Universitat Autònoma de Barcelona

Urban sprawl in arid environments: contrasting master plans and land use changes in Al Ain City, United Arab Emirates

ADNAN SHARAF

Urban sprawl in arid environments: contrasting master plans and land use changes in Al Ain City, United Arab Emirates

PhD Thesis written by / Tesi Doctoral escrita per

ADNAN SHARAF

Departament de Geografia

Universitat Autònoma de Barcelona

UAB Universitat Autònoma de Barcelona

Departament de Geografia

Urban sprawl in arid environments: contrasting master plans and land use changes in Al Ain City, United Arab Emirates

PhD Thesis written by / Tesi Doctoral escrita per

ADNAN SHARAF

Departament de Geografia
Universitat Autònoma de Barcelona

PhD in Geography / Doctorat en Geografia

Advisor / Director: **Pere Serra Ruiz**, PhD

Tutor: **David Saurí Pujol**, PhD

Cerdanyola del Vallès, June 2019

Universitat Autònoma de Barcelona

Departament de Geografia

ACKNOWLEDGEMENT

My long journey to pursuing and obtaining a PhD has been especially fruitful and enriching in large part due to the contributions of incredible people, who deserve special mention. Namely, I must begin by thanking my family, especially my father, mother, wife, and sons, all of whom created a support system upon which I could regularly rely, while inspiring me on a daily basis. My parents have nurtured my intellectual passions, my wife has served as my muse, and my sons have continuously reaffirmed my commitment to what has been a challenging yet incredibly rewarding pursuit. Without them, I could have faltered, but with them, I have surely thrived.

My professor, Dr. Pere Serra, has helped me more than he knows. I have seen him as a role model, mentor, and friend. His passion for GIS and Geography is unparalleled, and it is quite frankly contagious. He has built an intellectual discourse to which I have been proud to contribute. It has been my great honor to be his student. I take this opportunity to thank Professor David Saurí who was instrumental in my admission to the PhD research. I am profoundly grateful to him for his continuous encouragement and support.

Also I would like to thank Department of Geography and many people have made valuable comment suggestions on this thesis which gave us an inspiration to improve our assignment. We thank all the people for their help directly and indirectly to complete our assignment.

Lastly, I could not have completed a PhD on the subject of Change Detection in Al Ain City if it was not for the Al Ain municipality. The municipality has been more than generous with their time and support, consistently providing me incredibly useful data. More than that, Al Ain has been an immensely inspiring municipality, offering regular reaffirmations as to why I have chosen to delve so deeply into the topic of Change Detection in Al Ain City.

I am forever indebted to the profoundly impactful support of all of these people, and of Al Ain municipality. You deserve more than my thanks, and I thus wish for you to be acknowledged as a critical component of my success. I am grateful beyond words.

INDEX

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAFS

LIST OF ANNEXS

ABSTRACT

Land-use policy and planning concerns collective decision-making by which a society decides where, within its territory, different socioeconomic activities should take place, and establishes provisions that control the nature of such actions due to environmental, cultural or historical reasons. These controls determine features such as plot areas, their land consumption, their intensity, their density or technical standards of infrastructures. Goals of land-use planning may include environmental conservation, minimization of transport costs, prevention of land-use conflicts, and a reduction in exposure to pollutants. Therefore, land-uses determine the diverse socioeconomic activities that occur in a specific area, the patterns of human behavior they produce, and their impact on the environment.

Since the 1990s, with the initiation of the Land-Use and Land-Cover (LULC) change project of the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP), considerable advances in the field of modeling of LULC change have occurred. Monitoring LULC changes is critical to develop effective strategies for spatial management and environmental protection because human-induced changes have affected the performance of ecosystem services and contributed to alter the biochemical cycles that control the functioning of the Earth system. In land-use policy and planning diverse types of human actors, their relationships and the social and institutional structure influence LULC processes.

In most of the planet, urban growth appears to have taken the form of disperse or sprawled low density spatial patterns. However, although urban sprawl is a process equally shared by developed and developing countries, causes and characteristics may differ considerably. As a consequence, more examples are needed to explore trends, causes and consequences in order to enrich the understanding of urbanization processes.

Due to their geostrategic situation, located between the developed Western nations and the rising Asian economies, and world centres of oil production, cities in the Arabian Peninsula have rapidly gained significance in the global economy. In consequence, urban spaces in these cities have extended their presence far beyond the historic centres. Given the rapid development of Arab cities in recent decades, the term 'instant city' has been proposed to describe the way they seem to have suddenly appeared out of nowhere. In this PhD thesis the study area comprised Al Ain city, located in the United Arab Emirates (UAE). It is an interesting medium-sized town to analyse due to its very rapid urban development, and a strategic location on the border between UAE and Oman. It is characterized by a vast, arid desert, dominated by sand and gravel, with intermittent dry

riverbeds, a rugged mountainous region (Jabel Hafeet) and an area of fertile soils and oases, with large reserves of groundwater.

The thesis is structured in eight chapters with the main objective of assessing LULC trajectories of Al Ain, from 1984 to 2014, and of comparing them with the management of two master plans. To map and quantify LULC changes, a particular combination of remote sensing and GIS techniques was applied. After that, to verify the initial hypothesis about the specificity of Al Ain urban sprawl and to evaluate the consequences of LULC changes from a landscape point of view, landscape metrics of urban patterns (aggregated, linear, leapfrogging or nodal pattern) were calculated. The next step consisted in applying a statistical analysis using census data, at district scale, to improve the understanding of LULC processes, mainly those related to population, sex and origin. Later, the main driving forces of LULC changes were established based on expert knowledge and the socioenvironmental consequences of such dynamics. Finally, future growth was evaluated from the Plan Al Ain 2030.

This PhD thesis represents one step beyond the knowledge about urban trajectories and forms, being an empirical contribution with an innovative used combined of tools: a particular combination of RS and GIS techniques; a comparison of real urban growth with the guidelines provided by master plans; a detailed assessment of landscape patterns; a statistical analysis using census data at district scale; and, finally, an expert knowledge approach applied to determine main driving forces and socioenvironmental consequences.

In 2018, part of the results obtained from this PhD thesis was published in the following journal:

Sharaf, S.A., Serra, P., Saurí, D. A district and sector land-use and landscape analysis of urban sprawl in Al Ain municipality (United Arab Emirates): Just a quick conversion from sand to a built-up environment? *Applied Geography*, 95, 88-100.

RESUM

La política i la planificació del usos del sòl concerneix la presa de decisions col·lectives mitjançant la qual una societat decideix on, dins del seu territori, s'han de dur a terme diferents activitats socioeconòmiques i estableix les disposicions que controlin la naturalesa d'aquestes accions per motius ambientals, culturals o històrics. Aquests controls determinen característiques com ara les àrees de parcel·la, el seu consum de terres, la seva intensitat, la seva densitat o les normes tècniques de les infraestructures. Els objectius de la planificació dels usos del sòl poden incloure la conservació del medi ambient, la minimització dels costos de transport, la prevenció de conflictes i la reducció de l'exposició als contaminants. Per tant, els usos de la terra determinen les diverses activitats socioeconòmiques que es produeixen en una àrea específica, els patrons de comportament humà que produeixen i el seu impacte sobre el medi ambient.

Des dels anys noranta, amb l'inici del *Land-Use and Land-Cover (LULC) change project* del *International Geosphere-Biosphere Program* (IGBP) i del *International Human Dimensions Program* (IHDP), importants avenços en el camp de la modelització de l'LULC s'ha produït. Supervisar els canvis de LULC és fonamental per desenvolupar estratègies efectives per a la gestió espacial i la protecció del medi ambient, ja que els canvis induïts pels humans han afectat el rendiment dels serveis ecosistèmics i han contribuït a alterar els cicles bioquímics que controlen el funcionament del sistema terrestre. En la política i planificació dels usos del sòl diversos tipus d'actors humans, les seves relacions i l'estructura social i institucional influeixen en els processos LULC.

En la major part del planeta, el creixement urbà sembla haver pres la forma de patrons espacials de baixa densitat dispersos. No obstant això, tot i que l'expansió urbana és un procés compartit pels països desenvolupats i en vies de desenvolupament, les causes i les característiques poden diferir considerablement. Com a conseqüència, calen més exemples per explorar tendències, causes i conseqüències per enriquir la comprensió dels processos d'urbanització.

A causa de la seva situació geoestratègica, situada entre les nacions occidentals desenvolupades i les creixents economies asiàtiques, i els centres mundials de producció de petroli, les ciutats de la Península Aràbiga han guanyat ràpidament importància en l'economia global. En conseqüència, els espais urbans d'aquestes ciutats han ampliat la seva presència més enllà dels centres històrics. Atès el ràpid desenvolupament de les ciutats àrabs en les últimes dècades, el terme "ciutat instantània" s'ha proposat per descriure la forma en què semblen haver aparegut de sobte, fora del no-res. En aquesta tesi doctoral, l'àrea d'estudi correspon a la ciutat d'Al Ain, situada als Emirats Àrabs Units

(EAU). Es tracta d'una interessant ciutat de grandària mitjana per analitzar pel seu desenvolupament urbà molt ràpid i per una ubicació estratègica a la frontera entre els Emirats Àrabs Units i Oman. Es caracteritza per un vast i àrid desert, dominat per sorra i grava, amb llits de rius secs intermitents, una regió muntanyosa escarpada (Jabel Hafeet) i una zona de sòls i oasis fèrtils, amb grans reserves d'aigua subterrània.

La tesi s'estructura en vuit capítols amb l'objectiu principal d'avaluar les trajectòries LULC d'Al Ain, entre 1984 i 2014, i comparar-les amb la gestió de dos plans generals d'ordenació urbana. Per mapar i quantificar els canvis en els LULC, es va aplicar una combinació particular de tècniques de teledetecció i SIG. Posteriorment, per verificar la hipòtesi inicial sobre l'especificitat de l'expansió urbana d'Al Ain i per avaluar les conseqüències dels canvis d'LULC des d'un punt de vista paisatgístic, es van calcular les mètriques de paisatge dels patrons urbans (agregats, lineals, transversals o nodals). El següent pas va consistir en aplicar una anàlisi estadística a partir de les dades censals, a escala de districte, per millorar la comprensió dels processos LULC, principalment els relacionats amb la població, el sexe i el seu origen. Després, es van establir els principals motors de canvi d' LULC a partir del coneixement expert i de les conseqüències socioambientals de les dinàmiques. Finalment, es va avaluar el futur creixement del Pla Al Ain 2030.

Aquesta tesi doctoral, doncs, representa un pas més enllà del coneixement de les trajectòries i formes urbanes, essent una contribució empírica amb una combinació innovadora d'eines: una combinació particular de tècniques RS i SIG; una comparació del creixement urbà real amb les directrius proporcionades pels plans d'ordenació; una avaluació detallada dels patrons del paisatge; una anàlisi estadística mitjançant dades censals a escala de districte; i, finalment, una aproximació a través del coneixement expert aplicat per determinar les principals forces i conseqüències socioambientals.

El 2018, part dels resultats obtinguts d'aquesta tesi doctoral es van publicar a la següent revista:

Sharaf, S.A., Serra, P., Saurí, D. A district and sector land-use and landscape analysis of urban sprawl in Al Ain municipality (United Arab Emirates): Just a quick conversion from sand to a built-up environment? *Applied Geography*, 95, 88-100.

1.1. Introduction

The monitoring of land-use and land-cover (LULC) changes such as soil degradation, deforestation, biodiversity loss, global warming or the increase of natural disasters (Keken et al., 2014) is critical for optimized spatial management and for environmental protection (Lambin et al., 2003; Serra et al., 2008; Catalán et al., 2008; Abd El-Kawy et al., 2011; Biro et al., 2013). Traditionally, LULC mapping has sought to discriminate transformations of urban, forest and/or agricultural land. As urban growth is a world-wide phenomenon and the most irreversible land alteration, analysis of urban transformations has been one of the main areas of study (Aguilera et al., 2011).

In many parts of the world, the urban population increase has been very rapid and intensive. According to the most recent United Nations data, 55% of the population lived in urban areas in 2018. In 1950, 30% of the world's population was urban; by 2050, this proportion is expected to have more than doubled, to about 68%. Nevertheless, the specific trajectories and forms of urban growth remain relatively unknown (Salvati et al., 2016a), especially in developing countries (Bhatta et al., 2010).

Many factors are responsible for the diversity of urban development, including the geographical surroundings. Coastal or mountain locations offer different development options, compared with plains or rivers. The historical onset of urbanization marks the present outlook of cities, whereas land-use policy and the application of zoning restrictions can establish, for instance, areas to be protected from urban growth (Kasanko et al., 2006). In general terms, urban areas can grow in two directions: outwards or upwards. Outward growth is equivalent to a horizontal or disperse development, whereas upward growth is a vertical expansion or compact growth.

The compact city, as a vision of urban planning, is characterized by a high density of usage and short travel distances. The idea of the compact city is integrated into the concept of sustainable urban form, which includes compactness amongst other aims such as sustainable transport and a diversity of potential activities within a neighbourhood (Schwarz, 2010). Therefore, the vertical city has been associated with multiple benefits, especially due to the multifunctional buildings characteristic of some cities, which combine retail functions, hotels and residential activities in the same structure. This diversity of space and function is naturally appealing to the large population of a city. In addition, sky-high construction has proven to be important in enhancing the available working and living spaces. As opposed to destroying swamps, forests, and other vegetation to build shopping centres, factories, and houses, these functions can be sufficiently accommodated in vertical towers, which ultimately helps in environmental preservation during city expansions.

One example of problematic vertical growth occurs in the Boa Viagem district of Recife, Brazil, especially along the beach, where rapid urban development has generated issues for residents (Magarotto et al., 2016). As in Boa Viagem, urban and touristic coastal areas are often poorly served by public transport and expansion of water and sewer systems, solid waste collection, and other fundamental municipal services do not keep pace with urban development. Vertical growth in coastal environments often satisfies the demand for housing and commercial areas that face the sea without necessarily working together with ecological services (e.g., coastal protection).

A notable city of successful vertical growth is Singapore, known for its 'High-Rise High-Density Tropical Living' (Xue et al., 2016). In recent years, this city has overseen an exponential growth in tall building structures that have changed its skyline, experiencing more vertical than horizontal development. The changes are due to an increase in population and in business ventures across Singapore. The preference for high-rise building is related to the limited physical dimensions of the city. Therefore, its physical landscape contributed to urban planning and dictated the nature of the structures: the city has become a greenery-laden lattice, characterized by its staggered modules.

Similarly, the city of Jakarta in Indonesia has a vertical growth design, as evidenced by the Peruri 88 tower, 400 meters tall, which integrates offices, housing, parking, luxury hotel, and a theatre (Weburbanist, 2018). Like all other cities, it is important that vertical cities integrate the main logistics of city design, including walkable paths that weave throughout the tall structures. The use of towering buildings is also seen as a sustainable way of promoting reforestation in the cities, where housing, public areas, and gardens are blended together.

Vancouver, another world city of vertical growth, exhibits a contemporary design of stacked rectilinear modules poking out of a major tower at numerous angles. These modules project the living spaces outward and mimic the spacious feeling of ground-level living spaces, while creating cantilevered terraces. The increasing popularity of vertical urban growth is occasioned by the impossibility of extending the city's boundaries as a result of limited land availability (Hutton, 1994). In this case, Vancouver is Canada's most densely populated city, with a mean of 5,335 persons per km^2. The most significant factor prompting its vertical growth is that Vancouver is surrounded by water on three sides; therefore, the growing city has continually adopted tall building structures as a way of expanding the city's capacity and operations (Leo and Anderson, 2006). The vertical urban design of Vancouver has been credited with the easy, safe, and comfortable walkability of the city's streets. Therefore, the city's design has limited urban sprawl, while promoting preservation of environmentally sensitive areas like the sea, farmland, and open spaces.

Despite these advantages, questions have been raised about concentrating a large number of people within small spaces in the urban centres without compromising quality of life. For instance, Peen et al. (2010) argue that there are bound to be emotional anomalies occasioned by the limited sunlight, which could lead to depression and sadness among the residents of these buildings. Under natural circumstances, humans are best suited for the natural environment, which is obviously not available in the tall residential buildings.

Another likely consequence of urbanization is the potential impact of an increased urban heat island effect due to a combination of factors, including urban construction materials and morphology, anthropogenic heating, and a lack of moisture in urban areas (Heaviside et al., 2016). The urban heat island effect is characterized by an increased temperature that can increase the magnitude and duration of heat waves within cities. For instance, the Shanghai city centre has experienced additional hot days and heat waves as a result of increasing urbanization and a more extensive urban heat island effect, which was associated with increased summer mortality rates, (Tan et al., 2010).

On the other hand, Gargiulo, Morelli and Salvati (2010) report that most of the world's urban growth has been in the form of disperse or sprawled low-density spatial patterns, beyond the edge of a city's boundaries. Urban sprawl has been identified in Australia, China, India, Turkey, the USA, and some European countries, among others. For instance, Esbah (2007) analysed the land-use transformation of Aydin city (Turkey), a medium-sized town in the middle of the country where a clear process of urban sprawl was detected, whereas Kamh et al. (2012) evaluated the urban expansion of Hurghada city on the Red Sea coast of Egypt. In China, Tian et al. (2017) argued that the urban sprawl of Chinese cities was a direct result of internal economic changes promoted by the national government, producing a spread of economic activities into peripheral areas. In this way, the rapid urban growth of Shanghai was driven by the demand of the increasing urban population and by the ambition of local government to raise local revenue and attract investment through land leasing.

Although the process of urban sprawl is equally shared by both developed and developing countries, its causes and characteristics may differ considerably (Shahraki et al., 2011). Therefore, more case studies are needed, especially in developing countries, to explore trends, causes, and consequences in order to enrich our understanding of the urbanization processes (Kasanko et al., 2006).

