converted to hectares for use in the metrics calculations.

LCR (1972) = 4,107/50,700 = 0.081

LCR (1990) = 13,965/179,640 = 0.078

LCR (2000) = 21,160/264,000 = 0.080

The Land Absorption Coefficient (LAC) was calculated for two periods (1972-1990) and (1990-2000)

$$LAC\ (1972\text{-}1990) = \frac{13{,}965 - 4{,}107}{179{,}640 - 50{,}700} = \frac{9{,}858}{128{,}940} = 0.076$$

$$LAC\ (1990\text{-}2000) = \frac{21{,}160 - 13{,}965}{264{,}000 - 179{,}640} = \frac{7{,}195}{84{,}360} = 0.085$$

From the results, it is obvious that, the LCR across the three dates showed only a little difference (Table 4.4). There was a decrease in the land consumption rate from 0.081 to 0.078 between 1972 and 1990 then an increase to 0.080 in the year 2000. While the land absorption coefficient scored 0.076 between 1972 and 1990 and 0.085 in the second period 1990 - 2000.

Table 4.4: Land Consumption Rate and Absorption Coefficient

Year	Land Consumption Rate	Year	Land Absorption Coefficient
1972	0.081	1972/1990	0.076
1990	0.078	1990/2001	0.085
2000	0.080		

Annual Urban Growth Rate (AGR)

$$AGR\ (1972\text{-}1990) = \frac{(13{,}965 - 4{,}107)}{(77{,}000 * 19)} * 100\% = 0.67$$

$$AGR\ (1990\text{-}2000) = \frac{(21{,}160-13{,}965)}{(77{,}000*10)} *100\% = 0.93$$

Clearly, the second period witnessed a more rapid expansion in urban areas than in the first period.

The Percentage of built-up land (PLAND_U)

$$PLAND\_U\ (1972) = \frac{4{,}107}{77{,}000} *100\% = 5.33\%$$

$$PLAND\_U\ (1990) = \frac{13{,}965}{77{,}000} *100\% = 18.14\%$$

$$PLAND\_U\ (2000) = \frac{21{,}160}{77{,}000} *100\% = 27.48\ \%$$

Urban area increase across the period of study is shown in percentile in Figure 4.4.

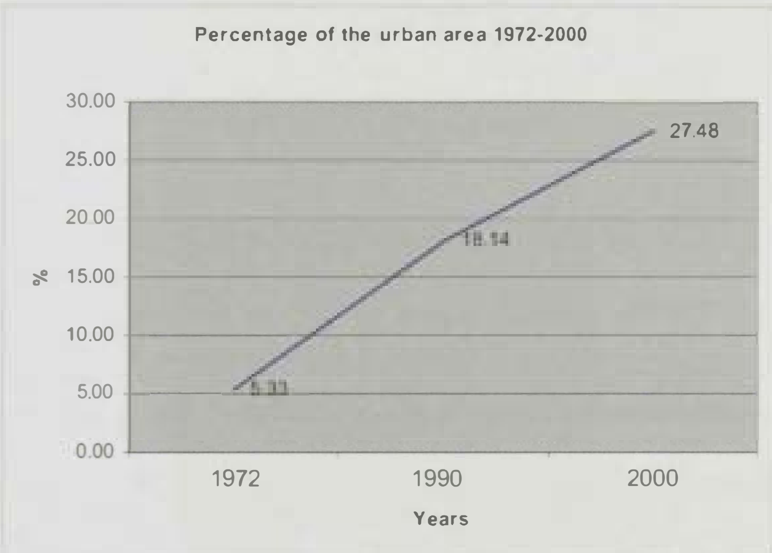


Figure 4.4: Percentage of urban area from 1972 - 2000

4.6 Conducting change detection analysis between 1972, 1990 and 2000.

As explained in chapter 3, change detection analysis across 1972, 1990 and 2000 was conducted based on the post-classification comparison method of the LULC maps of the three dates. Visual interpretation and statistical examination of the change in the area of each of the six main classes was carried out. The LULC classification results are shown in Table 4.1 and statistical results are illustrated in Figure 4.5. The GIS overlay analysis was also applied to the LULC maps which allowed the creation of the 216 (=6^3) possible combinations of classes over the 3 study periods and hence producing 216 different from-to-to change maps (not shown here!), e.g., CL1-CL1-CL1; CL1-CL1-CL2; CL1-CL1-CL3, etc. Visual interpretation of the three images indicates that the LULC classes of the study area followed two opposite trends over the study period testifying increase in some classes and decrease in others. For instance, vegetation, built-up, water body and shadow testified an increase while sand and gravel, sand dunes and limestone followed a decreasing trend over the same period (Figure 4.5).

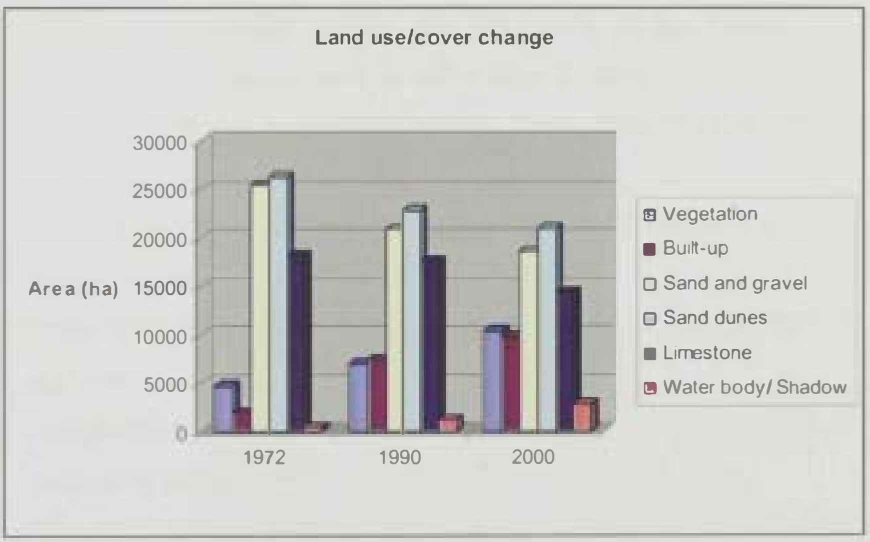


Figure 4.5: Trends in land use/cover changes from 1972 to 2000

4.7 GIS overlay analysis & Visualization.

Conversion of the binary maps to vector format was an essential step towards the application of overlay analysis in order to conduct a Polygon-Polygon-Polygon overlay analysis between the three dates. After conversion of the binary maps to vector format as seen in Figures 4.6, 4.7 and 4.8, the analysis was applied to trace back and visualize the urban change trajectory across the study period. Figure 4.9 is a map consisting of eight layers; each layer represents one of eight cases as explained in Chapter 3. The process to create these layers is summarized in the next paragraph.

After conversion of the urban map from raster to vector format for the three study dates, an overlay of the maps from 1972, 1990 and 2000 was performed in ArcGIS using the "Union Function". This operation resulted in merging urban features from the three dates into one layer whose attributes table included all the attributes of the input layers. The attribute table plays an important role in the analysis process. In particular, fields "GRIDCODE", "GRIDCODE_1" and "GRIDCODE_2" which correspond to the urban status of the associated polygon (1 for yes and 0 for no) in 1972, 1990 and 2000 respectively. These fields were used to trace the change in urban status from one study period to the next with the help of a well formulated database query using SQL to identify features that fall in any of the 8 cases discussed in chapter 3 . The SQL statements used in define these 8 cases:

1. ["GRIDCODE" =1 AND "GRIDCODE_1" =1 AND "GRIDCODE_2" =1] for the U-U-U case
2. ["GRIDCODE" =1 AND "GRIDCODE_1" =0 AND "GRIDCODE_2" =0] for the U-N-N case
3. ["GRIDCODE" =1 AND "GRIDCODE_1" =0 AND "GRIDCODE_2" =1] for the U-N-U case
4. ["GRIDCODE" =1 AND "GRIDCODE_1" =1 AND "GRIDCODE_2" =0] for the U-U-N case
5. ["GRIDCODE" =0 AND "GRIDCODE_1" =0 AND "GRIDCODE_2" =1] for the N-U-U case
6. ["GRIDCODE" =0 AND "GRIDCODE_1" =1 AND "GRIDCODE_2" =0] for the N-U-N case

7. ["GRIDCODE" =0 AND "GRIDCODE_1" =1 AND "GRIDCODE_2" =1] for the N-U-U case

8. ["GRIDCODE" =0 AND "GRIDCODE_1" =0 AND "GRIDCODE_2" =0] for the N-N-N case

The process to create a layer that contains features belonging to each one of the 8 cases starts by using the 'select by attribute' command to identify features to be included. Figure 4.10-A depicts an example of such a query for the U-U-U case. Features selected as a result of this query are highlighted on the map as seen in figure 4.10-B. The next step consists in using the "Create Layer From Selected Features" command to extract these features and save them in a new layer (figure 4.10-C) that can be displayed and used independently (figure 4.10-D).

This process was used to create the 8 layers containing features that belong to the 8 different cases of interest to this study. The 8 individual layers were then combined into one map for analysis. The results of the analysis are discussed in Chapter 5.

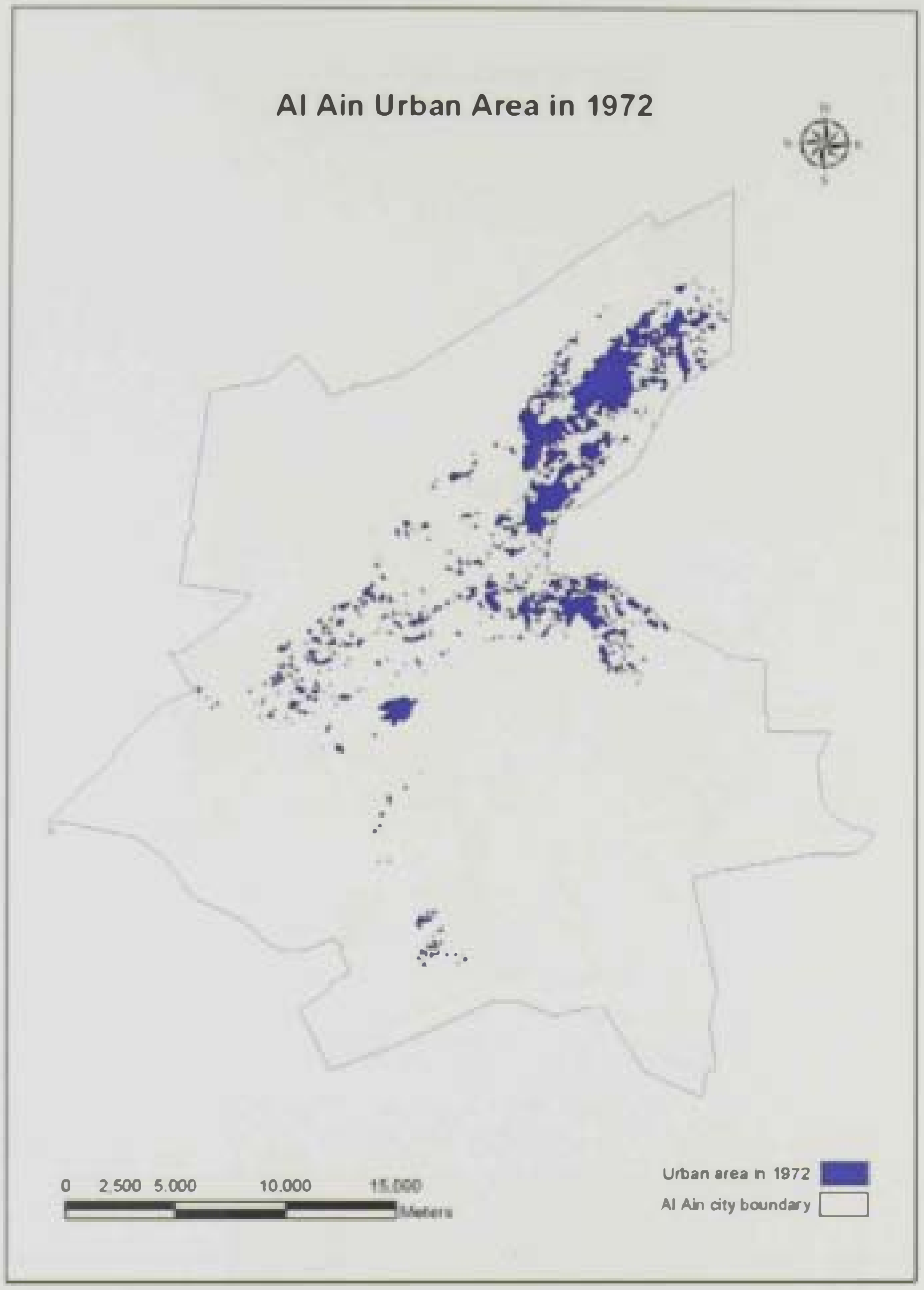


Figure 4.6: Al Ain urban area in 1972 (vector layer)