Teresina city, in Brazil, is an example of the urban areas that exhibit a horizontal pattern of expansion (Espindola et al., 2017). As in many other “developing” economies, urbanization in this city is characterized by massive rural-urban transitions, prompted by the relatively better living conditions and livelihood in an urban setting. Consequently, growth in Teresina is dominated by low-income families, which has made the accelerated informal and horizontal housing pattern a default form of settlement. Therefore, the city has been overwhelmed by poor infrastructure for expansion, prompting measures for verticalization of the urban growth in order to replace the horizontal housing that shelters low- and middle-income families.

Based on the arguments presented by Espindola et al. (2017), the expansion patterns witnessed in Teresina and in other Brazilian cities are a result of the ancient master plans that until 2000 prioritized the typical horizontal urban sprawl in the peripheral zones. For instance, Teresina embraced the country’s housing policies of the 1960s aimed at constructing massive settlements in dispersed and remote areas to shelter low-income families. Eventually, the city greatly expanded its urban parameter, with significant intra-urban spaces that remained unoccupied. In addition, most of the families with low income lived in areas with poor or nonexistent connections to the core of the city. Therefore, the urban sprawl witnessed in Teresina was a result of a dispersive housing policy meant to reduce construction costs, with the unanticipated challenges to the city of poor sanitation and transportation, along with increasing segregation and violence.

On the other hand, the significance of cities on the Arabian Peninsula in the global economy has grown rapidly, due to their geostrategic location between the developed Western nations and the rising Asian economies, together with oil resources and production. In consequence, the urban spaces have extended their structures far beyond the historic centres (Schein, 2009). The term 'instant city' is used to describe the way that these Arab cities seem to have suddenly appeared out of nowhere in recent years (Bloch, 2010). As reported by Hamouche (1999) in the case of the Arabian Gulf countries, and particularly in UAE, urbanization is regarded as a positive process that generates development and ensures social equity. For this reason, cities are considered as signs of success and progress. Another particularity of some Arab cities is the increasing role of branding urban spaces to give them a global image (Helmy, 2008). The iconic design of palm-shaped islands in Dubai (Nassar et al., 2014) has motivated the construction of similar projects around the Gulf countries, such as 'The Pearl' in Qatar or 'Amwaj Island" in Bahrain, which comprise large-scale urban megaprojects with global recognition created by their specific branding (Elsheshtawy, 2008).

In general, studies on urban sprawl have mainly focused on large cities and metropolitan areas (Rojas et al., 2013; Marraccini et al., 2015; Moreira et al., 2016; Salvati and Carlucci, 2016b); however, medium-sized urban areas may be experiencing the highest rates of urban growth. For instance, Shahraki et al. (2011) analysed the land-use transformation of Yazd (population ~100,000), a medium-sized city in the middle of Iran where a clear process of urban sprawl was evident. Other examples include research findings from Thessaloniki, Greece (Lagarias, 2012) and Coimbra, Portugal (Tavares et al., 2012).

Given that urban sprawl, characterized by a mix of low-density urban settlements primarily on the urban fringe, is predominant in many world cities, the next research question can be whether this type of urban growth is planned or unplanned. Urban sprawl often results from the lack of a clear or robust planning strategy, which can cause important contradictions with sustainable development (EEA, 2016; La Rosa and Priviera, 2013). Some European and Mediterranean cities have experienced the transition from compact towards dispersed urban patterns (Muñoz, 2003; Durà-Guimerà, 2003). As Rubiera et al. (2016) assert, most old European cities were strongly concentrated around a densely packed historical centre. Commercial and business extensions usually adhered to a monocentric growth model with a strong centre and hierarchical structure of sub-centres. Nevertheless, during the last four decades urban sprawl has grown in many European cities such as Athens, Rome, Lisbon, Madrid and Barcelona, as a result of different factors highlighting the planning management. In the Athens metropolitan area, urban sprawl has been identified and explained according to the influence of multiple factors, including land-use deregulation (planning deregulation), the land tenure or housing prices influenced by territorial factors such land availability, soil quality or topography, among others (Salvati et al., 2013a; Salvati et al., 2013b; Colantoni et al., 2016). In the Rome metropolitan area, the 1993-2008 master plan was enforced in law with the aim to protect green open areas and the traditional rural landscape around the city (the so called "Agro Romano"). Nevertheless, the green-oriented policy carried out by local institutions is sometimes just rhetoric because the Agro Romano is under increasing urbanization pressure, due to the diffusion of low-density settlements in cropland and seminatural areas (Salvati et al., 2012). This contradicts one of the measures for controlling urban sprawl: the clear separation of building zones and non-building zones, together with a long-term settlement restriction (EEA, 2016).

In the Lisbon metropolitan area, urban sprawl was allowed non-compliance in the land-use regulatory system; this is visible in the gaps between the original land-use assignments of the master plan and the existing development (Abrantes et al., 2016). As a consequence of a similar lack of planning control, the urban sprawl in the Madrid metropolitan area has been defined as inefficiently planned, producing an intense loss of agricultural land and natural grassland and causing unsustainable development (Hewitt and Escobar, 2011; Gallardo et al., 2016). Finally, in the metropolitan area of Barcelona, some research has shown that the planning system has not been capable of containing urban sprawl, one of the main reasons being 'planning inertia', namely the critical role of previous plans in allowing or shaping the pattern of urban sprawl (Paül and Tonts, 2005). The land use most affected by such urban growth has been crop land (Catalán et al., 2008) and, for this reason, a conservation strategy for agricultural fields has been proposed to avoid the insufficient protection provided in the current Territorial Metropolitan Plan of Barcelona (Serra et al., 2017).

Outside Mediterranean countries, there are also cities where urban sprawl is unplanned or inefficiently controlled. For instance, in Jeddah (Saudi Arabia) the lack of an appropriate and coordinated policy guidance and the absence of collaboration among government units has left the public sector authorities powerless to perform their assigned duties effectively (Mandeli, 2008). The main reason for this situation is the weakness of local municipalities and their limited financial and legal power to cope with huge waves of immigration and massive urban expansion.

A similar situation is the Guwahati Metropolitan Area (India), where the illegal and increasing trend of built-up land in the peripheral areas of the city has provoked an intensive decrease of natural and seminatural vegetated land, mainly on the hill slopes, the fringes of protected areas and the vacant government land (Pawe and Saikia, 2018). Another example from the Middle-east is Iran, where the main reasons for unplanned urban sprawl are the poorly constructed master plans, weak enforcement of urban development plans and fragile control of illegal construction, which encourage annexation of rural areas and permit people to build their own houses rather than employing infill strategies or vertical growth (Masoumi et al., 2018). Finally, in most African countries the urbanization development is characterized by unorganized expansion and increased immigration to nearby towns and cities, contributing to the phenomenon of urban sprawl. Examples include the case studies of Rwanda (Akinyemi, 2017), Côte d'Ivoire (N'go et al., 2013) or Ghana (Acheampong et al., 2018). Therefore, due to the implications of spatial planning for urban sprawl and environmental quality, this PhD thesis will highlight the main causes and after-effects of such urban growth in a Persian Gulf city.

From an instrumental point of view, much research has been done applying different sources and tools to analyse LULC, in general, and urban growth, in particular. Field work and remote sensing, including aerial photographs and/or satellite imagery, have been used to monitor and evaluate LULC changes (Shair and Nasr, 1999, Serra et al., 2003; Rogan and Chen, 2004; Patino and Duque, 2013; Lister et al., 2014). During the last 40 years, significant advances in sensor technologies have improved the spatial, spectral and temporal resolution and coverage of satellite imagery. Nevertheless, for many urban applications the very-high spatial resolution of the majority of current optical sensors does not meet the requirements of spectral resolution, due to the lack of the short-wave infrared (SWIR) bands that are useful to characterize building materials and surface properties (Gamba et al., 2011). Two additional issues are the high financial cost and the lack of a sufficiently long archival record of imagery (Moeller and Blaschke, 2006). In order to avoid such problems, some authors have used a combination of aerial photographs and remote sensing images to detect urban growth over a longer time period. A clear example is provided by Yagoub (2004), who monitored the urban expansion of Al Ain city between 1976 and 2000. Nevertheless, this approach can produce issues when complex legends are used to homogenize different sources and techniques, such as combining photointerpretation and automatic classifications.

From a long temporal perspective, Landsat series offer one of the best options to detect urban growth using remote sensing imagery. For instance, Issa and Shuwaihi (2012) used Landsat data (MSS, TM and ETM+ sensors) to characterize Al Ain urban development from 1972 to 2000 using automatic classifications. Nevertheless, as the authors recognized, accurate mapping of urban areas was not an easy task at 30-meter pixel resolution because the heterogeneous nature of urban environment produces mixed pixels that are the main source of errors. For this reason, they used a semi-automatic method, intervening manually by adjusting the ambiguous pixels based on researchers' knowledge of the study area. Another example using Landsat series is the work from Kamusoko et al. (2013), where the temporal perspective was extensive (from 1984 to 2013) but the legend considered only three LULC classes: built-up, non-built-up and water.

1.2. Objectives and hypothesis

In order to improve the knowledge about urban trajectories and forms, the present PhD thesis makes an empirical contribution to analyse spatial-temporal land-use and land-cover (LULC) dynamics from 1984 to 2014, applying remote sensing images and GIS techniques. The study area corresponds to Al Ain, located in the United Arab Emirates, being an example of a medium-sized desert city with rapid urban growth guided by two master plans from the 1980s.

The specific objectives of this research were fourfold: the first was to investigate LULC changes in Al Ain city according to data from four years: 1984, 1990, 2000 and 2014. This city, located in the United Arab Emirates (UAE), was an interesting medium-sized town to analyse due to its very rapid urban development, from land held by the State (the Ruler) and surrounded by a desert. To map and quantify LULC changes, the applied methodology differed from the works mentioned above because a particular combination of remote sensing and GIS techniques was applied to obtain historical data for the 1980s, establishing the LULC for each of the four years studied. These years were selected for analysis due to the availability of Landsat images without clouds or haze and with dates as close as possible to the Al Ain Master Plans (1986–2000; 2003–2014), with the exception of 1990 used as an intermediate year.

The second aim was to understand the consequences from a landscape point of view of LULC changes (mainly urban, including residential and services, industrial and agricultural land). The spatial scale of study was the district (a group of communities or neighbourhoods) and the sector (a group of districts). Landscape indicators related to urban sprawl were calculated in order to test the initial hypothesis. According to Xu et al. (2007), there are three main types of urban growth: infilling when vacant spaces within the urban area are converted to built-up environment; edge expansion (or urban fringe development), which is newly developed urban area spreading out from the fringe of existing urban patches; and outlying (or spontaneous) growth, the new urban patches that are formed and have no direct spatial connection with the existing urban patches. A fourth type can be strip development, which refers to clustered urban centres along the major roads. According to this analysis, the spatial geometric measures quantify the configuration and composition of an urban landscape. Configuration describes the geometry of an urban built-up area while composition depicts the level of heterogeneity. In a sprawling urban area, geometric configuration is scattered, irregular and fragmented whereas the LULC composition is segregated.

The third objective was to apply a statistical analysis using census data (from 2005 and 2010) at a less common level of analysis in UAE, the district scale, to improve the understanding of LULC processes. A factor analysis method was used, following the work from Serra et al. (2014), which has given very good results when applied in Mediterranean regions.

Finally, the fourth objective was to establish the main driving forces of LULC changes and the socioenvironmental consequences of such dynamics. Driving forces include both the socioeconomic and biophysical variables that explain LULC changes (Turner II et al., 1995).

All these objectives constituted a challenge, given the innovative application of the corresponding tools and processes to study and explain the urban growth of a Middle-eastern city. This methodology could be useful to implement in other cities and regions of the world.

This PhD thesis explores three main hypotheses: First, Al Ain city, a medium-sized town that developed very rapidly on land held by the State and surrounded by desert, provides a specific example of urban sprawl, characterized by horizontal urban growth, clearly differing from other urban development forms. Jaeger et al. (2010) summarizes that urban sprawl comprises at least three dimensions: first, an expansion of urban areas; second, the scattering of settled areas and area-intensive growth; finally, low-density development. Al Ain city seems to meet all three components and, therefore, is an excellent case study of urban sprawl within the context of the Gulf region. From an urban point of view, a particularity of Al Ain, compared with Dubai or Abu Dhabi cities, is that the urban growth has been horizontal instead of being vertical. This approach required the best landscape metrics to analyse the type of urban sprawl at sector and district scales.

The second hypothesis was that the particular urban sprawl of Al Ain city was due to the specific management of some master plans, causing an urban growth that was quite well planned, in contrast to the usual situation of unregulated development (Salvati et al., 2013a).

The third hypothesis was that our methodology, using a multivariate statistical analysis, would be able to distinguish spatial behaviour of local people from that of foreign workers, considering both urban land and services.

1.3. Methodology

According to Rui (2013), some classifications of urban LULC change models have been proposed by scientists. For instance, Briassoulis (2000) classified LULC change models based on their functional and methodological aspects: statistical and econometric, spatial interaction, optimization, integrated, natural sciences-based, GIS-based and Markov chain-based. On the other hand, Verburg et al. (2004) discussed six features that were considered to be of importance when modelling LULC changes: level of analysis, cross-scale dynamics, driving factors, spatial interaction and neighbourhood effects, temporal dynamics, and level of integration. More recently, Silva and Wu (2012) presented a list of comprehensive classification schemes according to different characteristics, methodologies, application areas and modelling approaches:

- Modelling approaches: mathematical/statistical models, GIS-based models, cellular automata-based models, agent-based models, rule-based models, and integrated models.

- Levels of analysis: micro level, macro level, and cross level models.

- Spatial scales: regional scale, metropolitan scale, local scale, and multi scale models.

- Temporal scales: long term, medium term, and short term models.

- Spatial emphasis: spatial oriented, aspatial oriented, and integrated models.

- Planning tasks emphasis: LULC change, urban growth, transportation land use, impact assessment, and comprehensive projection models.

Given the overall aim of this PhD thesis, to analyse the LULC dynamics of Al Ain city as an example of a medium-sized town affected by urban sprawl, the applied methodology was a land-use-based modelling approach, using GIS techniques at a macro level of analysis, considering the subregional and local scale at long term (Sharaf et al., 2018). Specifically, four different tools and techniques were applied: i) a combination of the 2014 Base Map from Al Ain Town Planning with Landsat imagery from 1984, 1990, 2000 and 2014, to establish the corresponding LULC for each year and to obtain the corresponding spatial changes; ii) estimation of selected spatial metrics to determine urban landscape processes and patterns such as aggregation, isolation and/or sprawl; iii) application of an multivariate statistical analysis using census data, at district scale, to improve the understanding of LULC processes; and iv) analysis of main driving forces of LULC changes and their socioenvironmental consequences using a qualitative modelling based on expert knowledge. Each method will be explained in its corresponding chapter of this PhD thesis. The main methodological challenge was the combination of the four tools, an innovative method used to obtain the LULC changes from the 2014 Base Map and the remote sensing images, together with the landscape and the statistical analysis.

1.4. Thesis structure

This PhD thesis has the following structure:

- Chapter 2: *The study area*. The main objective of this chapter is to describe, from a historical, bio-physical and socio-economic point of view, the Al Ain region, starting with a general view (UAE) and finishing with a specific vison (Al Ain city).
- Chapter 3: *The theoretical framework*. The features of two General Master Plans, 1986 to 2000 and 2003 to 2015, are presented. The main objective is to outline the basic projections and the urban development plan, including the urban structure and the housing needs.
- Chapter 4: *LULC changes and landscape analysis*. The first part of the chapter investigates LULC changes from 1984 to 2014, considering the sectors and district scales, according to three periods: from 1984 to 1990, from 1990 to 2000, and from 2000 to 2014. In the second part, the objective is to understand the consequences, from a landscape point of view, of LULC changes. Selected configuration and

composition landscape indicators were calculated in order to evaluate the magnitude of urban sprawl.

- Chapter 5: *A statistical multivariate analysis at district scale.* The objective of this chapter is to examine the spatial consequences at district scale of LULC changes, applying a multivariate statistical analysis. Specifically, the goal is to understand the spatial dynamics of urban (services, industry and residential land) and agricultural sprawl with respect to the 6 sectors and 62 districts of Al Ain.
- Chapter 6: *Driving forces and socio-environmental consequences of LULC changes in Al Ain*. This chapter is made up of two parts; the first one corresponds to the analysis of main driving forces of LULC changes in Al Ain city. The second analyses the socio-environmental consequences of LULC changes, mainly from the urban and agricultural sprawl point of view.
- Chapter 7: *Future planning: Master Plan 2030*. The objective of this chapter is to synthesize the main ideas of the Plan for Al Ain City 2030.
- Chapter 8: Final conclusions based on the research findings are presented.

1.5. Chapter bibliography

Abd El-Kawy, O.R., Rad, J.K., Ismail, H.A., Suliman, A.S. (2011) Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Applied Geography*, 31, 483-494.

Abrantes, P., Fontes, I., Gomes, E., Rocha, J. (2016) Compliance of land cover changes with municipal land use planning: evidence from the Lisbon metropolitan region (1990-2007). *Land Use Policy*, 51, 120-134.

Acheampong, M., Yu, Q., Enomah, L.D., Anchang, J. Eduful, M. (2018) Land use/cover change in Ghana's oil city: assessing the impact of neoliberal economic policies and implications for sustainable development goal number one – A remote sensing and GIS approach. *Land Use Policy*, 73, 373-384.

Aguilera, F., Valenzuela, L.M. Botequilha-Leitão, A. (2011) Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish Metropolitan area. *Landscape and Urban Planning*, 99, 226-238.

Akinyemi, F.O. (2017) Land change in the central Albertine rift: insights from analysis and mapping of land use-land cover change in north-western Rwanda. *Applied Geography*, 87, 127-138.