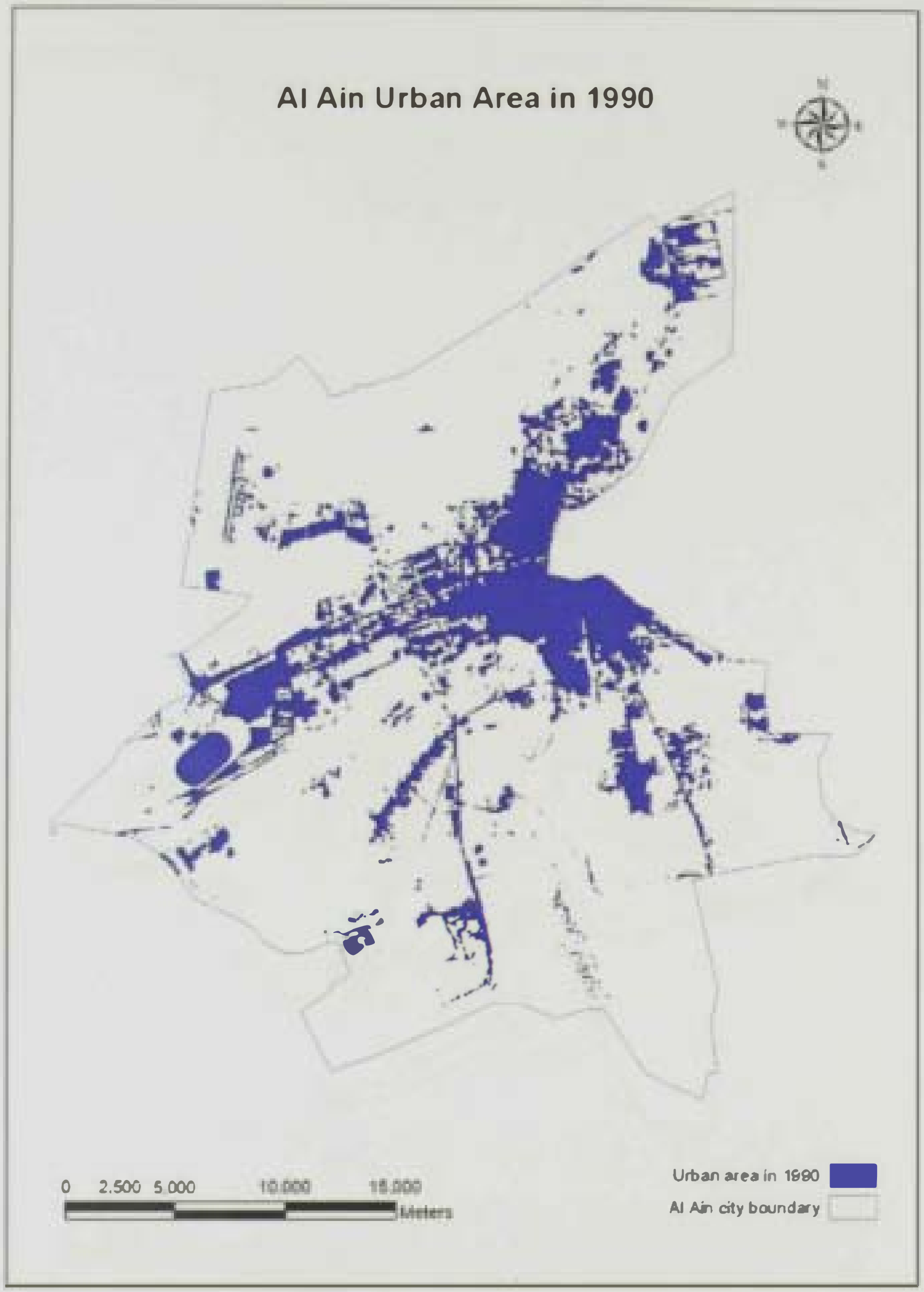


Figure 4.7: Al Ain urban area in 1990 (vector layer)

Figure 4.8: Al Ain urban area in 2000 (vector layer)

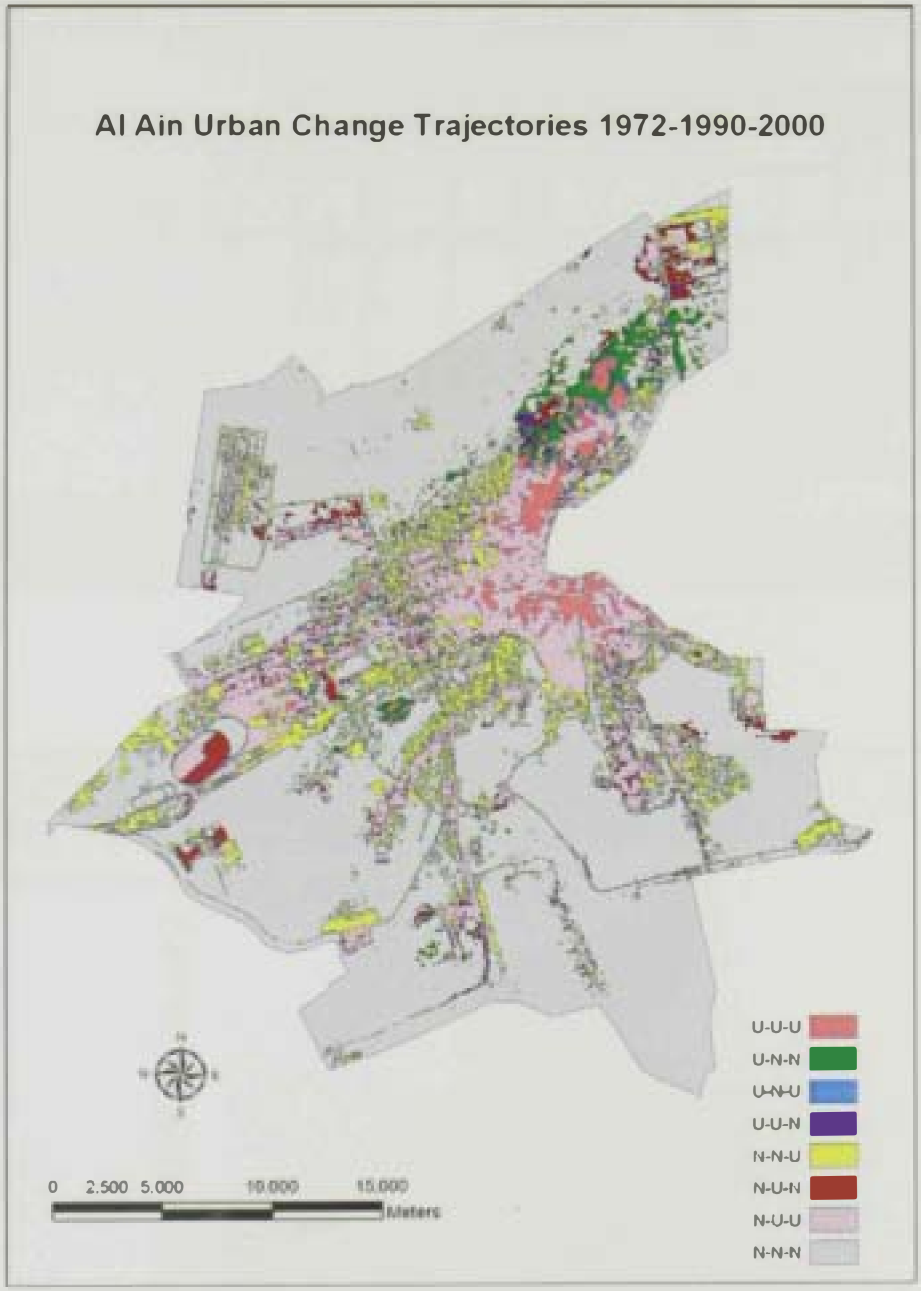
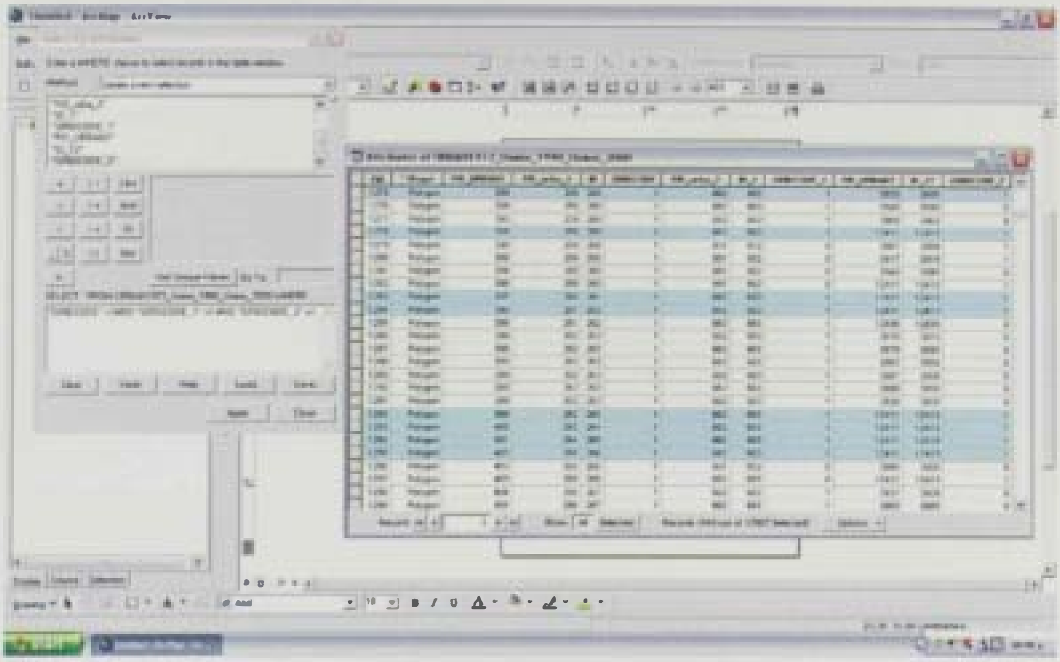
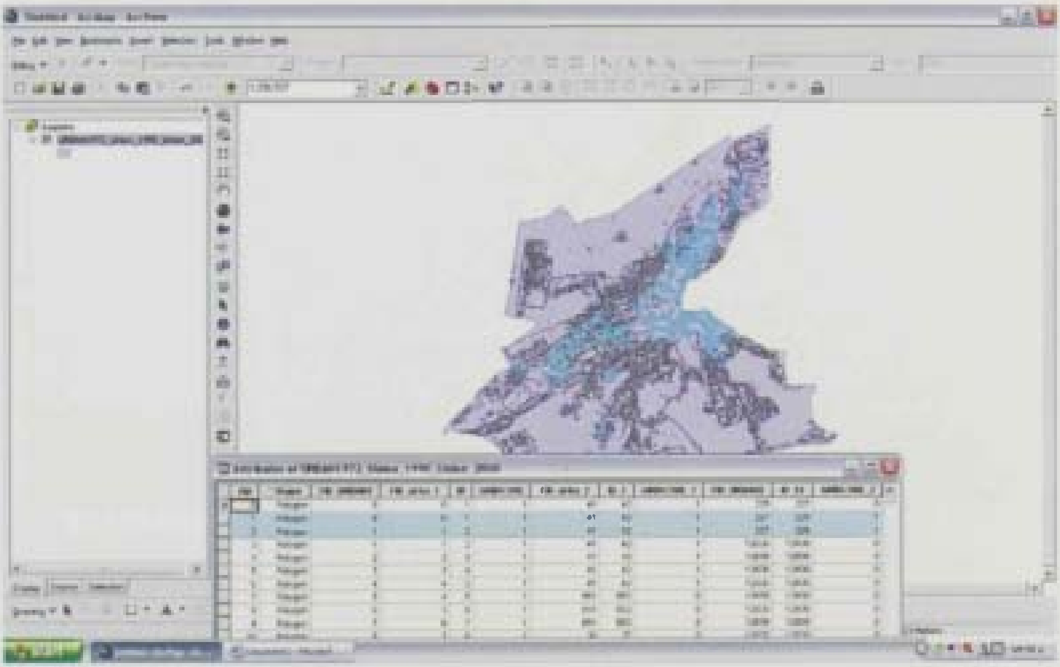


Figure 4.9: Combined Al Ain Urban vector maps in 1972, 1990 and 2000. U: Urban / N: Non-urban for the year 1972, 1990 and 2000, respectively.

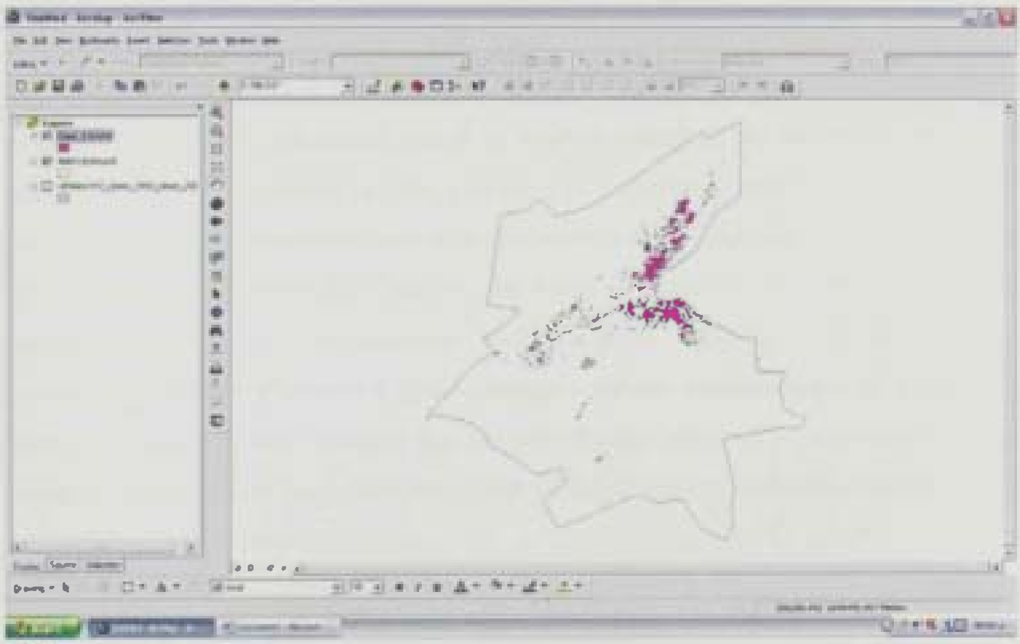


(A)



(B)

(C)



(D)

Figure 4.10 (A, B, C and D): The sequence of overlay analysis of the first case (U-U-U)

4.8 Accuracy assessment.

Accuracy assessment is an important step for thematic data derived from remotely sensed imagery as it provides a measure of the classification method performance by comparing classified images with ground truth data. The comparison is usually performed for a limited set of reference locations that constitute a representative sample of the whole land cover map. The reference sample should be selected independently of the data used for training and/or developing the classification procedure (Stehman, 1997). It can be performed with the assistance of aerial photographs, topographical maps and local knowledge (Mundia and Aniya 2005). Indeed, a variety of measures for assessing the land cover classification performance can be derived from the confusion matrix, such as, overall accuracy among all classes, the kappa coefficient, user's accuracy and the producer's accuracy (Kyriakidis and Zhang 2003; Foody 2002; Stehman 1997). However, it should be recognized that the resulting confusion matrix and the accuracy statement may be significantly distorted by errors in the reference data (Foody, 2002).

User's accuracy or commission error is calculated by **dividing the total number of correctly classified pixels in a given category by the total number of pixels that were classified in that category** (i.e. the total number of pixels in one row of the confusion matrix) and is an indicator of the probability that a classified pixel actually represents that category in reality (Rogan *et al*., 2002). While the Producer's accuracy or omission error, is calculated by **dividing the total number of correctly classified pixels in a given category by the total number of pixels that actually belong to that category** (i.e. the total number of pixels in one column of the confusion matrix) and is an indicator of the probability that, a reference pixel is being correctly classified (Jensen, 2005).

$$\text{User's Accuracy} = \frac{\text{\# of correctly classified pixels}}{\text{Total \# of pixels in a row}} * 100$$

$$\text{Producer's Accuracy} = \frac{\text{\# of correctly classified pixels}}{\text{Total \# of pixels in a column}} * 100$$

The Kappa statistic incorporates the off-diagonal elements of the error matrix that correspond to classification errors and represents the agreement between observed and truth after removing the proportion of that agreement that could be expected to occur by chance (Yuan *et al.*, 2005)

Overall accuracy is computed by dividing the total number of correctly classified pixels by the total number of reference pixels (Rogan *et al.*, 2002, Xiuwan 2002)

$$\textbf{Overall Accuracy} = \frac{\textbf{sum of major diagonal tallies}}{\textbf{total number of samples}} * 100$$

An Accuracy Assessment was performed twice in this study. Firstly, for the LULC maps and secondly when extracting the urban areas. Historical aerial photographs, land use maps and knowledge of the study area were used to collect reference data for the three dates: 1972, 1990 and 2000. Unfortunately, collection of reference data for assessing the accuracy of multi-temporal images always occurs with a serious constraint because of the absence of simultaneous 'ground truthing' data over a long period of time (Qiming *et al.*, 2008). All classified images were assessed using a random sampling design, a total of 135 sites were selected for each image. A confusion matrix was produced, from which the overall accuracy and kappa index of agreement for each scene were computed.

An aerial photography from 1976 was used to collect reference data for the 1972 LULC map. While for 1990, the land use map of the city from the same year at a nominal scale of 1:60000 was adopted for gathering the list of reference points. Finally, the Land use map produced by Massassati and Al-Thaibani (2000) together with an IKONOS 2000 image that covers part of the study area, were used as ground references for the year 2000 classified images. From Table 4.5, it is clear that the LULC map produced from the ETM+ image has the best overall classification accuracy of 79.26%, followed by that from the TM image at 76.30% and then the MSS image at 74.81%. An examination of the kappa indices of LULC categories reveals that, the ETM+ and TM images consistently gave better classification accuracy than that of the MSS image. Unfortunately, common usage of the term 'truth' when describing ground data is problematic because it contains some errors (Bird *et al.*, 2000; Khorram, 1999).

Table 4.5: Error matrix of land use/cover maps derived from Landsat data.

(a)

000	Water/shadow	Limestone	Agriculture	Urban	Sand&Gravel	Sand dunes	Row total	Producers accuracy	Users accuracy
ater/shadow	0	0	0	0	0	0	0	---	---
imestone	0	24	0	1	1	0	26	92.31%	92.31%
egetation	0	0	20	2	1	0	23	76.92%	86.96%
rban	0	0	2	11	1	1	15	52.38%	73.33%
and&Gravel	0	2	4	7	15	2	30	68.18%	50.00%
and dunes	0	0	0	0	4	37	41	92.50%	90.24%
olumn total	0	26	24	21	22	40	135		
verall Classification Accuracy = 79.26%			**Overall Kappa Statistics = 0.7363**						

(b)

990	Water/shadow	Limestone	Agriculture	Urban	Sand&Gravel	Sand dunes	Row total	Producers accuracy	Users accuracy
ater/shadow	0	0	1	1	0	0	2	---	---
imestone	0	20	1	1	2	0	24	86.96%	83.33%
egetation	0	1	13	0	3	2	19	56.52%	68.42%
rban	0	0	1	17	2	0	20	65.38%	85.00%
and&Gravel	0	1	6	7	15	0	29	65.22%	51.72%
and dunes	0	1	1	0	1	38	41	95.00%	92.68%
olumn total	0	23	23	26	23	40	135		
verall Classification Accuracy = 76.30%			**Overall Kappa Statistics = 0.7002**						

(c)

972	Water/shadow	Limestone	Agriculture	Urban	Sand&Gravel	Sand dunes	Row total	Producers accuracy	Users accuracy
ater/shadow	0	0	0	0	0	0	0	---	---
imestone	0	18	1	1	5	0	25	100.00%	72.00%
egetation	0	0	9	3	2	0	14	52.94%	64.29%
rban	1	0	2	11	9	0	23	64.71%	47.83%
and&Gravel	0	0	4	2	29	0	35	60.42%	82.86%
and dunes	0	0	1	0	3	34	38	100.00%	89.47%
olumn total	1	18	17	17	48	34	135		
verall Classification Accuracy = 74.81%			**Overall Kappa Statistics = 0.6762**						

Some sources of error that may affect the accuracy of the results of our classification can be summarized below :-

- The uncertainties of the input data limit the accuracy of the classification;
- The comparison of ground and thematic map labels based on differently sized units: MSS-57m, TM, ETM+ 30m, which can result in different estimates of classification accuracy (Biging *et al.*, 1999). Furthermore, the size and purity of the minimum mapping unit used and how it is related to the nature of the ground data (Biging *et al.*, 1999; Khorram, 1999);
- Spectral confusion is the major cause of classification inaccuracy of a spectrally-based classification method especially with old data in a desert study area without enough features to consider during the geometric correction process (Yang and Lo 2002);
- Geometric corrections of the 1976 aerial photography and the 1990 Al Ain land use map (planimetric error; locational inaccuracy);
- Misregistration problems between images of the three dates decreasing the overall accuracy of the classified data (Serra *et al.*, 2003; Townshend *et al.* 1991);
- Merging and recoding the classes either in unsupervised or supervised classification.