Bhatta, B., Saraswati, S., Bandyopadhyay, D. (2010) Urban sprawl measurement from remote sensing data. *Applied Geography*. 30, 731-740.

Biro, K., Pradhan, B., Buchroithner, M., Makeschin, F. (2013) Land use/land cover change analysis and its impact on soil properties in the Northern part of Gadarif region, Sudan. *Land Degradation & Development*, 24, 90-102.

Chapter 1: Introduction

Bloch, R. (2010) Dubai's long goodbye. *International Journal of Urban and Regional Research*, 34, 943-951.

Briassoulis H. (2000), Analysis of land use change: theoretical and modeling approaches. PhD Thesis in Geography, University of Aegean, Lesvos, Greece.

Catalán, B., Saurí, D., Serra, P. (2008) Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993–2000. *Landscape and Urban Planning*, 85, 174-184.

Colantoni, A., Grigoriadis, E., Sateriano, A., Venanzoni, G., Salvati, L. (2016) Cities as selective land predators? A lesson on urban growth, deregulated planning and sprawl containment. *Science of the Total Environment*, 545-546, 329-339.

Durà-Guimerà, A. (2003) Population deconcentration and social restructuring in Barcelona, a European Mediterranean city. *Cities*, 20, 387-394.

Elsheshtawy, Y. (2008) *The evolving Arab city. Tradition, modernity and urban development*. Routledge, London.

Esbah, H. (2007) Land use trends during rapid urbanization of the city of Aydin, Turkey. *Environmental Management*, 39, 443-459.

Espindola, G. D., Carneiro, E. C., & Façanha, A. C. (2017). Four decades of urban sprawl and population growth in Teresina, Brazil. *Applied Geography*, *79,* 73-83.

European Environmental Agency (EEA) (2016). *Urban sprawl in Europe*. EEA report 11. Copenhagen: European Environment Agency.

Gallardo, M., Martínez-Vega, J. (2016) Three decades of land-use changes in the region of Madrid and how they relate to territorial planning. European Planning Studies, 24, 1016-1033.

Gamba, P., Dell'Acqua, F., Stasolla, M., Trianni, G., Lisini, G. (2011) Limits and challenges of optical very-high-spatial-resolution satellite remote sensing for urban applications. In: X. Yang (Ed.) *Urban remote sensing: monitoring, synthesis and modelling in the urban environment*. Chichester, John Wiley & Sons Ltd., 35-48.

Gargiulo Morelli, V., Salvati, L. (2010) *Ad hoc urban sprawl in the Mediterranean city. Dispersing a compact tradition?* Roma, Edizioni Nuova Cultura.

Hamouche, M.B. (1999) Opting for growth: a strategy for Al Ain. *International Habitat*, 23, 303-317.

Heaviside, C., Vardoulakis, S., Cai, X.M. (2016) Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental Health*, 15, 49-59.

Helmy, M. (2008) *Urban Branding Strategies and the Emerging Arab Cityscape*. Stuttgart, Germany, Universität Stuttgart.

Hewitt, R., Escobar, F. (2011) The territorial dynamics of fast-growing regions: Unsustainable land use change and future policy challenges in Madrid, Spain, *Applied Geography*, 31, pp. 650–667.

Hutton, T.A. (1994) Vancouver. *Cities*, 11, 219-239.

Issa S., Shuwaihi A.L. (2012). Characterization of Al Ain city urban growth using multi-temporal remote sensing data and GIS. *International Geoinformatics Research and Development Journal*, 3, 1-17

Chapter 1: Introduction

Kamh, S., Ashmawy, M., Kilias, A., Christaras, B. (2012) Evaluating urban land cover change in the Hurghada area, Egypt, by using GIS and remote sensing. *International Journal of Remote Sensing*, 33, 41-68.

Kamusoko, C., Gamba, J., Murakami, H. (2013) Monitoring urban spatial growth in Harare Metropolitan province, Zimbabwe. *Advances in Remote Sensing*, 2, 322-331.

Kasanko, M., Barredo, J.I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V., Brezger, A., (2006) Are European Cities Becoming Dispersed? A Comparative Analysis of Fifteen European Urban Areas. *Landscape and Urban Planning*, 77:111–130.

Keken, Z., Sebkova, M., Skalos, J. (2014) Analyzing land cover change –The impact of the motorway construction and their operation on landscape structure. *Journal of Geographic Information System*, 6, 559-571.

La Rosa, D., Privitera, R. (2013) Characterization of non-urbanized areas for land-use planning of agricultural and green infrastructure in urban contexts. *Landscape and Urban Planning*, 109, 94-106.

Lagarias, A. (2012) Urban sprawl simulation linking macro-scale processes to micro-dynamics through cellular automata, an application in Thessaloniki, Greece. *Applied Geography*, 34, 146-160.

Lambin, E.F., Geist, H.J., Lepers, E. (2003) Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205-241.

Leo, C., Anderson, K. (2006) Being realistic about urban growth. *Journal of Urban Affairs*, 28, 169-189.

Lister, T.W., Lister, A.J., Alexander, E. (2014) Land use change monitoring in Maryland using a probabilistic sample and rapid photointerpretation. *Applied Geography*, 51, 1-7.

Magarotto, M.G., da Costa, M.F., Tenedório, J.A., Silva, C.P. (2016) Vertical Growth in a Coastal City: An Analysis of Boa Viagem (Recife, Brazil). *Journal of Coastal Conservation*, 1, 31-42.

Mandeli, K.N. (2008) The realities of integrating physical planning and local management into urban development: a case study of Jeddah, Saudi Arabia. *Habitat International*, 32, 512-533.

Marraccini, E., Debolini, M., Moulery, M., Abrantes, P., Bouchier, A., Chéry, J.-P., Sanz Sanz, E., Sabbatini, T., Napoleone, C. (2015) Common features and different trajectories of land cover changes in six Western Mediterranean urban regions. *Applied Geography*, 62, 347-356.

Masoumi, H.E., Hosseini, M., Gouda, A.A. (2018) Drivers of urban sprawl in two large Middle-eastern countries : literature on Iran and Egypt. *Human Geographies – Journal of Studies and Research in Human Geography*, 12, 55-79.

Moeller, M.S., Blaschke, T. (2006) *Urban change extraction from high resolution satellite image*. ISPRS Technical Commission II Symposium. Vienna, 151-156.

Moreira, F., Fontes, I., Dias, S., Batista e Silva, J., Loupa-Ramos, I. (2016) Contrasting static versus dynamic-based typologies of land cover patterns in the Lisbon metropolitan area: towards a better understanding of peri-urban areas. *Applied Geography*, 75, 49-59.

Muñoz, F. (2003) Lock living: urban sprawl in Mediterranean cities. *Cities*, 6, 381-385.

Nassar, A.K., Blackburn, G.A., Whyatt, J.D. (2014) Developing the desert: the pace and process of urban growth in Dubai. *Computers, Environment and Urban Systems*, 45, 50-62.

N'go, A.Y., Ama-Abina, J.t., Kouadio, A.Z., Kouassi, H.K., Savané, I. (2013) Environmental change in agricultural land in Southwest Côte d'Ivoire: driving forces and impacts. *Journal of Environmental Protection*, 4, 1373-1382.

Patino, J.E., Duque, J.C. (2013) A review of regional science applications of satellite remote sensing in urban settings. *Computers, Environment and Urban Systems*, 37, 1-17.

Paül, V., Tonts, M. (2005) Containing urban sprawl: trends in land use and spatial planning in the Metropolitan Region of Barcelona. *Journal of Environmental Planning and Management*, 48, 7-35.

Pawe, C.K., Saikia, A. (2018) Unplanned urban growth: land use/land cover change in the Guwahati Metropolitan Area, India. *Geografisk Tidsskrift - Danish Journal of Geography*, 118, 88-100.

Peen, J., Schoevers, R. A., Beekman, A. T., Dekker, J. (2010) The current status of urban-rural differences in psychiatric disorders. *Acta Psychiatrica Scandinavica*, 121, 84-93

Rogan, J., Chen, D. (2004) Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning* 61: 301-325.

Rojas, C., Pino, J., Basnou, C., Vivanco, M. (2013) Assessing land-use and -cover changes in relation to geographic factors and urban planning in the metropolitan area of Concepción (Chile). Implications for biodiversity conservation. *Applied Geography*, 39, 93-103.

Rubiera, F., González, V.M., Pérez, J.L. (2016) Urban sprawl in Spain: differences among cities and causes. *European Planning Studies*, 24, 207-226.

Rui, Y. (2013) *Urban growth modeling based on land-use changes and road network expansion*. Doctoral Thesis in Geodesy and Geoinformatics with Specialization in

Geoinformatics Royal Institute of Technology Stockholm, Sweden, 2013

Salvati, L., Munafo, M., Morelli, V.G., Sabbi, A. (2012) Low-density settlements and land use changes in a Mediterranean urban region. *Landscape and Urban Planning*, 105, 43-52.

Salvati, L., Sateriano, A., Bajocco, S. (2013a) To grow or to sprawl? Land cover relationship in a Mediterranean city region and implications for land use management. *Cities*, 30, 113-121.

Salvati, L., Zitti, M., Sateriano, A. (2013b) Changes in city vertical profile as an indicator of sprawl: Evidence from a Mediterranean urban region. *Habitat International*, 38, 119-125.

Salvati, L., Venanzoni, G., Serra, P., Carlucci, M. (2016a) Scattered or polycentric? Untangling urban growth in three southern European metropolitan regions through exploratory spatial data analysis. *The Annals of Regional Science*, 57, 1-29.

Salvati, L., Carlucci, M. (2016b) Patterns of sprawl: the socioeconomic and territorial profile of dispersed urban areas in Italy. *Regional Studies*, 50, 1346-1359.

Schein, E. (2009) *Built on sand? Emerging cities on the Arabian Peninsula in the knowledge economy context*. PhD dissertation, Technischen Universität München.

Schwarz, N. (2010) Urban form revisited—Selecting indicators for characterising European cities. *Landscape and Urban Planning*, 96, 29-47.

Serra, P., Pons, X., Saurí, D. (2003) Post-classification change detection with data from different sensors. Some accuracy considerations. *International Journal of Remote Sensing*, 24, 3311-3340.

Serra, P.; Pons, X.; Saurí, D. (2008) Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, 28, 189-209.

Serra, P., Vera, A. and Tulla, A.F. (2014) Spatial and Socioenvironmental Dynamics of Catalan Regional Planning from a Multivariate Statistical Analysis Using 1980s and 2000s Data. *European Planning Studies*, 22, 1280-1300.

Serra, P., Saurí, D., Salvati, L. (2018) Peri-urban agriculture in Barcelona: outlining landscape dynamics vis à vis socio-environmental functions. *Landscape Research*, 43, 613-631.

Shahraki, S.Z., Saurí, D., Serra, P., Modugno, S., Seifolddini, F., Pourahmad, A. (2011) Urban sprawl pattern in land-use change detection in Yazd, Iran. *Habitat International*, 35, 521-528.

Shair, I.M., Nasr, A.H. (1999) Using satellite images to detect land-use change in Al-'Ain city, United Arab Emirates. *The Arab World Geographer*, 2, 139-148.

Sharaf, A., Serra, P., Saurí, D. (2018) A district and sector land-use and landscape analysis of urban sprawl in Al Ain municipality (United Arab Emirates): Just a quick conversion from sand to a built-up environment? *Applied Geography*, 95, 88-100.

Silva A. and Wu N. (2012) Surveying models in urban land studies. *Journal of Planning Literature*, 27 139-152.

Stuttard, M. 1992. GIS and remote sensing. In: Cadoux-Hudson, J.; Heywood, I. (Ed). *Geographic information 1992-93*. Taylor & Francis, London, 173-182.

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song; G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F., Chen, H. (2010) The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology*, 54, 75-84.

Tavares, A.O., Pato, R.L., Magalhães, M.C. (2012) Spatial and temporal land use change and occupation over the last half century in a peri-urban area. *Applied Geography*, 34, 432-444.

Tian, L., Biqiung, G. and Yongfu, L. (2017). Impacts of state-led and bottom-up urbanization on land use change in the peri-urban areas of Shanghai: planned growth or uncontrolled sprawl? *Cities*, 60, 476-486.

Verburg, P.H., Schot, P.P., Dijst, M.J., Veldkamp, A. (2004) Land use change modelling: current practice and research priorities. *GeoJournal*, 61, 309-324.

Weburbanist (2018) *Vertical cities: 12 towers take urban density to the skies*. https://weburbanist.com/2015/06/17/vertical-cities-12-towers-take-urban-density-to-the-skies/

Xu, C., Liu, M., Zhang, C., An, S., Yu, W., Chen, J.M. (2007) The spatiotemporal dynamics of rapid urban growth in the Nanjing metropolitan region of China. *Landscape Ecology*, 22, 925-937.

Xue, F., Gou, Z., Lau, S.Y.(2016) Human factors in green office building design: The impact of workplace green features on health perceptions in high-rise high-density Asian cities. *Sustainability*, 8, doi:10.3390/su8111095

Yagoub, M.M. (2004) Monitoring of urban growth of a dessert city through remote sensing: Al Ain, UAE, between 1976 and 2000. *International Journal of Remote Sensing*, 25, 1063-1076.

2.1. Introduction

The main objective of this chapter is to present the chief biophysical and socioeconomic characteristics of Al Ain city, the study area in the United Arab Emirates (UAE), a county situated in the Southeast of the Arabian Peninsula, neighbouring Oman and Saudi Arabia (Figure 2.1). In December of 1971, the UAE was founded as an alliance of six emirates - Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al-Quwain, and Fujairah; the seventh emirate, Ras Al Khaimah, joined the organization in 1972.

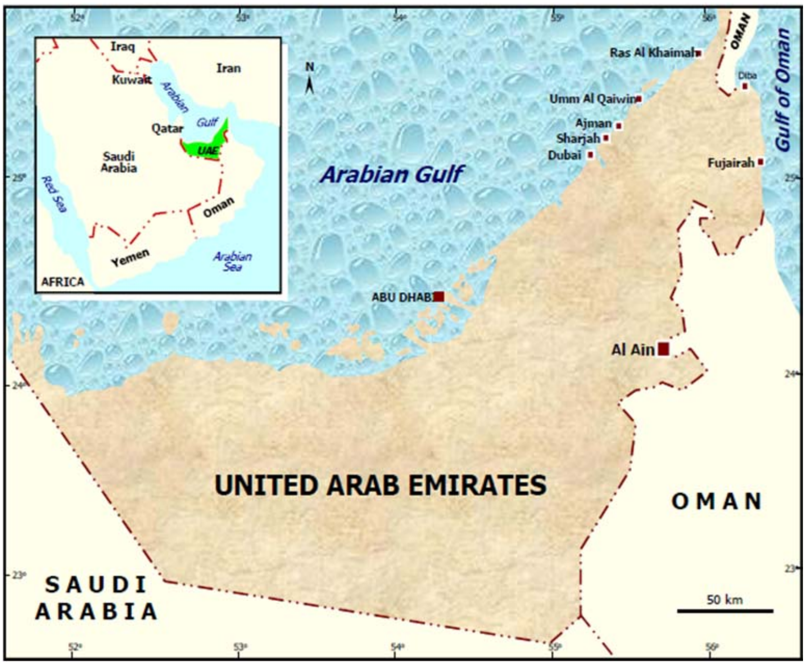


Figure 2.1. Location of the United Arab Emirates (UAE). Source: Yagoub, 2002.

The UAE developed quickly and is currently noted for its governmental framework, international events, and status as an exchange and transport centre. Since the discovery of oil and gas in 1958, the UAE's economy has become overwhelmed by this segment, which represents more than 30 percent of the aggregate. The Supreme Petroleum Council, headed by the crown sovereign of Abu Dhabi, has extreme control over the progress of this key economic segment in the UAE. Despite the commitment of the UAE president to broaden the economy by lessening reliance on oil, the UAE government is contributing billions of dollars to expand the raw petroleum limit beyond approximately 2.4 million barrels per day in 2017 (Statistics Centre Abu Dhabi, 2018).

2.2. Brief UAE political outline

The UAE federation is ruled by a set of absolute monarchs. The Ruler of Abu Dhabi Emirate serves as President of the UAE. The Ruler of Dubai Emirate is the Vice-President, Prime Minister, and Defence Minister of UAE. The UAE's government structure incorporates a Supreme Council (containing the Rulers of each Emirate), a Council of Ministers, and a semi-selected Federal National Council. Each Emirate is administered by its Ruler, with its own neighbourhood government, courts and police force. UAE is a part of the Gulf Cooperation Council (GCC), the Arab League, the Organization of Islamic Cooperation, the United Nations, the Organization of the Petroleum Exporting Countries, the Non-Aligned Movement, and the World Trade Organization. Moreover, the International Renewable Energy Agency, established in 2009, has its central command in Abu Dhabi. On the other hand, the United Arab Emirates ended 2016 with a total population of 9,267,000 people (72.9% men), with 111 inhabitants per km^2 (Country Economy, 2018).

2.3. Climate and topography

The UAE has a subtropical dry, hot desert climate with low annual rainfall, with very high temperatures in summer and a big difference between maximum and minimum temperatures, especially in the inland areas. The coastal areas are slightly influenced by the waters of the Red Sea, and have lower maximum but higher minimum temperatures and a higher moisture percentage in the air. Summer (from June to September) is characterized by very low rainfall and daily maximum temperatures of 40°C or higher, whereas winter is cooler with occasional rainfall. Spring and autumn are warm, mostly dry and pleasant, with maximum temperatures between 25°C and 35°C during the day and between 15 and 22°C at night. A hot, dust-laden wind, the *Shamal*, blows in the spring and summer, from March until August. Sometimes this wind can be very strong and cause sandstorms, which can occur throughout these seasons. During the late summer months, a humid south-eastern wind known as *Sharqi* ("Easterner") makes the coastal region especially unpleasant. Finally, the average annual rainfall is less than 120 mm in the coastal area, but often reaches 350 mm in some mountainous areas.