Urban area maps were produced using a semi-automatic method including the manual editing of the boundaries of certain classes based on knowledge of the study area. The accuracy assessment of these areas was performed using sixty random points for each date. Fortunately, the overall accuracy of the urban areas class increased across the three dates giving a better accuracy than with the original LULC six classes produced in the first step as can be seen in Table 4.6. However, the accuracy of Landsat MSS 1972 is better than the Landsat TM and ETM+, because of the quality of the ground data where it was the best in 1972 and low in 1990 and 2000. Furthermore, the Kappa coefficient can be considered to have moderate agreement according to the classification of Landis and Koch (1977). Indeed, Landis and Koch classified Kappa value into three classes; K values >0.80 represents a strong agreement of accuracy between the classification map and the ground reference information; K values between 0.40 and 0.80 represents moderate agreement; while K values < 0.40 represents poor agreement. Accordingly, the K values calculated in the first and second assessment in this study are considered to have relatively moderate, to strong agreement.

Table 4.6: The overall accuracy and Kappa coefficient of Urban areas on the three dates

	1972	1990	2000
Overall accuracy	96.67%	86.67%	90%
Kappa coefficient	0.65	0.68	0.74

Chapter Five

DISCUSSION

5.1 Al Ain urban growth characteristics.

Urban areas were extracted primarily from the three LULC maps of 1972, 1990 and 2000 by merging urban/built-up and vegetated areas classes to form the Urban class in all three dates (§ 3). In addition, water-body and shadow classes were added to the built-up area class of the city in both the 1990 and 2000, because they were either man made or caused by man-made features, e.g., buildings and newly constructed roads (§ 3). By contrast, water-body and shadow classes were merged into the non-Urban class on the 1972 map because the largest percentage of shadow occurred in places that were not urban, e.g., Hafeet Mountain (Figure 3.3).

Following the production of the Urban/non-Urban binary maps, a conversion of the bitmap images to vector formats was applied to facilitate the calculation and interpretation of spatial metrics used to characterize Al Ain urban growth.

Four spatial metrics were used in this study to quantify and characterize the urban growth of Al Ain city (§ 4.4). Explicitly: The Land Consumption Rate (L.C.R), which is a measure of compactness which indicates a progressive spatial expansion of a city; The Land Absorption Coefficient (L.A.C), which is a measure of change in consumption of new urban land by each unit increase in urban population; The Annual Urban Growth Rate (AGR), which is used to evaluate the urbanization speed of a unit area; and The Percentage of built-up land (PLAND_U), which is a measure of the concentration of built-up area in a region and is equal to the sum of the area (hectares) of a specific land cover divided by total landscape area (hectares) multiplied by 100

It is clear that Al Ain witnessed a notable growth during the study period as can be seen in Table 4.3. The percentage of urban area increased over the twenty-eight years study period from 5.33 % in 1972 to 18.14 % in 1990 and 27.48 % in 2000 (Figure 4.4). The annual urban growth rate (AGR) was calculated for two different periods: 1972 - 1990 and 1990 - 2000. The rate of urban growth was greater in the second period i.e. 1990 - 2000. Although the percentage of change in the urban area at 240% in the first period from 1972 to 1990 was greater than that of 51.5% in the second period (Table 5.1), a comparison of the pace of change between them shows that the second period witnessed greater expansion. This can be explained by considering the first period as the initial phase of urbanization when the city was transformed from a cluster of small villages to a modern city. While over the second period, the city experienced urbanization accompanied by rapid increase in population, mostly expatriates brought to meet the requirements and challenges of the rapid modernization processes and increase in employment demands.

LCR played a significant role in explaining the effect of the shape of urban growth in the compactness of the city. As can be seen, urban growth in Al Ain city took the shape of a star with four main axes, that is, north-east to Dubai, west to Abu Dhabi, south-east to the Dhaher and Mezyad Districts, south-west to Ain Al Fayda and the road to the farming areas of Dhahra, Abu Krayyah and Al Araad.(Figure 5.1). The two new axes that appeared in the 1990 map (Figures 5.1 and 5.7) affected the compact nature of the city and was translated in a decrease of the LCR calculated value from 0.081 in 1972 to 0.078 in 1990. One would expect LCR to increase as a result of the urban growth between 1972 and 1990. However, it decreased as a result of the greater increase in population than in urban areas (See Table 5.2). In the second period from 1990 through 2000, the LCR witnessed an increase to 0.080 as the growth in urban areas was greater than population growth. Therefore, there is an indication that there was more compactness in 2000 than in 1990 demonstrating that the former was a period of gap-filling following the establishment of the two urban axes that appeared in the 1990 map.

The land absorption coefficient, a measure of consumption of new urban land by each unit increase in urban population, was low between 1972 and 1990 (0.076) and increased to 0.085 between 1990 and 2000.

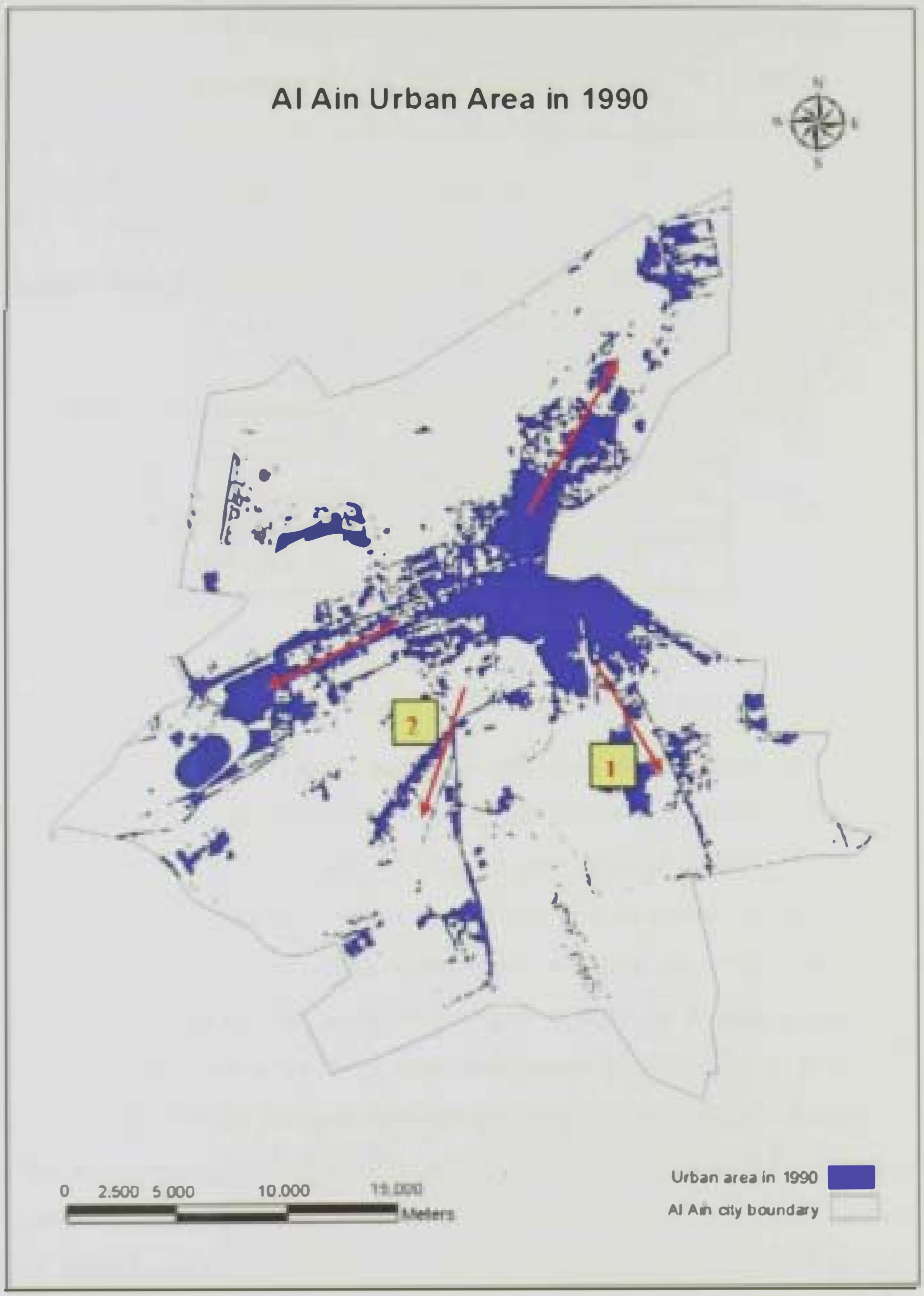


Figure 5.1: Direction of urban growth in 1990.

Table 5.1: Area and percentage of urban expansion

Date	1972-1990	1990-2000
Urban Change in hectare	9,858.00	7,195.00
Percentage of urban change	+240%	+51.5%

Table 5.2: Percentage of change in population and urban growth

	Population%	Urban%
1972-1990	254	240
1990-2000	46.9	51.5

Table 5.3 was created to give a quick and qualitative analysis of significant milestones in the change process of the city. It was produced by careful investigation and visual interpretation of the three LULC maps produced on the three different dates. It presents a quick analysis of the Spatio-temporal trajectory of some main land cover types especially in the urban areas. For instance, in 1972, natural green vegetation was abundant in the north-eastern part of the city though it witnessed a decrease in vegetation cover by 1990 and continued to do the same in 2000. This may be a false alarm in the interpretation caused by an increase in soil moisture at the end of the rainy season in the UAE which coincided with the capturing date of the 1972 Landsat MSS image, while the other two images were captured in August of 1990 and 2000 respectively, which may also explain the disappearance of natural green vegetation on the images of the later two dates.

In contrast, the distribution of green vegetation in the centre of the city demonstrated an increase in area during the whole study period when new urban areas led to an increase in the green areas due mainly to the construction of new roads accompanied by trees and grass plantation along these roads and in the roads islands and roundabouts. The effort to green more areas came as a result of government concern to preserve the character of the city as a green oasis. Historically, it is also known that the people of Al Ain city were confined to tree plantation particularly palm trees. Therefore, it is rarely found that private houses or buildings are not surrounded by planted trees such as palm trees, mango, banana and lemon. Other indications of the city urbanization are new constructions such as: Al Ain International Airport in the north-west and the Camel Racing Stadium in the west.

Table 5.3: Spatio-temporal trajectory analysis of main land-cover types

Type	1972	1990	2000
Al Ain International Airport	X	√	√
Camel Race Stadium	X	√	√
Intensification of urbanized city center	X	√	√
Urbanized areas W of city	X	√	√
Urbanized areas SE of city	X	√	√√
Urban Sprawl S of city	X	√	√√
Natural green vegetation distribution NE of city	√√√	√√	√
Distribution of green areas in city center	√	√	√√
Distribution of green areas near airport	X	√	√

Tracing the urban growth trajectories during the study period using GIS overlay analysis delivered not only an insight into the growth of the city in the past, but also revealed a good vision of the trend of the city growth in the future. Differentiating between eight different possible urban change trajectories (§ 4.4) drew the obvious conclusions and following observations:

- the oases resisted change over time as seen in Figure 5.2,

- some urban features, farms for example, that existed in 1972 disappeared by 1990 (Figures 5.5 and 5.11).
- some farms and ranches in different parts of the city that existed in 1990 disappeared by 2000. (Figure 5.4)
- in the second period (1990 - 2000), the city witnessed a huge expansion in comparison to the first period (1972-1990), as it was actually a completion of what had begun in the 1990s, for example, Al Ain International Airport, and the Al Toyawwa and Zakhir districts.
- likewise, new urban districts appeared, for example, Al Agabiyaa, Falaj Hazza and Al Shuaibah (Figure 5.5).
- the map representing non-urban areas in the three periods (N-N-N) provides the possibility of predicting where urban expansion may occur in the future. (Figure 5.6)
- the maps representing urban in 1972 and non-urban in1990 or 2000 (e.g. U-N-N; U-N-N; U-U-N) related to vegetated areas rather than built-up areas.