The terrain of the UAE is principally flat or moving desert. Its coast, which extends along the southern shore of the Arabian Gulf, is comprised of a salt plateau that reaches out far inland. The biggest common harbour is Dubai. The UAE additionally reaches out around 90 km along the Gulf of Oman. The UAE's most elevated point, at 1,527 meters, is Jabal Yibir in the rugged Al Hajar al Gharbi mountain chain, which parts the UAE from north to south in the northern emirates. Starting at the UAE–Oman border on the Arabian Gulf shore of the Musandam Peninsula, the mountains range south-eastward for about 150 km to the southernmost UAE–Oman border on the Gulf of Oman.

2.4. Abu Dhabi Emirate

The Emirate of Abu Dhabi is located in the western and southwestern part of the UAE along the southern cost of the Arabian Gulf between latitudes 22°40' and 25° north and longitudes 51° and ~56° east. The total area of the Emirate is 59,402 km^2, which represents about 87% of the UAE area. The territorial waters of the Emirate embrace about 200 islands off its 700 km of coastline. Abu Dhabi is the richest of the seven emirates that compose the UAE federation and Abu Dhabi city is the capital. It is made up of three regions: Abu Dhabi, Al Ain, and the Western region (Figure 2.2). The Emirate sits atop 10% of the world's oil reserve and 5% of the global reserves of natural gas, whereas Abu Dhabi accounts for 90% of the UAE's oil production (Statistics Centre of Abu Dhabi, 2011).

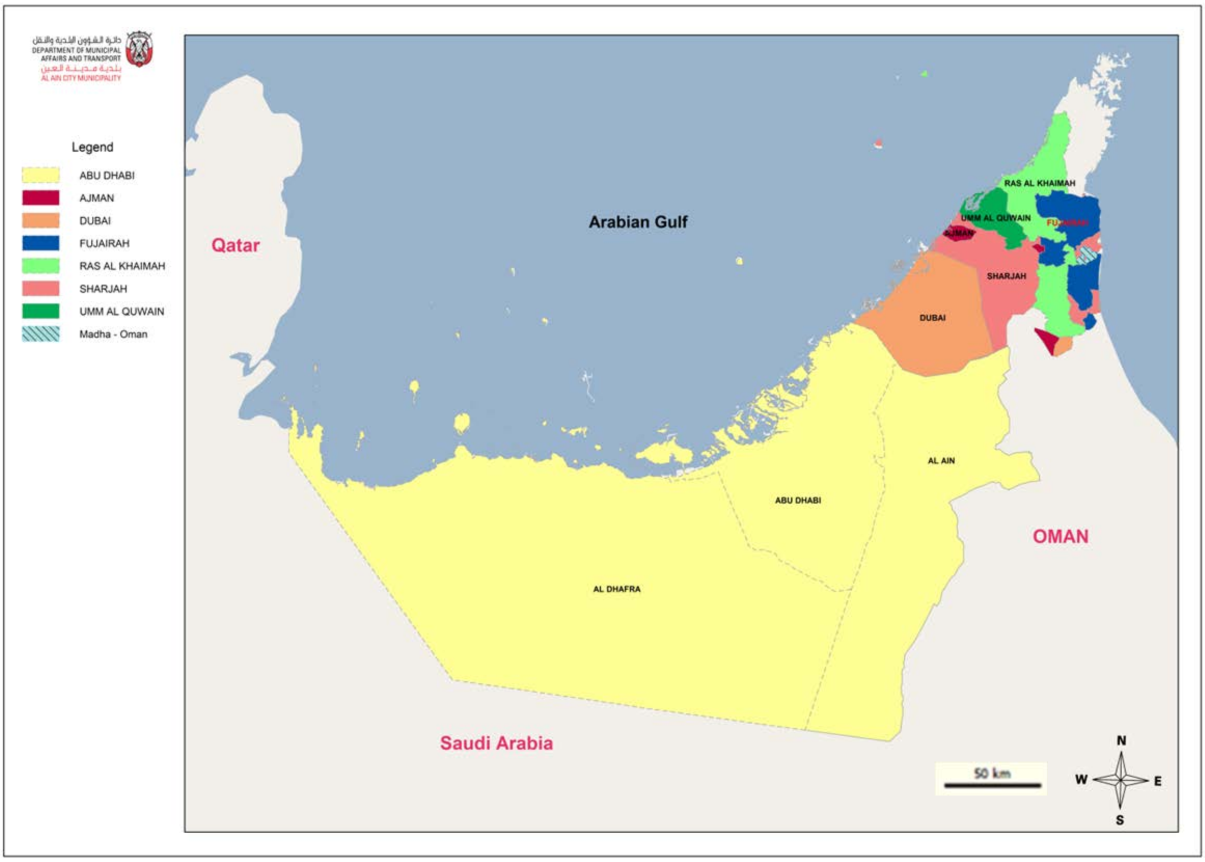


Figure 2.2. Abu Dhabi Emirate and its three regions: Abu Dhabi, Al Ain and Al Dhafra or Western region. Source: Al Ain City Municipality – UAE.

2.4.1. Climate and topography

Böer (1997) classified the UAE climate as hyper-arid and divided it into four climatic regions: the coastal zone along the Arabian Gulf, the mountain areas in the northeast, the gravel plains around Al Ain, and the central and southern sand desert. More rainfall and lower temperatures occur in the northeast than in the southern and western regions. The Emirate of Abu Dhabi has a desert climate with high temperatures, especially in summer. Abu Dhabi is located in the dry tropical zone, where the Tropic of Cancer passes through the southern part of the Emirate. Moreover, high summer temperatures cause high relative humidity, especially in coastal areas where average winter temperatures are generally warmer than in inland areas (Table 2.1).

Month	Monthly Average	Absolute Minimum	Average Minimum	Absolut Maximum	Average Maximum
January	18.7	5.9	13.8	30.9	24.0
February	19.9	7.9	14.9	32.3	25.1
March	22.5	7.7	17.7	40.0	28.5
April	26.5	14.2	20.9	43.9	33.1
May	32.7	20.2	26.1	46.1	40.0
June	33.0	19.5	26.6	47.6	39.8
July	36.1	24.8	30.5	48.9	42.8
August	36.0	25.4	30.8	48.3	42.8
September	34.3	21.1	28.4	46.4	40.3
October	29.4	15.7	23.3	42.4	35.7
November	25.3	12.5	20.1	36.0	30.5
December	21.7	8.1	16.9	32.7	26.5

Table 2.1. Abu Dhabi air temperature (°C) by month. Source: Statistics Centre Abu Dhabi, 2013.

Seasonal northerly winds blow across the UAE helping to ameliorate the weather when they are not loaded with dust, in addition to the brief moisture-laden south-easterly winds. The wind often blows from south, southeast and southwest or north, northwest and northeast. Another characteristic of the Emirate's weather is the high rate of water evaporation due to several factors, including wind speed, blowing force, high temperatures and low rainfall.

Jebel Hafeet (Hafeet Mountain) is considered one of the monuments of Al Ain, extending just to the southeast and rising to 1,300 meters in elevation (Photograph 2.1). The mean annual rainfall is about 147 mm (Table 2.2) and the average relative humidity is 60%. Low humidity in Al Ain, particularly during the summers, makes it a popular destination for many people at that time of year.

Photograph 2.1. Jebel Hafeet mountain. Source: Al Ain Municipality, 2009.

	Abu Dhabi		Al Ain	
Month	Heaviest rainfall in one day	Total for month	Heaviest rainfall in one day	Total for month
January	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0
March	0.6	0.8	0.4	0.6
April	5.2	12.9	6.6	19.1
May	0.0	0.0	6.0	6.6
June	0.0	0.0	0.0	0.0
July	0.0	0.0	6.2	6.4
August	0.0	0.0	33.6	47.6
September	0.0	0.0	0.4	0.4
October	0.0	0.0	0.0	0.0
November	2.8	6.0	33.4	49.4
December	3.6	9.2	6.0	17.8

Table 2.2. Rainfall in Abu Dhabi and Al Ain regions by month, 2012. Source: Statistics Centre of Abu Dhabi, 2013.

2.4.2. Population

According to the population census, the total population of the Abu Dhabi Emirate was 211,812 in 1975 and 2,908,173 in 2016 (Statistics Centre of Abu Dhabi, 2012a and 2018), indicating that the population was 10.2 times greater at the end of those 40 years (Table 2.3). About 21% of the population is Emirati nationals, and approximately 53% of the Emirate's populations reside in Abu Dhabi region. The population density of Abu Dhabi Emirate in 2016 was 36.4 persons per km^2, compared to Abu Dhabi (120.3/km^2), Al-Ain (44.5/km^2) and Western (7.3/km^2) (Table 2.4).

Census Year/Gender	Nationals	Non-Nationals	Total
1975	54,886	156,926	211,812
Males	29,238	125,820	155,058
Females	25,648	31,106	56,754
1980	90,792	361,056	451,848
Males	47,993	283,695	331,688
Females	42,799	77,361	120,160
1985	135,982	430,054	566,036
Males	69,975	310,278	380,253
Females	66,007	119,776	185,783
1995	222,627	719,836	942,463
Males	113,365	537,379	650,744
Females	109,262	182,457	291,719
2001	296,152	874,102	1,170,254
Males	148,982	640,844	789,826
Females	147,170	233,258	380,428
2005	350,277	1,049,207	1,399,484
Males	176,926	749,888	926,814
Females	173,351	299,319	472,670
2011	455,100	1,706,600	2,161,700
Males	234,400	1,289,900	1,524,300
Females	220,700	416,700	637,400
2016	551,535	2,356,638	2,908,173
Males	282,632	1,574,986	1,857,618
Females	268,903	781,652	1,050,555

Table 2.3. Abu Dhabi Emirate population by gender and nationality, 1975-2016. Source: Statistics Center Abu Dhabi 2011 (2012a) and 2018.

The population density of Al Ain City has grown from 33.2 per km^2 in 2005 to 57.3 per km^2 in 2016 (Table 2.4).

Region	2005	2010	2016
Abu Dhabi Emirate	23.1	33.1	48.9
Abu Dhabi Region	74.3	109.9	164.2
Al Ain Region	33.2	42.5	57.3
Al Gharbia	3.4	5.8	9.5

Table 2.4. Population density by region (inhab/km^2), 2005-2016. Source: Statistics Centre of Abu Dhabi, 2013 and 2018.

2.4.3. Water management

Abu Dhabi derives its water from two major sources: groundwater and desalinated water from the Arabian Gulf (Columbia University, 2010). In 2008, groundwater contributed 71% of total water demand for all purposes, desalinated water 24% and treated wastewater 5%. Of 1,816 Mm^3 of groundwater used every year, the vast majority is used for agriculture (64%), mainly in Al Ain and Liwa (in Western region), and forestry (32%), which also makes these sectors opportune targets for water conservation strategies (Figure 2.3). On the other hand, desalinated water totalled 1,084.7 Mm^3 in the Emirate in 2012, of which 1,059.2 Mm^3 were consumed (Table 2.5). Most (83%) of the desalinated water comes directly from desalination plants while the remaining 17% comes from water reuse via treated sewage effluent. Only 183 Mm^3 (21%) of desalinated water is used by the people, while 366 Mm^3 (42%) is used solely for amenity irrigation, another 91 Mm^3 (11%) is used for forest irrigation, and 76 Mm^3 (9%) is used to irrigate agriculture. Table 2.3 also shows the increase in the availability of desalinated water in 2017 (1,112 Mm^3) and the daily consumption (3.0 Mm^3).

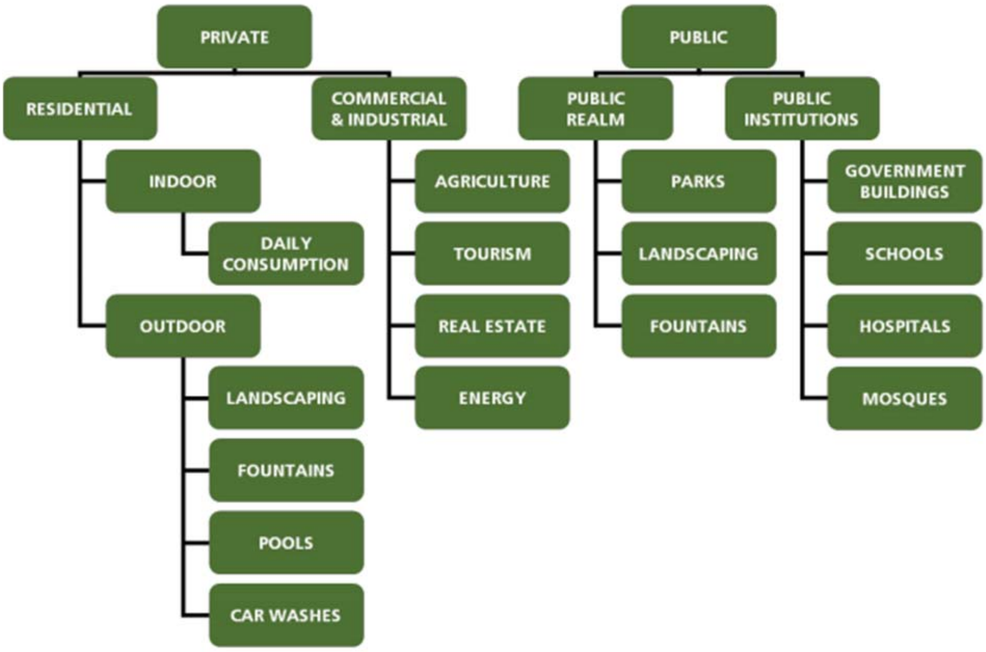


Figure 2.3. Water demand network. Source: Columbia University, 2010.

Item	2005	2009	2012	2017
Total of available desalinated water	742.1	961.3	1084.7	1112.0
Supply from Al Fujairah station	102.2	115.9	201.3	217.4
Consumption	667.0	790.0	1059.2	1101.3
Daily consumption	1.8	2.2	2.9	3.0

Table 2.5. Availability and consumption of desalinated water (Mm^3) in Abu Dhabi, 2005-2017. Source: Abu Dhabi Water and Electricity Company (ADWEA) Statistical Report 1999-2015 and Statistics Centre of Abu Dhabi, 2018.

Table 2.6 shows that consumption of desalinated water by region increased in 2017 by 3.8% compared with 2012; the Abu Dhabi the region consumed 61.3% of the total. Table 2.7 displays consumption by sector, where the domestic sector ranked first with 51.8% of the total consumption in 2012, followed by the government sector with 26.5%, the commercial sector with 13.7%, the agriculture sector with 5.4% and the industrial sector consumed just 1.7% of the total. In 2017, these percentages decreased in the government sector and increased in the commercial and agriculture sectors. Finally, Table 2.8 shows the percentage of desalinated water consumption by region and sector in 2012, highlighting the 60.7% of water consumed in Al Ain in the agriculture sector.

Region	2005	2009	2012	2017
Total consumption	667.0	790.0	1059.2	1101.3
Abu Dhabi	413.9	490.2	653.1	675.6
Al Ain	161.2	190.9	286.4	291.5
Al Gharbia	92.0	108.9	119.8	134.1

Table 2.6. Consumption of desalinated water by region (Mm^3), 2005-2017. Source: Abu Dhabi Water and Electricity Company (ADWEA) Statistical Report 1999-2015 and Statistics Centre of Abu Dhabi, 2018.

Sector	2005	2009	2012	2017
Total	667.0	790.0	1059.2	1101.3
Domestic	456.0	540.1	548.6	515.4
Commercial	63.7	75.5	144.6	223.6
Government	112.3	133.0	280.6	124.4
Agriculture	22.8	27.0	56.9	209.5
Industry	4.5	5.3	18.3	25.3
Other	7.7	9.1	10.3	3.3

Table 2.7. Consumption of desalinated water by sector (Mm^3), 2005-2017. Source: Abu Dhabi Water and Electricity Company (ADWEA) Statistical Report 1999-2015.

Sector	Abu Dhabi	Al Ain	Al Gharbia
Domestic	60.8	28.0	11.2
Commercial	83.4	8.1	8.6
Government	49.4	28.9	21.8
Agriculture	36.3	60.7	3.0
Industry	87.0	2.8	10.2
Other	83.5	14.6	2.0

Table 2.8. Percentage of desalinated water consumption by region and sector, 2012. Source: Abu Dhabi Water and Electricity Company (ADWEA) Statistical Report 1999-2015.

2.4.4. Economy

2.4.4.1. Agriculture and industry

Agriculture is one of the key productive sectors and a major component of gross domestic product (GDP), in addition to being the main supplier of food commodities and raw materials for much of the food industry in the Emirate. According to the Statistical Year Book of 2012, the number of agricultural holdings in the Emirate of Abu Dhabi totalled 24,394 holdings, with a total area of 752,839 *donums* (one *donum* is equivalent to 1,000 m^2) (Table 2.9). The total number of sheep and goats in the Emirate of Abu Dhabi totalled 2.5 million head, with the majority (62%) in Al Ain area, and the total number of camels was 330,220 head, mostly in Al Ain (56%) as well.

Analysing the number of farms by region and area category allows for the determination of their suitability for agricultural production to meet the growing demands for raw materials and food commodities. The Al Ain region has over 11,985 farms accounting for a total area of 446,898 *donums*, or 59% of the total area of farm units in Abu Dhabi (Table 2.10). The high number of farms shows that Al Ain region is a key player in the agricultural sector whereas the statistics reveal that about 72% of agricultural holdings fall under the 30-39 *donums* category and the 60 *donums* category accounts for 16% of the total agricultural area, followed closely by the 20-29 *donum* area category.

Total number of agricultural holdings)	24,394
Total agriculture (*donums*)	752,839
Area cultivated with field crops	17,960
Area cultivated with field vegetables	16,522
Area cultivated with fruit trees	303,084
Number of sheep and goats	2,551,432
Number of cattle in traditional holding	21,139
Number of cattle in commercial farms	18,907
Number of camels	330,220

Table 2.9. Agriculture statistics, 2012. Source: Statistic Centre Abu Dhabi, 2013.

Donum area category	Abu Dhabi	Al Ain	Al Garbia
Less than 20	9,721	8,109	24,346
20-29	76,544	27,525	51,278
30-39	2,931	323,088	30,966
40-49	2,308	9,870	97,890
50-59	699	6,365	1,676
More than 60	3,280	71,941	4,302
Total	95,483	446,898	210,458

Table 2.10. Area of farms (*in donums*) by area category and region, 2012. Source: Statistic Centre - Abu Dhabi 2013.

As one of the world's major producers of oil, the Emirate of Abu Dhabi has achieved remarkable progress since 1958 in the investment and development of its oil wealth and natural gas resources. Mainly as a result of an increase in the price of oil, the contribution of "oil and gas" to the Emirate's GDP increased from 48.9 per cent in 2010 to 57.9 per cent in 2011. The government adopted a long-term plan aimed at diversifying the economic base and increased the contribution of non-oil activities to economic growth in the Emirate. Such diversification is regarded as essential for the balanced and sustainable future growth of the Abu Dhabi economy. The Emirate's daily average production of crude oil increased from 2.3 million barrels per day in 2010 to 2.5 million barrels per day in 2011 or by 10.7 per cent. The daily average exports of crude oil increased from 2.0 million barrels per day to 2.3 million barrels per day or by 12.3 percent over the same period (Statistics Centre of Abu Dhabi, 2013).

The Emirate of Abu Dhabi with its large reserves of natural gas and associated liquids is well positioned to increase its participation in the global chemicals industry. The petrochemicals industry in Abu Dhabi continuously expands its well established production, marketing and export activities. Total production of petrochemical products increased by 38.5% in one year, from 2,014,568 metric tons in 2010 to 2,789,528 metric tons in 2011, while exports of these products increased by 62.2% over the same period. The most significant petrochemical exports were polyethylene and urea fertilizer. A significant drop in the volume of ammonia exports during 2011 was mainly due to increased production of urea fertilizer, for which ammonia is the key input.

Several focus sectors have been identified by the Abu Dhabi government for their potential to provide long-term, sustainable growth and diversification of its economy over the next two decades and beyond. New infrastructure such as hotels and resorts are required for development of the tourism industry, and construction is one of the enabler industries that will contribute to the development and support of the sectors targeted for future growth. Construction activity contributed 10.1% to the GDP in 2011 compared with 13.0% in 2010. The number of residential building permits issued in 2011 reached 9,275, an increase of 19.7% compared with 2010. In addition, 6,458 non-residential building permits were issued in 2011 compared with 3,785 in 2010. Construction of new buildings represented 14.3% of the total number of building permits issued in 2011.

Transport activity provides some of the key infrastructure that is required for continued economic development. Strong economic growth requires ongoing investment that will create new transport links and upgrade existing infrastructure while improving connections between the UAE geographical regions and with global markets. Continued investment in transportation infrastructure contributed to the transportation and telecommunication activities maintaining a significant share in GDP during 2011. The number of vehicles increased by 5.7% in 2011, while total aircraft movements were about 145,200 flights compared with 138,800 flights in 2010, an increase of 4.6%. The number of air passengers equalled 12.6 million, an increase of 13.6% compared with 2010. Water transport statistics include data on vessels, containers, cargo, and vessels turnaround time. The number of vessels increased 7.6%, from 2,086 in 2010 to 2,244 in 2011.

2.4.4.2. Services and tourism

The Abu Dhabi government is the regulative body of the healthcare sector in the Emirate and ensures excellence in healthcare for the community by monitoring the health status of the population. Abu Dhabi government defines the strategy for the health system, monitors the health status of the population and analyses the performance of the system. In addition, it shapes the regulatory framework for the health system, inspects compliance with regulations, enforces standards, and encourages adoption of world–class best practices and performance targets by all healthcare service providers in the Emirate. The number of hospitals, health centres and clinics increased in all the regions from 2008 to 2014, with an increment in Al Ain of 72.3% (Table 2.11).

Region and sector	2008	2010	2012	2014
Abu Dhabi				
Hospitals	24	18	22	27
Health centres	286	310	385	442
Clinics	125	168	201	212
Al Ain				
Hospitals	9	9	11	12
Health centres	95	110	129	161
Clinics	66	68	100	120
Al Gharbia				
Hospitals	6	6	6	6
Health centres	5	15	26	26
Clinics	5	3	15	30

Table 2.11. Number of hospitals, health centres and clinics by region, 2008-2014. Source: Statistics Centre Abu Dhabi, 2013 and 2018.

The government of Abu Dhabi identified tourism as an important development sector to diversify the economy and to increase sources of income. From 2010 to 2011, the number of hotel establishments increased by 11.2%, from 116 to 129, with an average stay of three days in 2011 and an annual occupancy rate of 68.9%, an increase of 6.5% compared with 2010 (Table 2.12). As a result, the number of rooms rose from 18,800 to 21,300 (13.3%) and the number of guests totalled about 2.1 million in 2011, an increase of 16.5% compared with the previous year. During the same period, the number of guest nights grew by 22.2% and the average length of stay increased by 0.14 days.

Item	Abu Dhabi	Al Ain	Al Gharbia	Total
Number of hotel establishments	109	13	7	129
Number of guests (thousand)	1,769	266	76	2,112
Number of guest nights (thousand)	5,471	542	257	6,270
Average length of stay (in days)	3.1	2.0	3.4	3.0
Annual occupancy rate (%)	70.1	59.4	63.3	68.9

Table 2.12. Hotel establishments' indicators by regions in 2011. Source: Statistics Centre of Abu Dhabi, 2013.

Over a seven-year period, the number of hotel guests from all countries increased 132.4%, from 1,502,954 in 2008 to 3,494,063 in 2014 (Table 2.13). The number of UAE nationals increased 123.1%, from 516,243 to 1,152,085, whereas the number of guests from Asia increased 376%, from 192,369 to 723,291. European nationals, the second main group of visitors, totalled 360,413 in 2008 and increased to 651,804 in 2014, a growth of 80.8%. Finally, the fourth largest provenance was from other Arab countries with an increase from 2008 to 2014 of 233,586 guests, corresponding to a gain of 149.8%.

Nationality	2008	2011	2014
Total	1,502,954	2,111,611	3,494,063
United Arab Emirates	516,243	824,442	1,152,085
Other Gulf Cooperation Council (GCC) countries	96,280	133,277	240,278
Other Arab countries	155,893	252,626	389,479
Asia (except Arab countries)	192,369	323,094	723,291
Australia and Pacific	28,970	40,414	57,430
Africa (except Arab countries)	20,051	21,280	53,642
Europe	360,413	380,980	651,804
North and South America	102,137	109,327	185,023
Not Specified	30,598	26,171	40,831

Table 2.13. Guests of hotel establishments by nationality, 2008-2014. Source: Statistics Centre of Abu Dhabi, 2013 and 2018.

2.5. Al Ain City

Al Ain is the second largest city in the Emirate of Abu Dhabi and is an economic hub in the UAE. Christened Al Ain, meaning “the spring,” due to its green scenery, it is also considered one of the world’s greatest cultural centres based on its national population’s association with the Bedouin culture. With an area of over 13,000 km^2, the region is rich in archaeological and geographical features, which make it an important tourist attraction site. The growth of the city has been attributed to driving forces such as the city’s unique demography, its governance structure, income, and geography, as will be explained in chapter 6.

Al Ain Municipality was established by royal decree in 1967, after which it began providing public services in the city and its neighbouring districts, with a total area of 8,370 km2. After the issuing of a royal decree in 1974, the municipal government began to take a more active role in regulating the city's affairs and providing a wider range of public services. As shown in Annex 2.1, the study area included 64 administrative districts, two of which (Al Qua'a and Um El Zumol) were not included due to their remote southern location.

The Municipality has witnessed significant growth over the years, and has earned recognition as the fourth largest city in the Emirates. A key to its expansion as a global city has been the role that the government of Abu Dhabi has played, under the leadership of its Ruler. With guidance from the Emirates, the government has invested in the development of road networks, government houses, health infrastructure, and educational facilities (Town Planning Department of Al Ain, 1986), as discussed in Chapter 3.

2.5.1. Sand dunes

The city's environs are covered by dunes of different texture, extending from the east to north of Al-Ain. These sand dunes have high carbonate contents that increase toward the mountain of Jabal Hafit and the Arabian Gulf coast (Abdelfattah, 2009). The well-sorted fine sands of the dunes contain carbon grains and unstrained quartz. Interdune elements include fine and poorly sorted sands with small concentrations of silt, clay and gravel. Many of the sand dunes are related, sharing certain characteristics. Tracks pass through them, with some having unpaved roads to make it possible for visitors to explore their depths. They extend from the city to the capital, Abu Dhabi. Many hotels and travel enterprises have been developed to give visitors a breathtaking view of the scenic dunes around the city.

The region experiences perpetual sand storms, which shape the sand dunes and give them their attractive profile. Some of the dust storms last for days, impairing visibility in the city and its environs. The storms often bring transport and aviation to a standstill and at worst they cause road accidents due to the high-velocity winds. While these storms impact health and travel, they help in forming the region because it is the well-known sand dunes that are a key attraction for many people.

2.5.2. Social history

Historically, Al Ain was located at the junction of two major trade routes: between Abu Dhabi and the mountain pass to the Gulf of Oman, and between Dubai and the settlements along the foothills of the Omani mountains. The routes themselves were mostly determined by access points with emergent settlements located at places where shallow pools of sweet water were provided for a largely nomadic population and their camels (Town Planning Department of Al Ain, 1986). With the successful exploitation of oil after 1962, the main aim was to stabilize the Bedouin population and to distribute equitably the oil income among the citizens. As a consequence, the city's population jumped from 13,000 in 1968 to 142,000 in 1985, comprising almost 80% of the regional population. Major investment programs were initiated in housing, education, health, parks, roads and utilities.

The history of Al Ain has been dated to 4000 B.C. Archaeological excavations have revealed that an advanced human settlement existed there around 3,000 B.C. (Photograph 2.2). Based on Sheikh Zayed's vision in the 1970s, Al Ain has developed into the current city, being one of the greenest in Arabia today. For instance, from a traffic regulation point of view, the huge number of roundabouts offers a showcase of water, design, and tree-lined streets with no need for aerial structures (Photograph 2.3). On the other hand, Al Ain is currently the home of UAE University and the nation's biggest warehouse, greatest zoo (Photograph 2.4), an airport and other facilities, including camel racetracks, parks and museums, among others (Annex 2.2).

Photograph 2.2. Hili archaeological park. Source: Al Ain Municipality, 2009.

Photograph 2.3. Example of planned green roundabout. Source: Al Ain Municipality, 2009.

Photograph 2.4. View of the zoo. Source: Al Ain Municipality, 2009.

The revelation of a Bronze Age site on the Island of Umm a Nar and discoveries at other archaeological locales in the eastern district of Abu Dhabi 45 years prior led Sheikh Zayed to protect the historical centre. One of the numerous steps taken was to secure the legacy, which he acknowledged would be soon in peril in light of development planning that he considered as a top priority. The historical centre, the first to have been secured in the nation, was established in 1969 and announced by H.H. Sheikh Tahnoon in 1971.

2.5.3. Population

Census data show that in 2005 the total population of Al Ain was of 444,700 inhabitants whereas in 2011 it had increased 34%, to 595,800. The population density in 2005 was 33.2 persons per km^2, compared to 44.5 and 47.1 persons per km^2 in 2011 and 2012, respectively (Statistics Centre of Abu Dhabi, 2013). Although there appeared to be an equal number of male and female citizens, with the difference being 3,214 persons, overall population estimates in mid-2012 indicated that there were nearly twice as many men (409,434) as women (221,571) living in the city, a difference of 187,863. It is also apparent from the census that the region has a young population, as the largest age group irrespective of gender was children 0-4 years old.

The non-citizen population appeared to explain the gender imbalance in the region. In this subgroup, women accounted for about 28.8% of the population. Regarding urban population distribution in mid-2012, there was nearly an equal number of men and women (56,959 and 56,022, respectively) among citizens. In contrast, there were more than twice as many non-citizen men as non-citizen women (207,755 and 99,978, respectively) in the urban population.

In rural areas, also in mid-2012, there were well over twice as many men as women (144,720 and 65,571, respectively). The number of male citizens living in rural areas was 41,727 as compared to 39,450 female citizens. In contrast, there were nearly four times as many non-citizen men as non-citizen women living in rural areas (102,993 as opposed to 26,121).

From these data, it would appear that both rural and urban areas attracted and retained more male than female non-citizens to the region. This trend creates an imbalance in an otherwise balanced citizen population.

2.5.4. Water resources

In any city, water management is critical to ensure the smooth running of everyday activities ranging from the individual resident to industries. Efficient water management is even more important for cities located in areas that have desert-like features, such as Al Ain. The city is not on the sea, and so depends on numerous other sources of water supply. It has oases, which are renowned for the underground irrigation system known as *aflaj* that conveys water from the wells to palm trees and farms. *Aflaj* is an ancient irrigation system that dates back many centuries. In this system, water flows naturally to the destination (Photograph 2.5). It comprises a mother well, the main water channels, and access shafts which are built along the channel. Although water distribution is complicated, it ensures adequate supply to all farming lands by gravity (Tourenq and Launay, 2008). Regular maintenance is done to ensure maximum water flow to meet the needs of farmers. According to Mohamed (2014), in Al Ain the total annual volume of desalinated water distributed in 2012 was estimated in 219.0 Mm^3/year, the main wastewater treatment plants received 54.7 Mm^3/year, and treated sewerage totalled 5.5 Mm^3/year.

Photograph 2.5. *Aflaj* system in Al Ain. Source: Environment Agency of Abu Dhabi, 2006.

On the other hand, Al Ain has seven oases, with the largest being Al Ain Oasis, located near Old Sarooj (Photograph 2.6). Other oases include Al Jimi, Hili, Al Muaiji, Al Mutaredh, and Qattara. These oases are key water sources for the city. In addition, the city has some aquifers, which are recharged by rainfall in the Hagar Mountains, providing a natural source of water for consumption and other purposes. Some of the individual wells produce an output exceeding 150 m^3/hour. Over 96 groundwater wells provide support to the *aflaj*. Although Al Ain is located in a desert region, it receives some rainfall. However, the rains are erratic as the city experiences a long dry spell (Table 2.2). Even so, much of the rainfall is a harvested on the rooftops and stored for future use. This helps to augment the supply of water for human consumption.

Photograph 2.6. Al Ain oasis. Source: Al Ain Municipality, 2009.

Water is important for the city to meet not only domestic demands, but also industrial and landscaping demands. The city has about 18 million date palms and 100 million assorted trees watered by reprocessed wastewater, leaving groundwater for human consumption. The staggering amount of landscaping within the city and its environs shows a commitment by government to reclaim the desert area and transform it into a beautiful place. This requires huge amounts of water to maintain the greenery. Without adequate water supply to meet the water demands of the many green areas in the city, Al Ain would lose its stature as a tourist attraction centre.

Besides landscaping purposes, water is important for industries located in the city. Al Ain has a designated industrial area located on the eastern border, extending about ten km^2. The industrial area lies to the west of Zakher region and overlooks several mountains and red sand dunes. It is considered a model industrial area due to the presence of integrated services. Some of the leading companies include Al Rowaidhi Well Drilling, Al Ain General Contracting, Strata Manufacturing, Flora Engineering Services, Al Ain Mineral Water Company, among many other firms. These corporations need huge volumes of water to meet their production demand; therefore, they depend on the available water resources.

The city has numerous health and educational institutions that depend on the available water resources as well. However, the most important industry that requires a sufficient supply of water is food and agriculture, which accounts for over 55% of water use in Al Ain, exceeding any other industry or sector (Oxford Business Group, 2016). The sector is a major player in the economic development of the region and contributes to the national GDP. Agriculture is vital to the success of all other sectors in the region, meeting the needs of Al Ain and other regions as well. Agricultural processed products, such as milk, meet the daily needs of the residents. Al Ain has distinguished itself as a key agricultural centre, with agricultural land use supported by many agricultural processing plants. One of the main food processing firms is Agthia, with many agricultural products including flour, animal feed, juice, bottled water, and dairy products. It is the largest producer of bottled water, commanding about 25% market share. The company requires huge amounts of water for treatment and purification to meet the demand in the market. Another major agricultural company is Al Dahr, which produces both animal feed and human food.

Some of the main plants cultivated in the region include fruit trees, field crops, and vegetables. Fruit trees occupy the largest proportion of agricultural land, accounting for about 40% of the total area (Statistics Centre Abu Dhabi, 2013) (Photograph 2.7). In essence, palm trees are the most important fruit trees due to the conditions in the region, producing dates that meet the food needs of the residents. Crops occupy about 2% of the total agricultural holdings (Photograph 2.8) whereas vegetable crops cultivated in greenhouses and open fields constitute a similar percentage. Among the vegetables, the main crops are dry onion, watermelon, tomatoes, cabbage, and cucumber. Meanwhile, the rest of the vegetable crops occupy 25% of the land allocated to vegetables. Finally, windbreaks and forest trees occupy about 3.4% of the total agricultural holding area.

Photograph 2.7. Fields of fruit trees. Source: Al Ain Municipality, 2009.

Photograph 2.8. In foreground, crop fields in Hili. Source: Al Ain Municipality, 2009.