As a result of monitoring the direction of urban growth during the twenty-eight years study period, it is obvious that in 1972, the urban expansion followed two axes; the first westward to Abu Dhabi and the second, north-east to Dubai (see Figure 5.7). These two axes have played an important role in linking Al Ain to the capital of the United Arab Emirates, that is, Abu Dhabi, and to Dubai, the trading capital to the north-east. Whilst, in 1990 and 2000, new axes occurred to the south-east and the south-west. In the south-east where it is structurally suitable, construction was underway for industrial usage, such as, light and heavy industry, wholesale, warehousing and company camps, whereas the area to the east of Hafeet Mountain was set aside for the armed forces. The area to the south and south-west witnessed the growth of a number of tourism features including Hafeet Mountain, Green Mubazzarah and Ain Al Fayda, all of which are attractions that lure people from the other emirates to the area. As mentioned previously, these axes had an effect on the compactness of the city (See Figures 5.1 and 5.8).

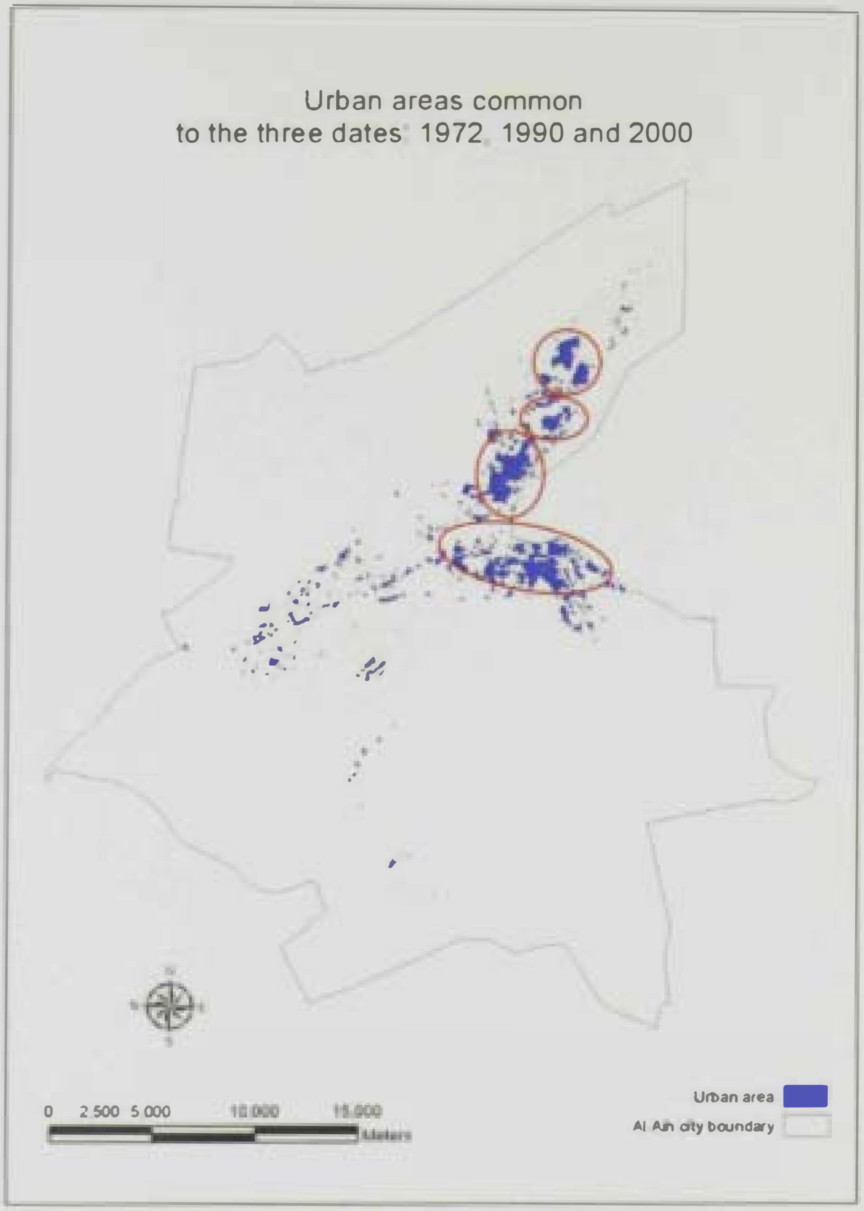


Figure 5.2: Urban areas common (preserved) to the three dates: 1972, 1990 and 2000.

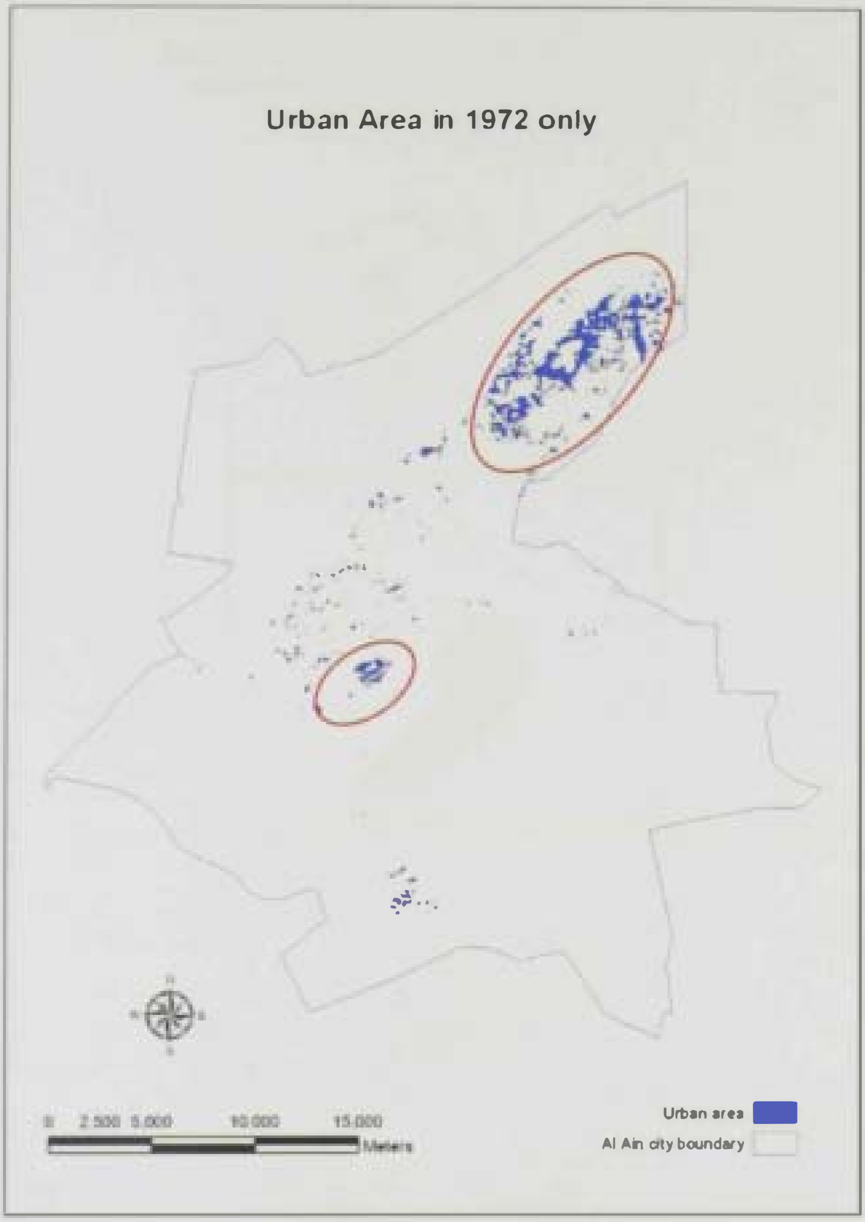


Figure 5.3: Urban areas of the 1972 only that do not exist in 1990 and 2000.

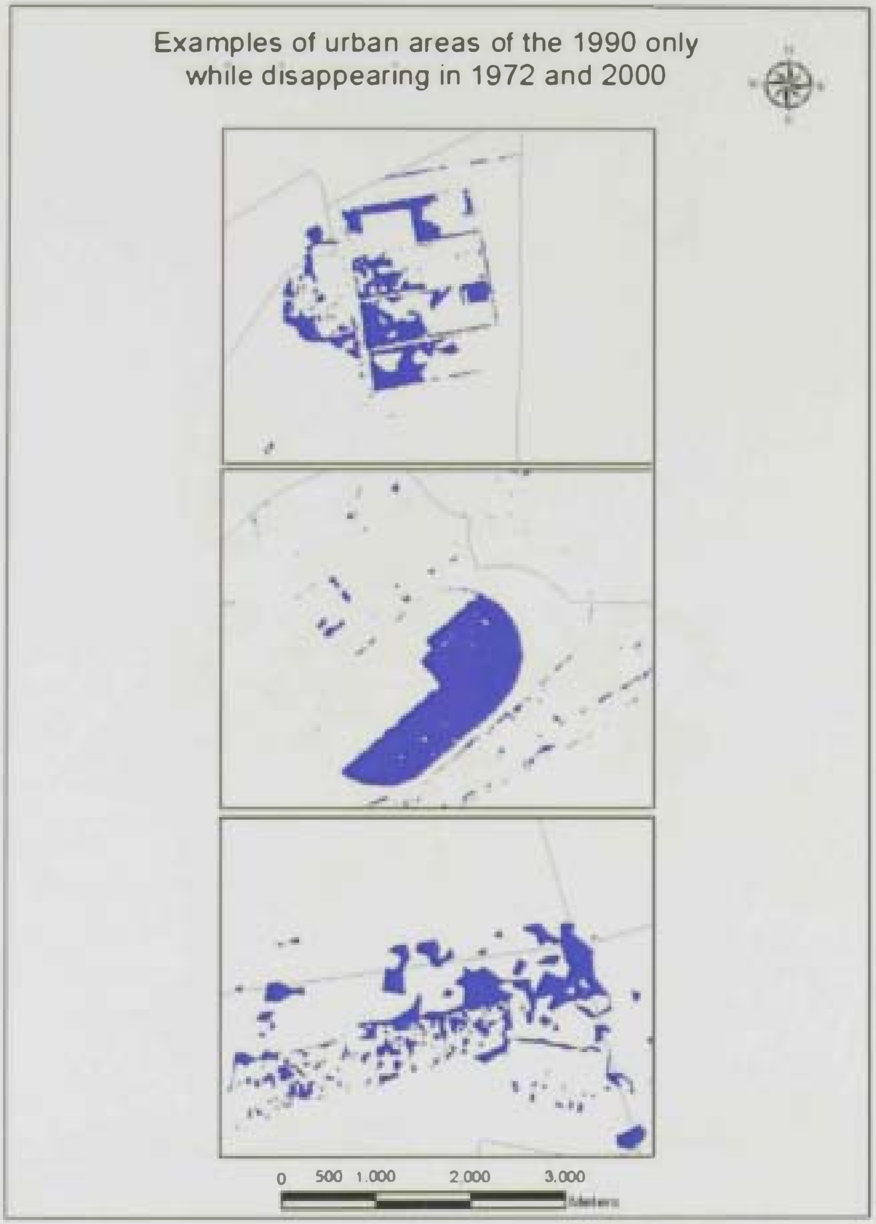


Figure 5.4: Urban areas of the 1990 only that do not exist in 1972 and 2000.

Figure 5.5: Urban areas of the 2000 only that do not exist in 1972 and 1990.

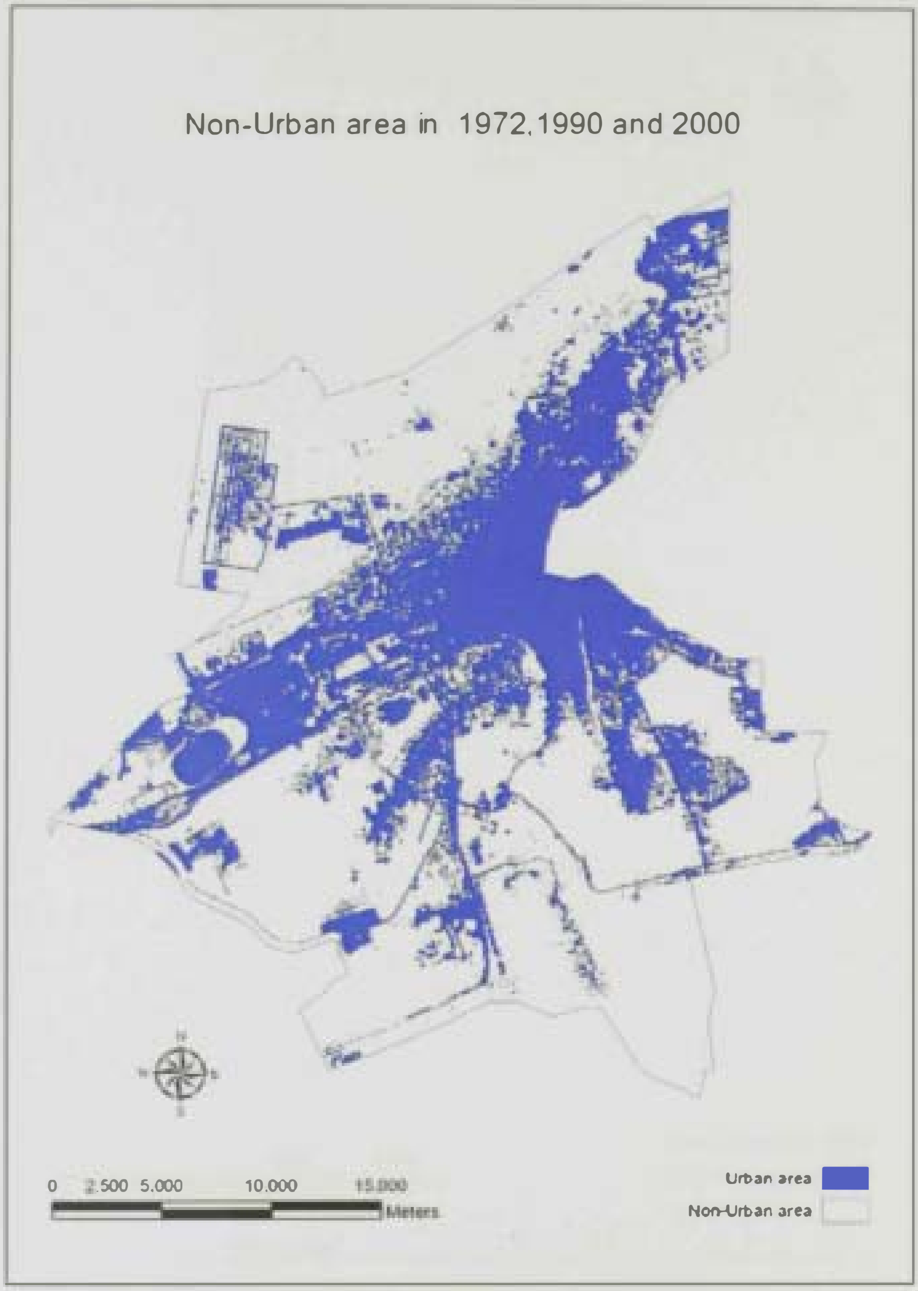


Figure 5.6: Non-Urban area common to the three dates.

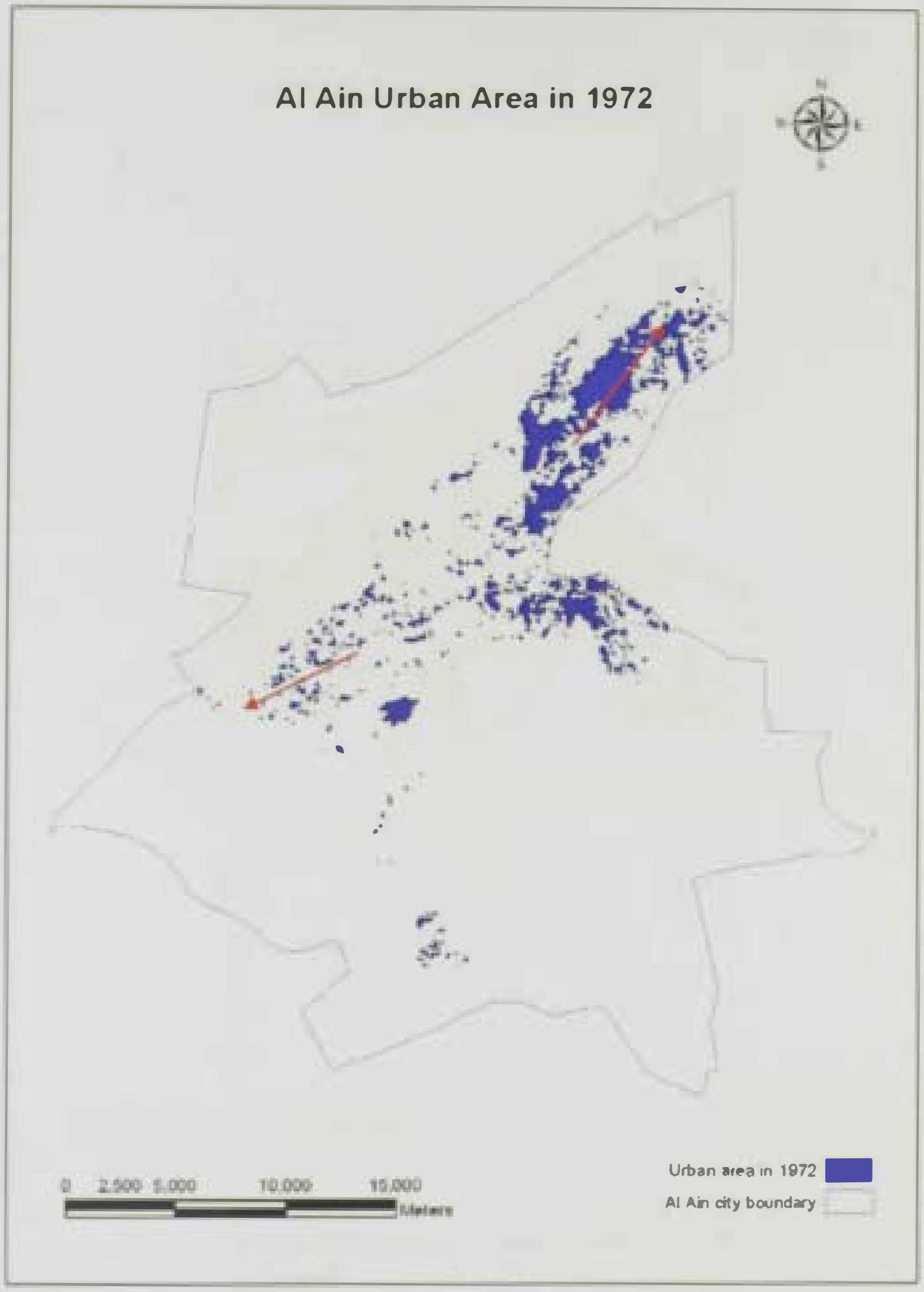


Figure 5.7: Direction of urban growth in 1972.

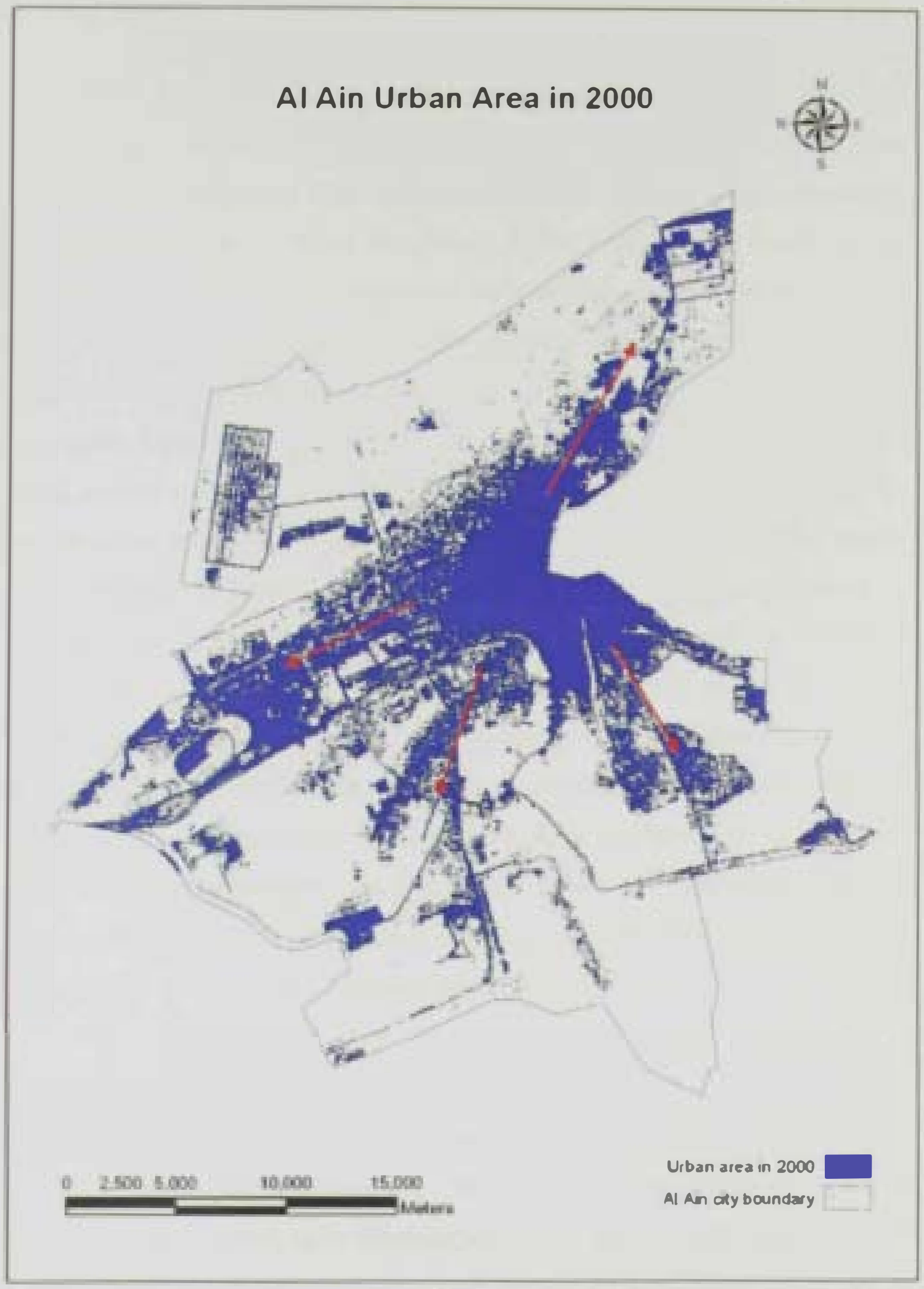


Figure 5.8: Direction of urban growth in 2000.

5.2 Driving forces

Al Ain city is the result of a great conversion process from rural area to a large and most modern city over the past forty years. It was created from a cluster of small villages and nomads living from their camel stocks and palm plantation products. Rapid and planned expansion marked the growth of the city over the study period. Many factors have contributed to its expansion and continue to affect its present and future growth. One of the main objectives of the actual study is to unveil some of the main factors behind its growth rate and directions.