2.5.5. Economy

In mid-2012, the largest age group in the overall workforce was 25-29 years old, followed by those aged 30-34 years (Statistics Centre of Abu Dhabi, 2013). Only 0.9% of the Al Ain male population aged between 15 and 19 years were employed, compared to 2.9% of their female counterparts. Employment among men was highly concentrated in the population aged 25-49 years and younger than 50 years; in contrast, the highest concentration of employed women was between 25 and 34 years of age. In this case, the male population remained in the workforce longer than the female population.

The number of employed women aged 45-49 years was 4.4% of their age group, compared to twice as many of their male counterparts, at 8.8%. By the age of 60-65 years, there were five times as many employed men as women (1.5% compared to 0.3%, respectively). For the age group older than 65 years, 0.2% of the male population was employed, but no women were in the workforce. The data suggest that after the age of 34 years, many women in Al Ain leave their workplaces to attend to family responsibilities, resulting in the sharp gender disparity in employment data.

2.5.5.1. Agriculture and industry

The area of agricultural holdings increased by 8,078 *donums* between 2005 and 2011. The largest surface was of 323,088 *donums* for the category 30-39, followed by the category of more than 60, covering an area of 71,941 *donums* (Table 2.10). Al Ain's land use is mostly for fruit production (194,465 *donums*), followed closely by fallow land (154,659 *donums*) and distantly by crops (14,900 *donums*) and vegetables (4,501 *donums*). Out of this, 61,999 *donums* of land were potentially productive and 827 *donums* were covered by greenhouses. On the other hand, the area cultivated with field crops grew by 16,052 *donums* from 2005 to 2011, although tons of production decreased from 758,609 to 667,801, a reduction of 90,808 tons. In 2012, the largest area of orchard corresponded to lemon trees (984 *donums*), followed by cinder, mango, and orange. In the case of vegetables, the largest area corresponded to onion (4,638 *donums*), followed by tomato and cabbage fields. Finally, Al Ain has vast areas of palm farms in different central districts, with huge productivity of dates, up to 51,456 tons in 2012, an increase of 16,136 tons from 2009.

Al Ain has a designated industrial area, situated near the UAE's eastern border. The zone houses many industries, including manufacturing and services that provide employment to many locals. Manufacturing industries in the industrial zone include plastic, steel, cement, and household commodities firms, producing for both domestic and export demands for the construction industry. The city houses many technology companies, in addition to the bottled water firms that deliver quality drinking water to the residents.

The construction industry is another major sector in the city. Many companies and consultancies are involved in construction projects in the city and throughout the UAE. Some of the leading firms include Astraco Construction, Al Jaheeli General Contracting, Al Geemi & Partners, and Ginco General Contracting, among others. These companies have built some of the landmark buildings in the city.

Furthermore, Al Ain has a thriving hospitality industry. Some of the leading groups include Concord, Al Ain, Ayla Bawadi, Action, and Hilton Hotels. The sector employs many people and serves many customers, both domestic and others foreign.

The food industry is one of the largest sectors in the city, playing a critical role in meeting the food demands of residents in a desert climate. Considering that the majority of the people live in the city, they depend on processed food commodities, including drinking water from food and beverage companies located in the city. As compared to Abu Dhabi and Al Gharbia regions, in addition to agricultural holdings, Al Ain has many commercial dairy processing plants, including Al Ain Dairy, which is the largest in the city.

2.5.5.2. Services and tourism

Al Ain region offers several institutions of higher learning, such as the UAE University, Al Ain Women's College and Al Ain Men's College. The city also houses the Abu Dhabi Education Council and several international education institutions. In 2011-12, Al Ain region had nearly twice as many government schools as there were private schools. Pupil enrollment showed near gender balance, with 51.4% males and 48.6% females. Al Ain's citizens enrolled in cycle 1, cycle 2, and secondary schools chose government schools (rather than private schools) at a rate of 67.4%, 81.6%, and 80.5%, respectively; this compares with 20.1%, 27.4%, and 39.5%, respectively for non-citizens. For comparison, Al Ain citizens enrolled in private schools at a rate of 32.6%, 18.4%, and 19.5% for cycle 1, cycle 2, and secondary schools, respectively, compared to 79.9%, 72.6%, and 60.5%, respectively, for non-citizens. Al Ain had 1,354 teachers in cycle 1, 778 in cycle 2, and another 640 teachers in cycle 3 (Statistics Centre of Abu Dhabi, 2012b). There were many more female citizen teachers than there were males. Although there were nearly as many non-citizen as citizen teachers, in general more non-citizen teachers were male, compared to female non-citizen teachers. Private institutions employed 3,309 non-citizen teachers and only 22 citizen teachers.

Al Ain had between 9 and 13 pupils per teacher. Al Ain region has had a consistent rise in the number of students. Only 14% of Al Ain population had attained higher education, a statistic that included university, higher diploma, masters, and PhD. The number of students in the Institute of Applied Technologies showed a consistent rise over the years analysed. Only 7.3% of the population was illiterate.

In 2011, Al Ain Region had 10 hospitals (six of them private), 124 health centres, and 81 clinics to cover the health care of all the districts, with an average of 47 patients per available bed. In 2014, there were two more hospitals, 161 health centres, and 120 clinics (Statistics Centre of Abu Dhabi, 2018). Some of the leading hospitals are Al Ain Hospital (public), Oases Hospital (photograph 2.9), Tawam Hospital (public), and Ain Al Khaleej Hospital.

Al Ain is an important services centre for a wide area extending into Oman. In 2011 Al Ain had 13 hotel establishments, with 266,000 guests and an annual occupancy rate of 59.5% (Table 2.12). There are three major shopping centres, Al Ain Mall (photograph 2.10), Al Jimi Mall and Al Bawadi Mall (opened in 2009 in the Al Khrair area), as well as traditional *souks* selling fruit, vegetables, and livestock. Other services include service industries such as car sales, mechanics, and other artisans that are located in the area known as Sanaiya and Pattan Market. Finally, in addition to public universities, well-equipped medical facilities, and the teaching hospital at Tawam, social and governmental infrastructure includes military training areas and the Al Ain International Airport.

Photograph 2.9. Oasis Hospital in Al Mutawa'a. Source: Al Ain Municipality, 2009.

Photograph 2.10. Al Ain Mall in the Central District. Source: Al Ain Municipality, 2009.

2.6. Conclusions

The UAE has undergone considerable changes since its federation, with oil remaining the most important export. The Emirate of Abu Dhabi is one of the world's major producers of oil, which was first discovered in 1958 and has been successfully exploited since 1962. Oil has contributed to the modernization of the country and the development of international cities such as Abu Dhabi and Dubai. Along with the modernization and growth of trade in the UAE, its population has grown to just over nine million people. This has seen the mostly arid UAE come up with unique and innovative ways to manage water, which is increasingly viewed as the most critical resource for maintaining the ever-expanding nation. The Emirate derives its water from three major sources: groundwater (about 70% of water withdrawals), reused treated wastewater (6%), and desalinated water from the Arabian Gulf (24%). Agriculture uses 64% percent of the water harvested from rain and groundwater, but it continues to be a significant GDP component and a vital production area mainly in Al Ain region.

The UAE government is gradually diversifying the oil-reliant economy to ensure that non-oil activities contribute a large chunk of the nation's economic base. These efforts have been identified as necessary in ensuring the UAE achieves balanced and sustainable future economic growth. The service industry and particularly tourism has gradually improved, with more visitors arriving each year and a corresponding increase in hotel room occupancy. Demand for water remains one of the most critical issues facing UAE cities as new water management practices such as water reclamation are developed to ensure that industrial and domestic use in the modern cities is maintained.

Thanks to an ambitious forestation program, the city of Al Ain, known as the "garden city", boasts of having the greenest urban community in Arabia. It is the second largest urban area in the Emirate of Abu Dhabi and the fourth largest in the UAE. Its strategic location on the border between UAE and Oman is characterized by a vast arid desert, with intermittent dry riverbeds, known as *wadi*, a rugged mountainous region (Jebel Hafeet) and an area of fertile soils and oases, with large reserves of groundwater. The climate is hyper-arid with a very low mean annual rainfall. The city has shown rapid development during the last 40 years, partly thanks to the creation of a designated industrial area that houses many industries, including manufacturing and services that provide employment to many locals and foreigners. The Municipality of Al Ain was established by a royal decree in 1967, after which it began providing public services in the city and neighbouring districts. After another royal decree in 1974, the municipal government began to take a more active role in regulating the city's affairs. Al Ain is divided into six sectors, with a total area of 8,370 km2, and 64 administrative districts (two of which were not included in this study due to their south remote location).

As shown in this chapter, agriculture is one of the key productive sectors in Al Ain, being additionally the main supplier of food commodities and raw materials to the Emirate food industry. According to 2013 data, more than 11,000 agricultural holdings were located in the city, with a mean size per farm of about four hectares. The cultivated area includes field crops, vegetables, and fruit trees. Livestock is an important subsector, with about three million head of sheep and goats, and more than 300,000 camels are located in Al Ain.

2.7. Chapter bibliography

Abdelfattah, M.A. (2009) Land degradation indicators and management options in the desert environment of Abu Dhabi, United Arab Emirates. *Soil Horizons*, 50, 1, 3-10.

Abu Dhabi Water and Electricity Company (ADWEA) (2016) *Statistical Report 1999-2015*. Abu Dhabi, United Arab Emirates. Available at: http://www.adwec.ae/Documents/Report/2015/2015StatisticalReport.pdf

Böer, B. (1997) An introduction to the climate of the United Arab Emirates. *Journal of Arid Environments*, 35, 3-16.

Columbia University (2010) *Sustainable water management. Assessment and recommendations for the Emirate of Abu Dhabi*. New York, School of International and Public Affairs, 128. http://mpaenvironment.ei.columbia.edu/files/2014/06/AbuDhabiFinalReport.pdf

Country Economy (2018) *United Arab Emirates –Population*. Available at: https://countryeconomy.com/demography/population/united-arab-emirates

Environment Agency of Abu Dhabi (2006) Current status of Aflaj in the Al Ain area. Abu Dhabi.

Mohamed, M.M. (2014) An integrated water resources management strategy from Al Ain city, United Arab Emirates. In: Attilio Castellarin, Serena Ceola, Elena Toth and Alberto Montanar (Ed) *Evolving Water Resources Systems- Understanding, Predicting and Managing Water-Society Interactions*. Proceedings of the 6th International Commission on Water Resources Systems (ICWRS) 2014, Bologna, Italy. International Association of Hydrological Sciences Publications, 364, 273-278.

Oxford Business Group (2016) *Abu Dhabi boosting the local food industry*. Available at: https://oxfordbusinessgroup.com/overview/future-harvest-emirate-working-boost-efficiency-and-yield-local-food-industry-through-range

Statistics Centre Abu Dhabi (2018) *Statistical Yearbook of Abu Dhabi 2018*. Abu Dhabi.

Statistics Centre Abu Dhabi (2013) *Statistical Yearbook of Abu Dhabi 2013*. Abu Dhabi.

Statistics Centre Abu Dhabi (2012a) *Statistical Yearbook of Abu Dhabi 2011*. Abu Dhabi.

Statistics Centre Abu Dhabi (2012b) *Social indicators series: Education 2011-12*. Abu Dhabi.

Tourenq, C., Launay, F. (2008) Challenges facing biodiversity in the United Arab Emirates. *Management of Environmental Quality: An International Journal*, 19, 283-304.

Town Planning Department of Al Ain (1986) *Master Plan for the Region of Al Ain*. Final Report, Volume 1. Regional Strategy and Urban Development Plan. Town Planning Department, Al Ain, UAE.

Yagoub, M. (2002) *The historical remote sensing atlas of Al Ain, UAE (1976-2000)*. Department of Geography, United Arab Emirates University. Available at: http://faculty.uaeu.ac.ae/myagoub/alain/Atlas_alain.pdf

3.1. Introduction

This PhD thesis tries to verify the second initial hypothesis, as explained in the introductory chapter, about the particular urban sprawl of Al Ain city: due to the implementation of two master plans, urban growth was quite planned, in contrast to the usual situation of unregulated development (Salvati et al., 2013a). For this reason, the main objective of this chapter is to summarize the main aims of two master plans that will be compared with the actual growth and management (analysed in chapter 4).

Therefore, this chapter provides the features of two general master plans including land use requirements based on urban settlements, streets, drainage systems, and public amenities, among others. The first section offers a summary of the General Master Plan for the period between 1986 and 2000. The section outlines the basic projections and the urban development plan including the urban structure and housing needs for 2000. The next section continues with a summary of the next master plan, covering the period between 2003 and 2015.

3.2. General master plans

The general master plan offers a comprehensive plan for urban and rural development. Essentially, a general master plan is a legal framework that stipulates land use by local governments based on population estimates (Association of New Jersey Environmental Commissions, 1997). The plan facilitates the development of capital improvement programs and the adoption of official maps showing the location and extent of current and future settlements, streets, drainage systems, public amenities, and control basins, among other features. A holistic master plan describes the current and proposed patterns of a town's land use through diagrams, maps, and text. Fundamentally, a master plan articulates the vision of the community in terms of its social, economic, and physical aspirations.

On the other hand, a city's master plan can drive the protection of natural resources. According to the Association of New Jersey Environmental Commissions (1997), a master plan should strive to conserve open space and protect the environment while utilizing the available resources. The plan should guide a municipality in developing land use plans that utilize the environmental or resource inventory as the foundation while taking into account the capacity of the natural infrastructure. The master plan can map the critical environmental areas that require protection and preservation while explaining the rationale for the development of other areas. It identifies the areas suitable for growth in which development would cause little or no environmental impact. The inclusion of an appropriate resource preservation plan offers the town a multiplicity of benefits, most importantly a defensible, cohesive, and consistent approach to the protection of critical environmental areas. Some of the general elements of a master plan include the statement of objectives, assumptions, and principles, land use elements, population estimates, housing plan, recreation plan, community facilities plan, and utilities plan, among other features. This chapter provides a brief summary of the Al Ain General Master Plan for 1986 to 2000 and for 2003 to 2015. The plans were in the form of an executive plan, summarizing the main elements of the reports for these two time periods.

3.3. Al Ain General Master Plan (1986 to 2000)

The development programme set out the costs and phasing of the master plan in terms of projects and programmes. Its main purposes were to indicate the order in which development should occur, how development could be phased to produce a stable development programme, and the approximate public sector development spending required to implement the master plan.

In this section, the main ideas of the first General Master Plan of Al Ain city for the fourteen years from 1986 to 2000, according to the Town Planning Department of Al Ain (1986), will be summarized. In November of 1983 the Town Planning Department of Al Ain commissioned Shankland Cox, in association with Binnie & Partners, and Minster Agriculture Ltd to undertake a comprehensive master plan, including a traffic and transportation study for Al Ain and its region (Town Planning Department, 1985), for the year 2000.

The main objectives of such Master Plan were:

- Continuation of the traditional role of Al Ain as a centre for educational, cultural and recreational activities of national importance, as the main agricultural producer of the Emirate and as an environmentally attractive garden city.
- Minimization of water consumption to ensure a strategic reserve of groundwater

- Economic diversification to provide stable conditions for local businesses and improve the competitive position of Al Ain.
- Agricultural self-sufficiency in those products for which Al Ain is suited.
- Reducing work contracts and increasing employment for citizens, always with the goal of supporting sustainable economic development of the region.
- Maintenance of high levels of services.

Projections and estimations guided the preparation of the Master Plan. The projections included the number of people and jobs to be accommodated over the periods and the quantitative demands on transportation, land, and public utilities (Town Planning Department of Al Ain, 1986).

Population and employment

The main population data considered were past growth, extant characteristics and components of population change. The key findings were the following:

- Population rose by 19% between 1968 and 1980 in Al Ain. The citizen population was projected to rise from 45,000 in 1986 to 166,000 in 2000 whereas the total population was projected to rise from 138,000 to 324,000 (an increase of 4.3% per year).
- In 1980, more than half of the citizens and over three-quarters of the non-citizens were men.
- In 1980, the total fertility rate for citizens in Al Ain was 2.2 children/woman, compared to 1.5 for non-citizens; in 2000 the rate was 1.4 for citizens and 0.5 for non-citizens.
- Urban population was projected to increase to 274,911 in 2000.

As of 1980, a population census indicated 64,573 employed individuals in the region, but the figure could have been an underestimate because of illegal workers and the rural population. Citizen employment increased from 9% to 20% between 1980 and 2000 because of increased population growth and a high number of people taking employment. The basic regional activities included agriculture, defence, university education, construction, industries, and services. The increasing number of citizens and non-citizens seeking higher-level services was expected to lead to the projected increase. According to the Town Planning Department of Al Ain (1986), the industrial structure was composed of diverse sectors: agriculture, construction defence, as well as the community, social, and personal services (*sic*). The structure was expected to change towards a mature economy with a decline in construction and agriculture but an increase in social, community and social services such as governmental, education, domestic, and health services. Servants would form the largest population in the industrial structure as of 2000.

The occupational structure was composed of 55% agricultural workers and labourers as of 1980, which represented the strength of the construction and agricultural sectors. The various categories in the occupational structure were expected to undergo different changes. Notably, the agricultural and production sectors were expected to experience a decline in the size of their workforce from 12.9% to 5.3 % and 42.3% to 31.8% respectively. Household income was expected to increase for the households earning between 3,000Dh and 15,000Dh. However, the population of households earning less than 3,000Dh would decline while the households earning more than 15,000Dh was expected to remain stable between 1980 and 2000. Other than employment, the sources of income for the citizen population included social security payments, commercial and residential investment property, and subsidized farming incomes.

Transportation and road network

The transportation subsection offers the projections of private vehicle ownership, modal choice, and goods vehicles. The main findings included the following:

- The ratio of private car ownership in 1984 was 0.14 cars per person. Private car ownership would increase by 84% and 140% among citizens and non-citizens, respectively.
- Private cars were expected to dominate the modal choice of transportation, accounting for 83% of the forecasted 1,257,000 trips in 2000.
- The trips for goods vehicles were expected to increase up to 85% by 2000.