- **Geographic location**

Indeed, several driving forces contributed to its urbanization. Historically, the city had an important geographical location. Its location on the edge of the Empty Quarter played an important role in its development as a trading center and stopping point for caravans carrying merchandise across the Arabian Peninsula to India and Persia. Also, its physical nature as an oasis where natural fresh water, fertile and relatively deep loamy soils promoted the city to emerge as a permanent agricultural settlement, especially with the invention of the main intelligent irrigation system, Alaflaj, which was an articulation of the benefits of the exploitation of underground water for agriculture. Furthermore, the city plays a significant tourism role as the favorite holiday destination for inhabitants of the big coastal cities like Abu Dhabi and Dubai, especially in the summer season (Master Plan 1986).

- **Economic and social development**

The above factors alone contributed to the development of the city before oil discovery and the establishment of the state. However, after the discovery of oil in the Abu Dhabi Emirate in 1959, the establishment of the state in 1971 and the large scale modernization schemes which took place in the Arabian Gulf countries in general, the United Arab Emirates, and Al Ain city in particular, experienced rapid development in several sectors over a very short period of time. During this time, the government of the United Arab Emirates had a vision to add new developed land to the city; there was an attempt to expand the city and redistribute the population by giving subsidies, new government houses (60mx45m), private plots (90x90m) and farms away from the oases in the first move towards developing the city (Master plan 2006). In addition, the use of modern methods and equipment for agriculture and irrigation led to an increase in agricultural production thereby establishing the city as a market centre for the whole region. As well, economic development and an increased per-capita income led to more individual investment in different sectors such as industry, commerce and real estate.

Oil returns were used to develop the country in the areas of education, medical care, agriculture and industry, alongside with the development of its infrastructure such as roads, bridges, electricity, and sewage which contributed largely to its notable expansion. For example, the city witnessed the establishment of the United Arab Emirates University in 1977 and Higher Colleges of Technology in 1988; these led to the city playing a significant cultural role in the United Arab Emirates as well as the other Gulf countries. Also, establishing Al Ain and Tawam hospitals attracted the population from different Emirates as they sought medical care, especially at Tawam Hospital. Without doubt, facilities such as education, the healthcare system and social welfare services were causes of population growth.

- **Population growth**

On the other side, the enhancement of medical care had led to a reduction in infant mortality rates and resulted into longer life expectancy. There are three main causes of population growth in the UAE in general and in Al Ain city in particular. These are, the enhancement of health care; the migration of work forces including skilled and professional expatriate workforce, which played a critical role in the urbanization process; and the naturalization of people from different Gulf and neighboring countries. As a result, the total population of the city and the region has increased of more than 221% in 22 years, as shown in Table 5.4. Whereas the urban population of the city alone, increased of more than 159% during the same period, as shown in table 5.4 and illustrated in Figure 5.9.

Table 5.4: Urban /rural population distribution 1980 - 2001

Year	Urban	Rural	Total
1980	102,329	19,039	121,368
1985	144,672	27,386	172,058
1990	179,640	56,511	236,151
1995	218,510	68,739	287,249
2001	264,000	125,600	389,600

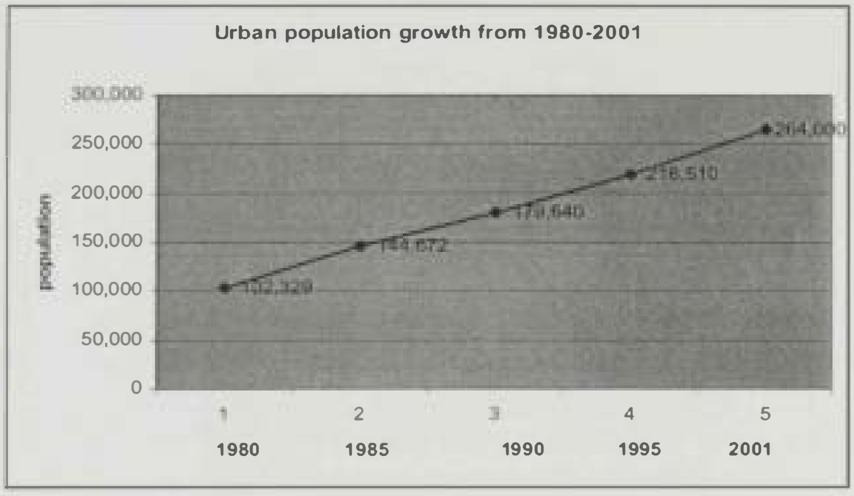


Figure 5.9: Urban population growth from 1980 - 2001

Comparing the percentage change of urban population growth and the growth of urban area across the two periods 1972 - 1990 and 1990 - 2000 as seen in Figure 5.10, it was found that, there was no noticeable difference between the change in population growth and urban growth. However, the percentage of change in urban population growth at 254% was greater than the urban at 240%, thus demonstrating good reason for the growth of the city based on the expectation that the population would continue to grow. This was reflected in the second period 1990 - 2000 when the change in urban growth of 51.5% was greater than in population growth at 46.9%.

- **Family pattern**

Urbanization also led to obvious changes in family settlement behavior patterns. In the United Arab Emirates in general and in Al Ain, in particular, this change saw families divided into more and smaller groups, especially as a result of the government granting new private homes or public housing to each married male citizen twenty years and over either resident or born in the Eastern Region. Moreover, housing is also granted to divorced and widowed women (Master plan 2006). Each of these decisions has led to an expansion of the city and to an increase in residential area.

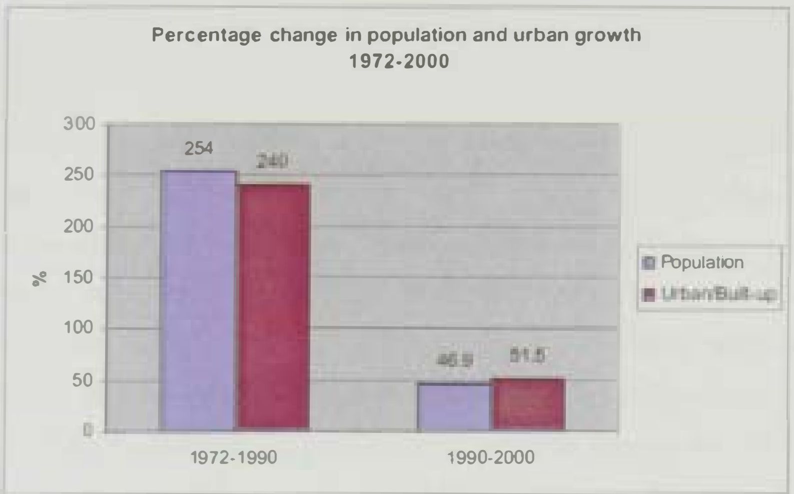


Figure 5.10: Percentage change in population and urban growth 1972 - 2000

- **Policies and structure**

As the home-town of the ruling family, Al Ain also became the beneficiary of the strong desire to develop it into a modern garden city while at the same time preserving its unique, original character as a green oasis. Consequently, the planning authority of the city adopted a by-law limiting building height to 22 meters for commercial buildings and 13 meters for residential buildings, that is, private plots and government houses (TPSS, 2009), so as to ensure everyone could benefit from the view to Hafeet Mountain as well as the preservation of the natural landscape. These constraints led to the city growing in a horizontal rather than a vertical direction.

While the proximity and open political boundaries, until recently, between Al Ain and Buraimi District, the Sultanate of Oman, contributed to the city, a substantial number of Omanis depend on Al Ain for employment, work, study and shopping.

• **Transportation network**

In addition, development of the transportation network has played a key role in reducing the distance between different parts of Al Ain and other cities thereby making movement of the population easier both in the city and in its surrounding region. Importantly, the roads to Abu Dhabi and Dubai led to its expansion in these directions, the occurrence of urban areas along the road networks, as well as of the road to the south-west to the farming areas of Dhahra, Abu Krayyah and Al Araad Districts.

5.3 Urban growth impact (on other land use classes)

Detecting the LULC change in the city and monitoring urban growth over the twenty-eight year period helped in the assessment of the impact of urban growth on other land use classes. In general, the urban growth of Al Ain came as the result of reclamation of barren land and preservation of the oases around which the city had been initially built, and gradually saw expansion in four directions; west, south-west, south-east and north-east. Table 5.5 shows a decrease in sand dunes, sand and gravel and limestone during the period of urban growth as can be seen on the classified maps of all dates. Whilst vegetated areas witnessed an increase over the study period, there is good indication that urban growth did not have a negative impact on vegetation as has been the case with other cities around the world. However, although the total area of vegetation increased, it does not mean that all vegetation covered areas were preserved over the study period. There are indications that some vegetated areas were cleared (Figure 5.11). This is an issue that requires further study and is beyond the scope of this work.

Table 5.5: Area in hectares of barren land in Al Ain city from 1972 to 2000

Barren Land	1972	1990	2000
Sand and gravel	25,413	20,857	18,614
Sand dunes	26,221	22,838	20,983
Limestone	18,183	17,618	14,422

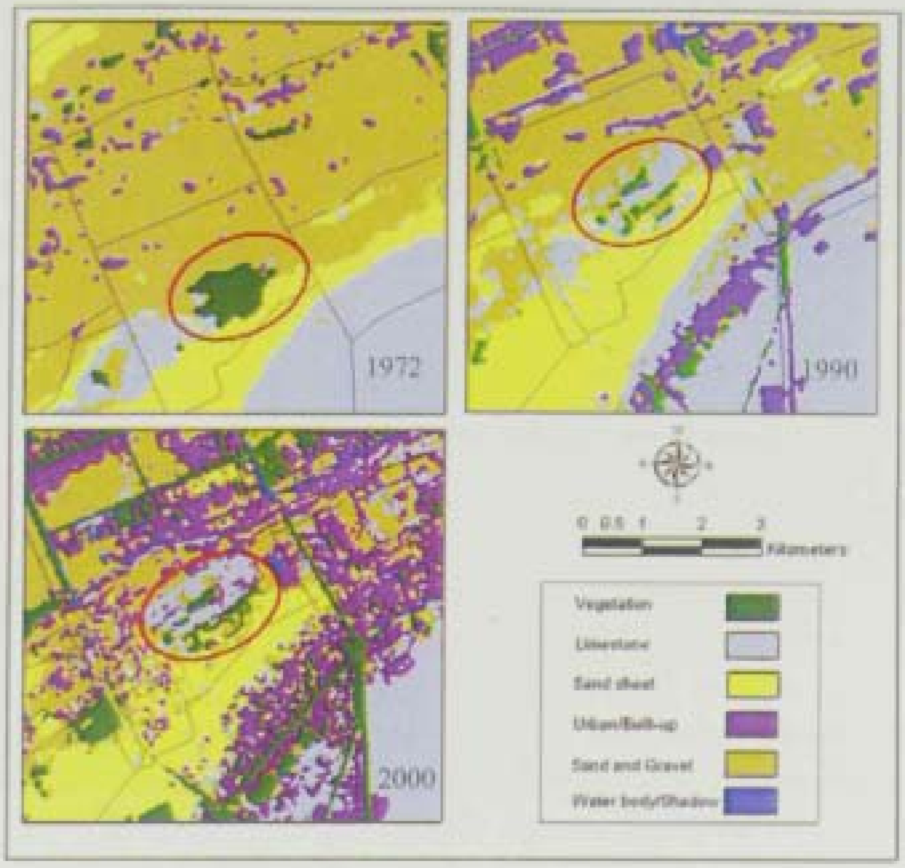


Figure 5.11: An example of vegetation clearance during the study period.