The proposed regional road hierarchy is shown in figure 3.1. In addition to a system of national and regional roads, there was also a special road for trucks between Al Ain and Abu Dhabi and a local scenic route (with asphalt) from Al Wagan to the summit of Jebel Hafeet. National roads link Al Ain to major destination points outside the region, namely Abu Dhabi, Dubai, Sharjah (on the east coast) and Sahar in Oman. The road was designed to accommodate speeds up to 120 km per hour.

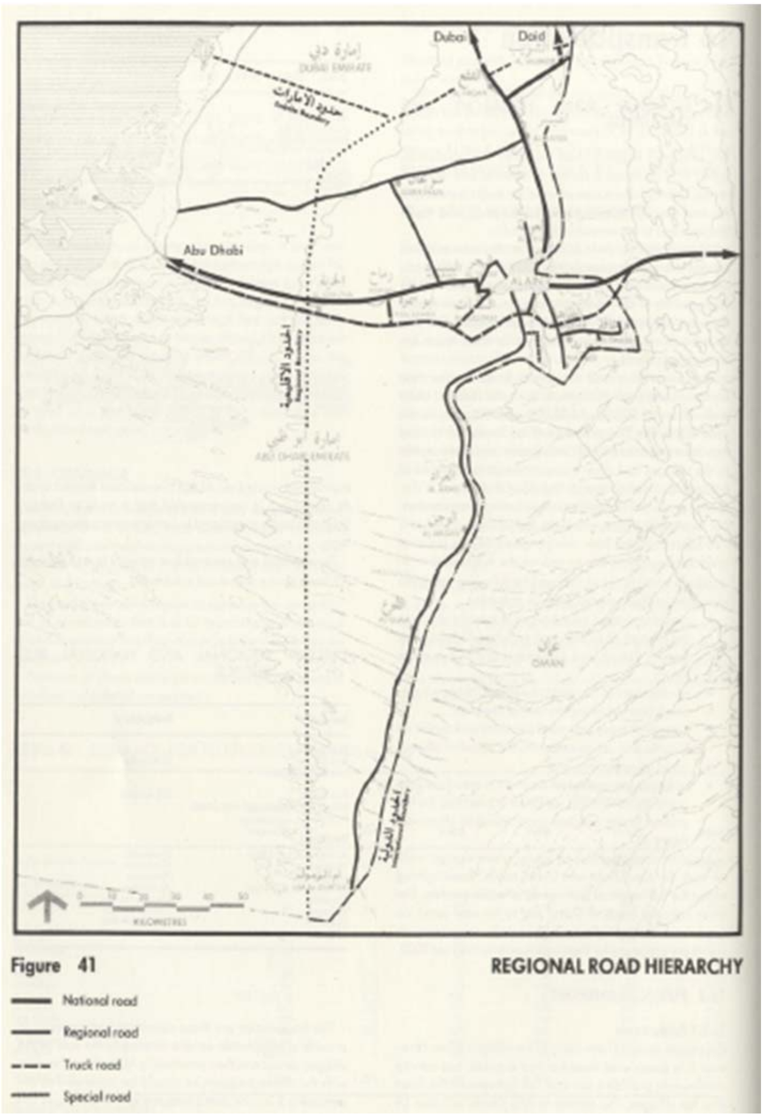


Figure 3.1. Regional road hierarchy map from Master Plan 1986-2000. Source: Town Planning Department of Al Ain, 1986.

Water and utilities

This section incorporated water demands for domestic and trade use, large-scale consumers, municipal landscaping, agriculture, forestry, and exports to Abu Dhabi. The following were expected to be the trends up to 2000:

- Total demand would fall by approximately 200 Mm^3 per annum by 2000 owing to 57% and 83% decreases in freshwater and brackish water demands, respectively.
- Domestic and export demand for water would rise from a restricted 200 litres per capita per day (lcd) to unrestricted 200 lcd and 350 lcd in rural and urban areas between 1986 and 2000.
- Municipal landscaping requirements (for gardens, etc.) would increase from 33.9 Mm^3/a to 43.7 Mm^3/a.
- Agricultural water demands would decline from 349.2 Mm^3/a to 139.2 Mm^3/a.

The utilities considered in the plan for 1986 to 2000 include electricity, sewerage, telecommunication, and solid waste, being the main objectives:

- The extension of Al Ain Power station would increase energy transmission from 262 MW to 700 MW adequate to serve the region.
- Urban sewerage flow would increase from 11,000 to 88,300 m^3/day.
- The demand for telecommunication lines would increase from 16,200 lines to 47,965 lines.
- Total urban solid waste would increase from 126 tonnes per day to 411 tonnes per day.

Agriculture

The main objective in this sector was to obtain agricultural self-sufficiency in those products for which Al Ain is suited and to secure the strategic grain growing capacity. According to Ben Hamouche (1999), agricultural development is also a means to settle local population, mostly Bedouins, in their territories and achieve social justice in the distribution of oil income among citizens. The restricted water availability reduced the extent and types of agricultural crops in Al Ain over the plan period. Nevertheless, agriculture continued to be a significant land use, extending over 2,000 hectares in the year 2000 with commercial farms developed on the better soils east of the town and traditional farms encouraged to concentrate on date palms and fodder rather than vegetable fields. The development of agriculture, especially palms, was used positively to help structure the urban area and provide visual amenity. With the exception of milk camels, agricultural livestock was not encouraged within the urban area for environmental reasons.

Urban development and structure

The urban development plan revolved around the socio-economic structure, urban structure, education, community, open space and leisure, cultural facilities, government, industries, agriculture, landscape and urban design, transportation, utilities, and local plan priorities. The urban development plan aimed at accommodating 113,100 jobs and a population of approximately 274,911, including 135,403 citizens. The settlement requirements included units for 18,100 citizens and 23,400 non-citizens. The residential areas were structured into districts accommodating between 38,000 and 40,000 people in neighbourhoods of 5,000 non-citizens and 8,000 citizens.

Facilities and retail services

The functional hierarchies of the urban structure focused on community facilities and retail services. The community structure was based on the following objectives:

- Ensure that the residential communities were served by an appropriate number, type, and size of schools, parks, clinics, and mosques.
- Distribute these facilities in a manner that would be convenient and offer a sense of identity at the district and local levels.
- For the areas served by three local mosques, provide a kindergarten serving both boys and girls, a park, and one or two corner shops.
- For the citizen's neighbourhoods, provide two single sex primary schools, a mosque, a shopping centre, a park, and children's play areas.
- For the non-citizen neighbourhoods, provide two single sex primary schools, a kindergarten for boys and girls, a neighbourhood park, several shops, and a children's play area.
- At the district community level, provide two intermediate schools and two secondary schools for citizens, two combined intermediate/secondary schools for non-citizens, recreation and open space facilities, and miscellaneous facilities

including police station, health clinic, post office, petrol station, municipality office, and library.

The principles guiding the retail service structure for the year 2000 included the following:

- A sufficient catchment population to offer a viable turnover for shops.
- Accessibility by consumers via their preferred modes of transport.
- Maximum exposure to the market that the shop serves.
- Prominent locations.
- Units of appropriate design and size for each type of business.

The needs of consumers guiding the retail service structure were the next:

- Decentralization of convenience shopping to the district centres.
- Strengthening the role of comparison-shopping in the town centre.
- Provision for limited shopping at the local level according to demand.
- Provision of shopping facilities that meet the specific features of the population groups.

Housing

In land use planning, housing would be based on density criteria, followed by:

- Social needs: define density standards that meet the needs of the residents. Large plots offered adequate opportunities and space for dwellings.
- Land economy: identify sufficient land suitable for urban development without encroachment on agriculture.
- Cost economy: in planning for development, consider the capital and maintenance costs for land preparation and infrastructure.
- Environmental and aesthetic issues: orientation was lost in the development of low-density communities while extravagant reservations for utilities and high standards for road construction created problems in environmental control.

The problems that residential planning principles aimed to mitigate by 2000 through the plan included the following:

- Lack of hierarchy of roads and pedestrian routes and universal use of grid networks.
- Lack of uniformity in plot shapes and sizes.
- Lack of identity in individual and group houses.
- Absence or poor distribution of community facilities.
- Extravagant reservations of land for roads and utilities.

The problems would be addressed as follows:

- Layout standards:
    - Improvements to layout standards through a clear hierarchy of roads and pedestrian routes.
    - Adoption of a range of plot shapes and sizes with contiguous looting.
    - Reduction of utility reservations through loop and cul-de-sac roads.
- Community structure: introduction of a systematic basis for the distribution and provision of community facilities at district and neighbourhood levels
- Urban development: planning for different scales of development reflecting the diverse functions and aimed at achieving a sense of identity and orientation.

The substandard housing addressed in the plan included non-citizen squatter housing, old government housing, and bachelor housing. These units required redevelopment or replacement. The development of new residential areas focused on the following (figures 3.2, 3.3 and 3.4):

- Infill of the vacant lots within the extant urban envelope.
- From the edge of the current urban area along the new Abu Dhabi road to the north of wadi Tawia and toward the west cloverleaf intersection.
- North of Qattara and Hili up to Al Foha.
- South from Zakhir to Al Faydah.
- Extension of Sarooj.
- Adjacent to the Mezyad road to the industrial area.

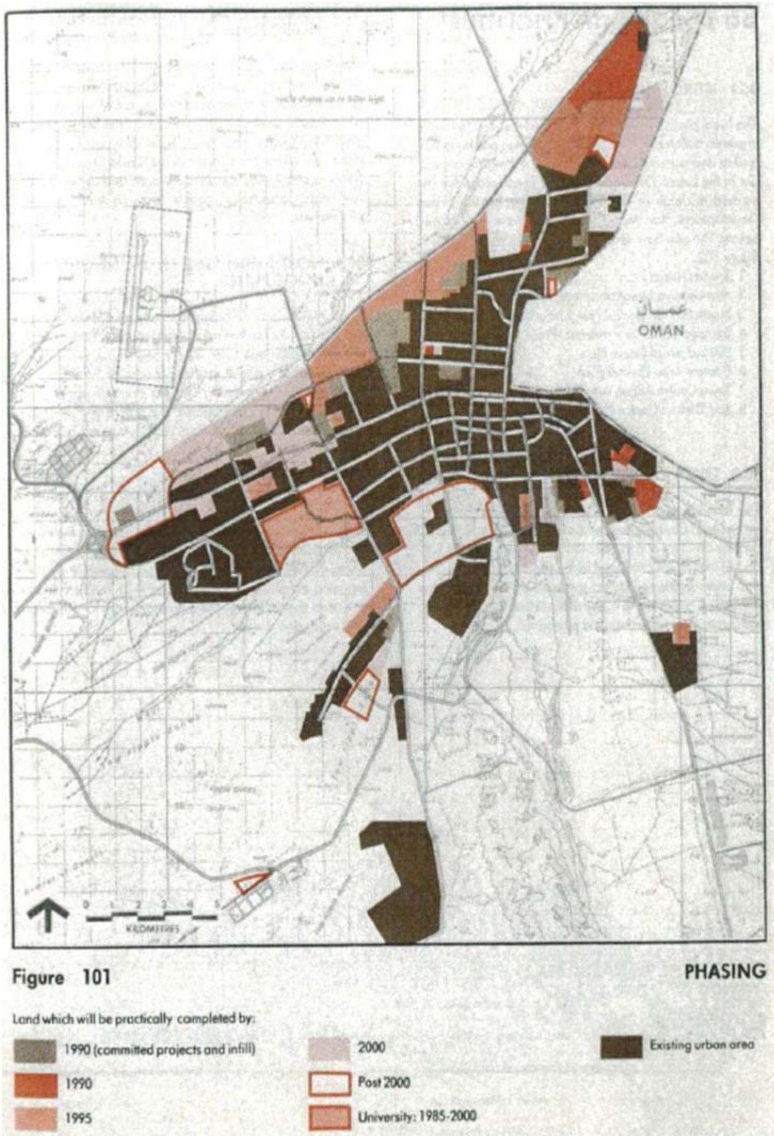


Figure 3.2. Phasing of urban development plan. Source: Town Planning Department of Al Ain, 1986.

The residential land included community facilities and other uses associated with housing, such as clinics, mosques, schools, neighbourhood centres, and local open spaces. Owing to the challenges imposed by the extant priorities and commitments, the allocation of specific areas for particular development phases had two objectives:

- Integration of the extant fragmented urban areas.
- Guaranteed continuity and cohesion of the town's urban structure at different stages of future growth.

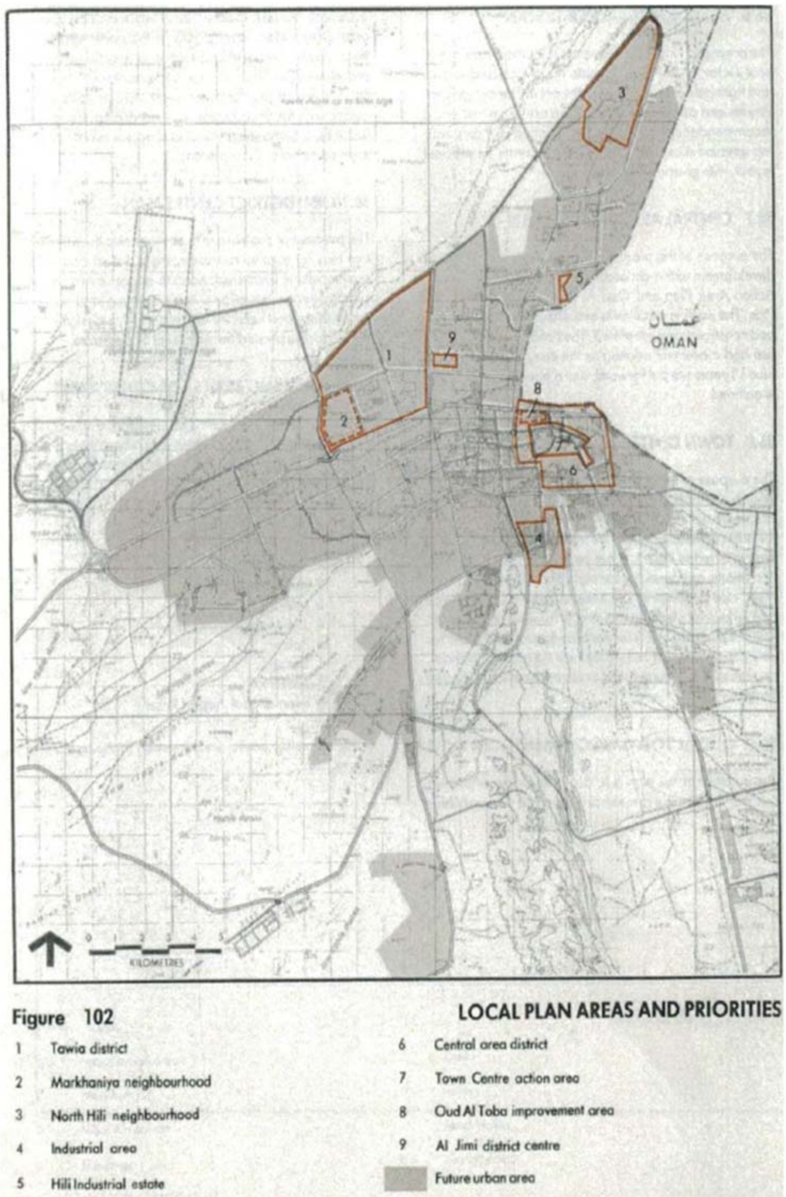


Figure 3.3. Urban development plan. Source: Town Planning Department of Al Ain, 1986.

The housing policies addressed the existing stock (old government and spontaneous housing areas) and new citizen housing. The policy guiding the use of government housing was directed to the following:

- Offering loans to citizens for renovation of the houses.
- Offering legal recognition to subletting citizens through licenses limited to 10-15 years.
- Providing community facilities.

- Upgrading the environment through the subdivision of the infill areas.

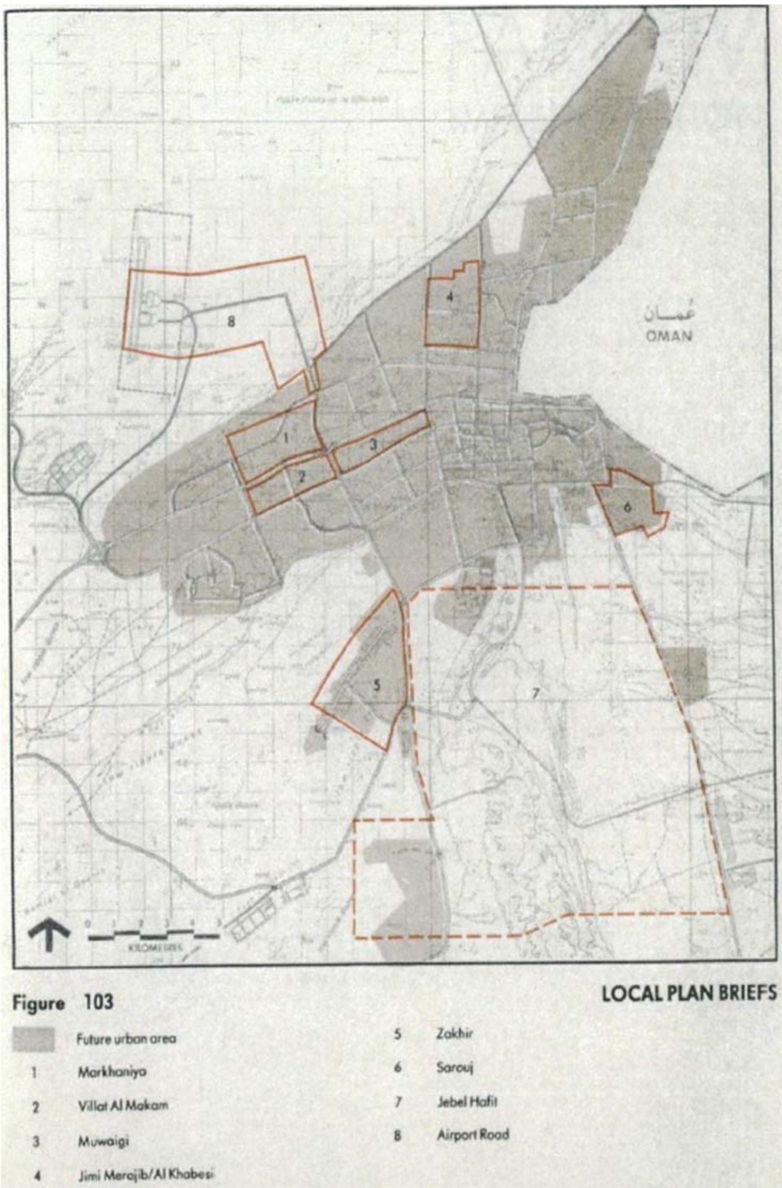


Figure 3.4. Urban development plan, additional areas. Source: Town Planning Department of Al Ain, 1986.