On the other hand, the expansion of the city led to an increase in the importance of some locations, such as, the Al Jimi District which saw a transformation after the Civic Centre was moved from the City Center District. Also, establishment of a the Al Jimi Shopping Mall, the first mall in the city, played a significant role in the increasing importance of the district as it drew customers to utilize it more than the centre of town shopping area.

In addition, the urban growth and development of the city over the three decades led to changing the main position of the oases, for example, the Al Ain oases which had been located in the downtown area were witness to the initial settlement when its palm trees were the main source of income. Now, however, these have become a historical and tourism site surrounded by commercial area and the Al Ain Municipality and Abu Dhabi Culture and Heritage Authority devote their efforts to preserving them though not only in the city, but across the whole region.

5.4 Future directions of urban growth

In accordance with the percentage of urban growth over the study period and along with the results of spatial metrics, it seems that the percentage of urban growth will continue to increase in the future so as to see the completion of projects begun in 2000. Clearly, the growth of the city will pursue the following four directions:

(1) Dubai Road to the north-east,

(2) Mezyad District road to the south-east,

(3) Zakhir, Neima and Ain Al Fayda to the south-west direction and,

(4) Abu Dhabi road to the west.

However, the city may not see expansion in the north-west because this area has been reserved for the Al Ain International Airport as can be seen on Figure 5.8.

It appears that structurally, the sand dunes have never formed a barrier to urban growth and will probably not do so in the future. Just as in the past, people without a developed transportation network could cross the sand dunes to travel to and from Abu Dhabi, the huge sand dunes have been conquered again to host a modern city. Moreover, Hafeet Mountain never formed a barrier in times past, and actual evidence demonstrates that it continues not to as the city has expanded in that direction, especially with the construction of a new road along the mountain, the building of a five star hotel and the discovery of the hot springs at Mubazzarah and their development to become one of the most popular tourist attractions in the city. However, the municipality desires to preserve the landscape of the city through preservation of the sand dunes, green oases as well as by the disallowance of buildings more than three stores in height. As such, these decisions can be considered a temporary and man-made constraint rather than natural ones that may otherwise impede the expansion of the city in the future.

From the point of view of the researcher, in the short-term, the city will not witness urban expansion across the sand dunes for reasons explained above. However, the decision-makers and planners may well be forced to review their decision not to further expand the city across the sand dunes in the longer-term, that is, perhaps three or four decades, as the city may become over-crowded though other solutions may also be sought. Examples would be the minimization of standard size government housing and private plots or an increase in permissible building height.

Chapter Six

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and conclusion

The outcomes from this study are a demonstration of the embedded powerfulness of remote sensing and GIS techniques for studying spatial and temporal changes of land use in general and urban areas in particular. These outcomes reveal that Al Ain city lived through a period of huge and rapid development after the foundation of the United Arab Emirates in 1971. During this process of rapid urbanization, barren lands, sand dune, sand and gravel and limestone were transformed into urban areas. Likewise, there was a significant increase in newly reclaimed agricultural land whilst successfully preserving the oases. The roads networks played a major role in the expansion of the city in the different directions. In addition to making the movement of people easier and more flexible at city and regional levels, their main arteries, connecting Al Ain to other major cities, defined the directions of new urban expansion. Moreover, the transfer of the Civic Center from the downtown to Al Jimi District shifted the importance and role of the historical center of the city.

To quantify the rates of change that occurred in Al Ain in the last three decades, this study relied on the use of remote sensing data to create urban area maps of Al Ain at three different dates using different sensors. Remote sensing is considered a significant source of data that can be used in detecting change in both the cover and use of land surfaces. Information acquired from monitoring the change in urban area across the three decades is valuable both for urban purposes and the appropriate allocation of services and infrastructure. However, the classification process by which maps are created from remote sensing data is not error free. The challenges that confronted this study included the accuracy of classification, especially as we used multi-temporal and multi-resolution images, which usually affect the analytical results of image classification (Qiming, Baolin and Alishir 2008), and the lack of ancillary data including ground truth for old images.

The application of unsupervised classification put in evidence the problem of mixed pixels where the footprint of the sensor encompasses multiple LULC classes. This problem reduced the accuracy of the classification and had to be addressed. This study examined two approaches to solving it, the first consisted in artificially increasing the resolution of the older Landsat MSS data and the second consisted in increasing the number of classes used in the unsupervised classification. The second approach combined with the use of the ISODATA clustering algorithm yielded better results and was thus adopted however, it required much more effort and time for labeling and clustering. Finally, the accuracy of the classification obtained from the 30m Landsat TM and ETM+ was sufficient to capture the urban features while some difficulty was encountered with the 57m Landsat MSS.

Analysis of the maps created from remote sensing data provided a quantitative measure of the change in Al Ain city. They revealed the notable urban expansion over the last three decades increasing from 5.33 % of the total area of the city in 1972, to 18.14 % in 1990 and to 27.48 % in 2000. In contrast, areas of sand dune decreased from 34.05 % to 29.66 % and to 27.25 %, and those of sand and gravel decreased from 33.0 % to 27.09 % and to 24.17 % over the same time period.

The expansion of the city generally occurred at the expense of sand dune, gravel sand and limestone with a high density in areas close to the city centre. This study found that urbanization in Al Ain city followed four major axes: 1) the north-east axis following the road to Dubai; 2) the west axis following the road to Abu Dhabi; (3) the south-west axis following Zakher and Hafeet Mountain; 4) the south-east axis following Myziad area. This expansion pattern is similar to what occurred in other cities of the world where spatial growth of urban areas often follows transportation lines and existing urban centers (Liu and Zhou 2005).

Human activities played a most significant role in the expansion of the city over the period of study articulating the ability to change and adapt the environment for lifestyle purposes.

Some constraints hampered the city expansion in some directions, such as Al Ain International Airport in the north-west direction. But the largest urban expansion occurred on sand and gravel areas, which were found more suitable for construction than sand dune and limestone. As sand and gravel areas are getting more scarce, future expansion of the city will probably occur in the sand dune and limestone areas.

An increase in vegetated areas was noticed a trend parallel to that of urban areas where the general trend of urban growth after 1972 was about 50% for built-up and 50% for vegetated area. Consequently, this study argues that urban growth has led to an increase in green areas in the city reflecting the ability of Al Ain Municipality to achieve its objective to preserve the city as green oases.

In general, Al Ain city has been able to preserve the natural features of the oases over the last few decades with some minor changes such as, building fences around palm tree farms to assert ownership, especially after the increase in land value.

Al Ain city has recorded high levels of greening accompanying its urbanization which contrasts with many other parts of the world. This achievement has come as a result of government policies encouraging trees plantation along the sophisticated roads network crossing sand dunes and remote areas, further leading to a reduction in air pollution and mitigation of the weather with the outcome being beautification of the city.

The Annual Urban Growth Rate recorded 0.93 in the second period from 1990 to 2000 witnessing rapid expansion whilst the first period from 1972 to 1990 had seen a lower Annual Urban Growth Rate of 0.67. It was also observed that future change will likely follow the trend of the 1990 - 2000 period as other growth drivers remain unchanged.

The horizontal growth of the city, dictated by the policy in place, has led to a far from optimum use of land suitable for construction, where that land was depleted quickly over a short period. Consequently, vertical growth will be a successful solution to this problem. In addition, urbanization has created some other problems such as, traffic congestion and air pollution, threatening the quality of life in the city on the long term unless remedial steps are taken.

6.2 Recommendations

In conclusion, the research approach and methodology adopted by this study may be used for analysis of the urban growth dynamics in developing countries where good quality geographic information and other associated ancillary data are in short supply. In addition, the results and findings of this study constitute a perfect starting point for a subsequent research to model and predict future urban growth in the city of Al Ain. They also can be used as the basis for a comparative study of urban growth in other cities of the country and the region in general, such as Abu Dhabi capital city, Dubai and Buraimi District in the Sultanate of Oman as these cities possess similar environmental and physical conditions.

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ملخص

إننا نعيش في عالم مليء بالتغيرات الناجمة إما عن العمليات الطبيعية أو الأنشطة البشرية. لذا جاءت هذه الدراسة لتقييم ورصد التغيرات التي شهدتها المنطقة الحضرية لمدينة العين في الفترة الممتدة ما بين عامي 1972 و 2000وذلك من خلال تحديد مقدار هذا التغير وتصوير جوانبه المختلفة. حيث أن نتائج هذه الدراسة ستكون فعالة لتخطيط المدنية واتخاذ القرارات والإجراءات التي تسهم في توفير حياة كريمة لسكان المدينة. فالتغيرات السريعة لاستخدامات الأرض و غطاءاته وخاصة المباني والمناطق المنيعة مثل الشوارع و الأرصفة، تجعل من استخدام التقنيات المبتكرة مثل الاستشعار عن بعد ونظم المعلومات الجغرافية ضرورة لوصف وتحليل هذه التغيرات. لذا تم استخدام تقنيتي الاستشعار عن بعد ونظم المعلومات الجغرافية في هذه الدراسة لرصد ورسم خرائط النمو الحضري لمدينة العين في الفترة بين 1972 و 2000. حيث أن صور الأقمار الصناعية لاندسات MSS و TM و +ETM لسنة 1972 و 1990 و 2000 على التوالي ، قد اختيرت لدراسة وتحليل هذا النمو.

تتميز تقنية الاستشعار عن بعد بالقدرة على تحديد فئات الغطاء الأرضي عن طريق عملية التصنيف. وفي هذه الدراسة تم اعتماد المنهجين المستخدمين في تصنيف صور الأقمار الصناعية و هما التصنيف غير الموجه والتصنيف الموجه. حيث أن العلم المسبق بمنطقة الدراسة ، و نتائج التصنيف غير الموجه ، والمعلومات من البحوث السابقة ومخطط لتصنيف أندرسون ساعد في إنشاء واعتماد مخطط التصنيف الخاص بهذه الدراسة والـذي يتـألف مـن 6 فئـات: المنـاطق الحضـرية،النباتات،الرمل والحصـى،الكثبان الرمليـة،الحجر الجيري،المسطحات المائية/ظل.

في هذه الدراسة تم الاعتماد على منهج مؤلف من مرحلتين الأولى المقارنة بعد التصنيف والثانية باستخدام التحليل الطبقي وذلك لاكتشاف التغيرات في غطاءات الأرض بين التواريخ المتتالية (1972- 1990- 2000) مع التركيز على المناطق الحضرية. حيث أن هذه المنهجية تمكننا من كشف التغيرات في المناطق الحضرية و التعرف على نمط النمو الحضري. كما أن استخدام المقاييس المكانية مثل معدل استنزاف الأرض و معامل امتصاص الأرض له دور في تحليل وفهم نمط النمو الحضري. و قد تم تحديد و مناقشة القوى الدافعة لهذا النمو والآثار المترتبة عليه و التنبؤ بمستقبل النمو الحضري للمدينة مما يسهم في تخطيط أفضل لمستقبل المدينة.

و قد أثبتت نتائج هذه الدراسة فاعلية تقنيتي الاستشعار عن بعد ونظم المعلومات الجغرافية في دراسة التغيرات المكانية والزمنية لاستخدامات الأرض بوجه عام و في المناطق الحضرية على وجه الخصوص. فقد شهدت مدينة العين فترة من النمو السريع والهائل و خاصة بعد تأسيس دولة الإمارات العربية المتحدة في عام 1971. كما أن توسع المدينة بشكل عام جاء على حساب الكثبان الرملية والحصى والرمل والحجر الجيري مع كثافة عالية في المناطق القريبة من وسط المدينة.

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إعداد

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