Education, community and cultural facilities

The locational criteria for schools were based on the following principles:

- The number of schools required would be calculated according to the catchment population.

- Kindergartens would be located off local access roads near the centre of the community served.
- Primary schools would have access from local distributary roads.
- Intermediate and secondary schools with separate areas for boys and girls would be reasonably situated to serve the target populations.

Land use also involved a projection of community uses for health, social, religious, and other community facilities. Extensions of Al Ain's three hospitals were expected to provide a combined capacity of 1,040 beds in accordance with the standard of 300 people per available bed in 2000. Additionally, the region had five government clinics with plans for the construction of three more clinics in Makam, Markhaniya, and Jahili, as well as the replacement of the clinics in Zakhir, Hili, and the town centre. The region also had projections for the construction of a new school clinic. The Ministry of Health would be responsible for the management of the clinics. The region expected to reach the capacity of one clinic per 25,000 people.

Social facilities included care centres for children and women, specialized centres for the handicapped, and youth centres, among others. At the time of the report, the Abu Dhabi Women's Society operated most of the existing centres for women and children, which dealt with educational programs, sewing, crafts, and cooking. Al Ain did not have a centre for the handicapped, instead relying on the centres in Abu Dhabi and Dubai. Consequently, the plan projected an increased need for the facilities in the future. Further, the plan indicated the need to construct youth centres for educational, recreational, and sports activities.

Religious-related facilities include mosques, cemeteries, and Eid prayer grounds (special prayers traditionally offered in an open space, *musalla* in Arabic, to commemorate two Islamic festivals). The region expected three mosques to serve a population of 4,000 people; each local mosque would serve from 100 to 250 households. Small Friday mosques would be provided in each neighbourhood. The town also required a central mosque located along the Abu Dhabi Road on the site reserved for the Islamic and Arabic Centre. The Eid prayer grounds would serve a population of 40,000 and would be located on the periphery of the developed areas easily accessible by feeder roads.

The plan also detailed land-use for open space and leisure activities. Al Ain had an equivalent of 1.9 hectares per 1,000 community members that included a children's city, zoo, and other recreational facilities. The region would require approximately 14 hectares to serve the expected population of 275,000 inhabitants in 2000. Different recreational, entertainment, and other amenities would also be expanded. The facilities included entertainment areas and overnight accommodation.

Finally, cultural facilities marked for preservation and improvement included archaeological sites, *aflaj* (irrigation), and forts and old villages. The conservation policy mandated the protection of archaeological sites from further exploitation or excavation. Other centres included the library, Al Ain Museum, Heritage Centre, Cultural Centre, and Islamic and Arabic Centre.

Industry

The public and private industrial sectors were considered in this master plan, as determined by natural resource availability, a continuing substantial construction programme related to population growth, an expansion of the regional and UAE markets, and abundant capital for investment.

Mineral exploitation was still in the hands of the Ministry of Petroleum and Mineral Resources. Even though some minerals such as gravel, sand, and limestone were exploited by existing building materials industries, exploitation of other minerals was limited. Gypsum was one such example, attracting attention as industries strategized exploitation of the 61.8 million available tonnes but falling prey to the high transport cost to the cement plants in Dubai and the Northern Emirates. Another mineral was clay, found above gypsum in the extraction process, which is used as a fill material for agriculture and in producing light-weight processed aggregates. Another example was celestine, a rare, high-value mineral used in sensitive industries such as electro-ceramics manufacturing; the identified reserves were approximately 76,000 tonnes, and extraction processes were considered efficient. The specific market for this mineral was Japanese companies that had an interest in purchase and extraction for use in their industries. On the other hand, the size of the construction sector was principally within the control of the government as the major source of development funding. There was a need to create awareness about the importance of increasing the lifespan of buildings and to improve standards of insulation, enhancing overall quality in the construction industry.

In general, the objectives of industrial development strategies were economic diversification, exploitation of naturally occurring minerals, creation of job opportunity in businesses, increasing private sector firms and their roles, minimizing the non-citizen work force, and commercial viability. A good working environment was important in determining the opportunities and prospects available for a business. Some of the essential factors that create a good working atmosphere included: availability of natural resources, adequate capital for investments, availability of ready markets, and high efficiency in executing contracts. The master plan mentioned the obstacles to industrial development in general and in the region in particular: the small market, the lack of a tradition of industrial entrepreneurship in Al Ain, the competition from imports, and the high transport costs to the main centres of population and ports on the coast.

3.4. Al Ain General Master Plan (2003 – 2015)

The executive summary was based on the report “Al Ain Urban and Regional Structure Plan to 2015” (Al Ain Town Planning Department, 2001). The plan comprised three interrelated forms of plans:

- Structure Plan: the plan documents both urban and rural development.
- Local Area Plans: contextualized within the Structure Plan for parts of the rural and urban areas.
- Action Area Plans: formulated in the context of the Local Plan and short-term implementation.

The Executive Summary focused on the development of urban areas. Therefore, it included part of the Structure and Local Area Plans.

3.4.1. Planning process

Purpose of the Structure Plan and Content of Planning Maps

The Structure Plan focused on urban structure maps and the strategy and policy reports (Annex 3.2). The maps and policy statements served three purposes:

- Coordination of planning and programming of the region's development and conservation activities.
- Provision of a guide to the private sector about the development opportunities in the region until 2015.
- Presentation of a planning context to produce local area plans for the implementation of the Structure Plan.

The maps included in the plan illustrated the following:

- New areas for housing.
- Key new office, commercial, health, retail, and leisure centres.
- Industrial areas.
- Areas for conservation of natural resources.
- Alignment of the current and future transport network.
- Location of new and improved utilities.

As a supplement of the Structure Plan Map, the Policy Report covered the strategies about new housing units and renovations, main centres with office space and retail stores, tourism and leisure, community facilities, transport, open space, environment and conservation, and industrial areas.

The planning process required a continuous monitoring and comparison of projections of future demands in retailing, housing, and commercial office space with the current demand, using GIS development records, updated demographic data, and developed project surveys. Yearly reviewed highlighted the requisite modifications to plans based on the monitoring process. Finally, amendments were conducted if required, probably once in five years.

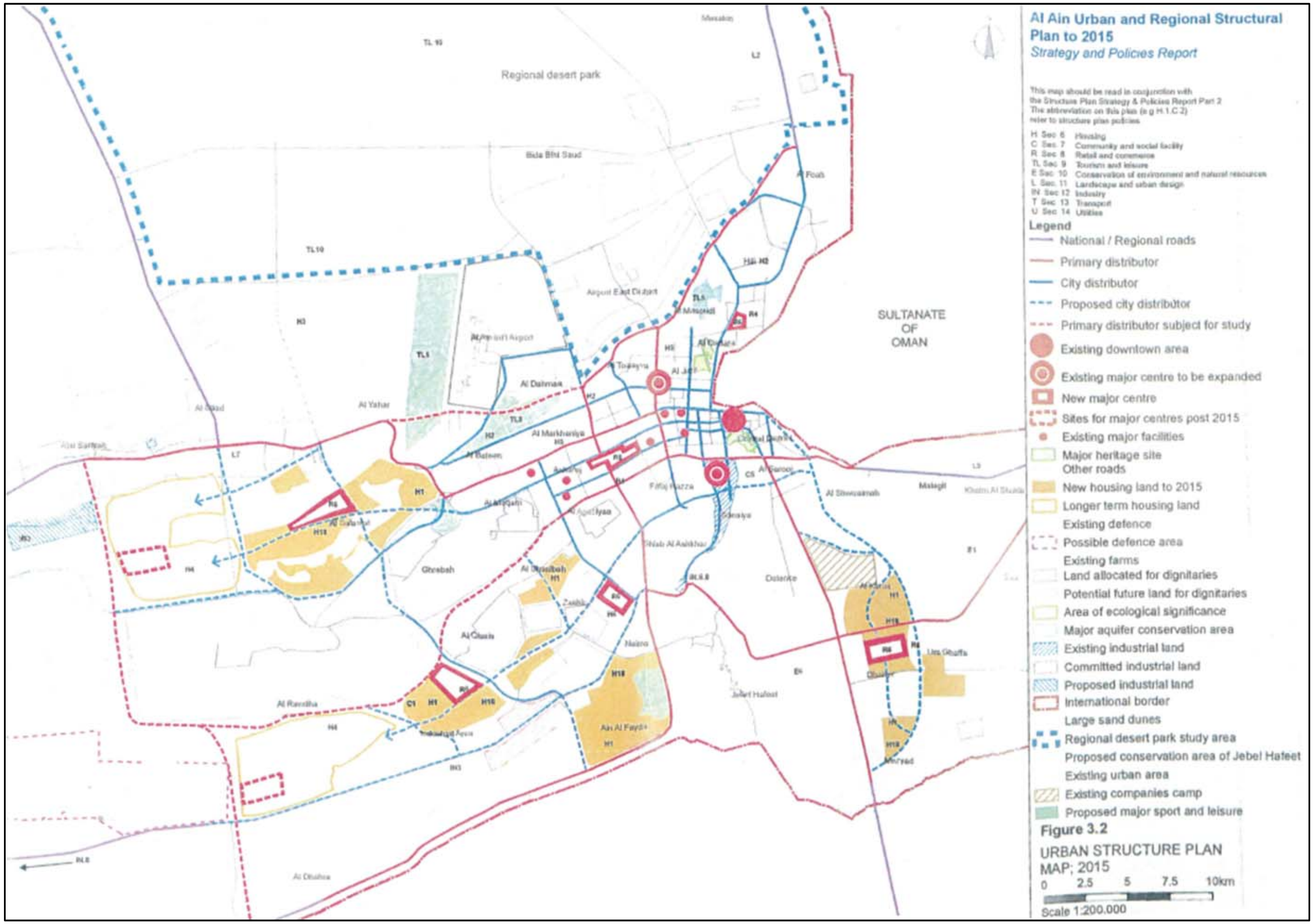


Figure 3.5. Regional structural plan Al Ain 2003-2015. Source: Al Ain Town Planning Department, 2001.

Local Area Plans

The report encompassed six Local Area Plans for specific areas marked for development, redevelopment, and conservation activities. The Local Area Plans helped in the completion of both rural and urban settlements, but on a short and medium term basis. The plans accomplished the following:

- Offer a basis for planning and implementation of the Structure Plan.
- Establish detailed boundaries and related land-use policies, as well as highlight the development concepts of chosen areas.
- Highlight the principles for the provision of roads in chosen areas.
- Define the Action Areas marked for short-term development.

3.4.2. Content of the strategy

Planning context

The Urban and Regional Structure Plan was based on the Housing and Establishment Survey conducted by the Ministry of Planning in 2001 and other Sector Studies. Collectively, the two studies covered the following: urban and regional economy, housing, population and workforce, retail and commerce, social and community facilities, tourism and leisure, industry, urban design and landscape, and transport and facilities.

Urban and Regional Economy

The future economic base presented was based largely on the growth in office-based business, tourism and leisure, higher education, financial services, and quality healthcare. However, it did not exclude manufacturing industry and other services. The report observed the challenges in forecasting the number of non-citizens. Therefore, the plan relied on targets rather than forecasts for planning purposes.

The growth of the agricultural sector was expected to decline because the government would not be allocating land for agricultural purposes in Al Ain in the future and subsidies to existing farms will be substantially reduced. Employment in the sector would fall by 2.5%. However, this would be associated with an increase in total jobs for citizens, savings in water resources, and reduction in the population use of ground water. Therefore, the plan set a target for 8,000 employees in the sector. An increase in employment for citizens was expected in four service sectors: office-based services, tourism and leisure, higher education, and health care.

Population and household projections: land availability and transport context

The total citizen population was expected to reach 212,930, a 60% increase since 2001. The total non-citizen population was targeted to reach 466,810, a 72% increase. Forecasts showed an approximate 5.5% annual growth in the total number of citizens' households, reaching 27,490 in 2015. Non-citizen households were expected to grow by 66%, from 50,700 to 84,120. The forecasts for urban development envision a total urban population of 642,946 (a citizen population of 182,949 and non-citizen population of 459,997). The urban population includes settlements in Al Khrair, Um Ghaffa, Dhaher, Mezyad, Salamat, Al Saad, and Yahar (figure 3.5).

The vacant land within the urban boundary was committed to housing and other uses or had other potential constraints for development. Therefore, the availability of land for further urban development was limited, and land would be allocated outside the urban boundary.

The city had high standards in its urban road network, with dual three-lane roads. Additionally, the city had a relatively low volume of traffic with high standards of services. However, the plan projected an increase in traffic, which would lead to congestion at peak hours. Consequently, the roads would require upgrading to meet the demand by 2015.

3.4.3. Summary of strategy and policy

The Urban Structure Plan aimed at achieving six goals:

- Social and economic prosperity.
- Natural resources conservation.
- Efficient and convenient transport systems.

- Enhancement and preservation of the environment.
- Conservation of the historic and landscape value.
- Effective engineering utility systems.

The combination of these six aims forms the "primary" goal used in locating and forecasting future needs for employment, housing, related road traffic, and community facilities and would help in the following tasks:

- Minimizing traffic congestion, environmental congestion, and the expense of elevated grade-segregated junctions and new road networks.
- Developing existing and new communities.
- Enhancing and conserving natural resources for sustainability purposes.
- Increasing the attraction of Al Ain for inward investments in tourism and other sectors.

Social and economic prosperity

The future of Al Ain's economic prosperity was focused on higher education, tourism, quality health care, and office-based financial and business services. Urban development would focus also on environment-friendly manufacturing industries. The growth was related to the major centres for regional and international investment located outside the Al Ain downtown area, with additional centres poised for development. The centres in the city would provide additional employment opportunities.

Urban strategy: major centres and housing provision

The social and economic prosperity of Al Ain depended on the attraction of inward investments in the sectors mentioned earlier. The attraction of investment depended on the proposed creation of eight major centres outside the Al Ain downtown area served by an effective road network. Investments in the tourism sector would be spread throughout the urban area, with many focusing on the new regional Desert Park proposed for the northern urban boundary.

Eastern sub-region

The Eastern sub-region was marked for major development based on a reduction in the size of citizen housing plots. The population of the region would grow from 47,500 to 90,000 by 2015, which would pave the way for urban development. The plan envisioned a Major Centre in the region, incorporating approximately 25,000m^2 of commercial and 65,000m^2 of retail space and a 350-bed public hospital, as well as public and private leisure facilities. The plan suggested no further development in the region to avoid traffic congestion, pollution, and increased water consumption.

Western sub-region

The Western sub-region would benefit from medium-term development through the incorporation of the rural settlements into an integrated urban area. The growth would accommodate 65,000 citizens and 60,000 non-citizens. The plan envisioned the use of new housing as 85% and 15% for citizens and non-citizens, respectively. The regional development would depend on two factors:

- New housing for citizens would be provided close to the region with the largest source of demand for housing over the plan period.
- Major centres with public and commercial services and employment opportunities would be relatively accessible to the majority of the population in the region and Southern sub-region.

New Major Centres would be constructed on Sheikh Khalifa bin Zayed Road (in Al Muwaiji) and on the road's extension in Al Salamat because of the convenient road transport linking the Major Centres to the city centre. High population growth was envisioned in the existing urban area. This called for the renewal of the obsolete urban housing and provided opportunities for residential development, especially in the Downtown Area.

3.4.4. Enhancement and preservation of the environment

Urban strategy

The urban strategy for environmental preservation and enhancement focused on high dune fields and other areas of ecological importance. Other than the scenic and ecological areas, the region aimed at cutting emissions from vehicles in accordance with UAE standards. This would involve random checks of heavy vehicles entering Al Ain at Khatm Al Shika border point.

The authorities would view the applications for the development of farms in the urban areas from owners favourably. Planning permission would depend on the location, the maximum area for development, and normal constraints to access. The authorities would also conserve and prevent the planting of any landscape value in forests or disused farms in the western corridor south of Abu Dhabi Road.

Urban network efficiency

Traffic in some parts of the urban region, especially the Downtown Area, had started showing signs of congestion because of increased retailing and employment in the region. The Western Sub-region would use the east-west roads. Further, an efficient public transport system would be established to connect the expansion areas. Trucks delivering supplies in the urban areas will only access the roads at restricted times based on permits and GVW (Gross Vehicle Weight). Congestion could occur towards the end of the plan period, which would lead to traffic demand management measures including the following:

1. Limiting and pricing commuter parking in the major centres and downtown area.
2. Establishing some form of toll-road pricing.

Development of the urban road network

The plan set priorities for the development of several urban roads (Figure 3.6).

1. Improvement of the extant roads in the Downtown area:

   a. Phase 1: Removal of flyover 110 (T.13a) and northward extension of the Salahudeen Al Ayubi Road.
   b. Phase 2: Upgrading R/As 103 to 110, 112, 115, and 120 to Area Traffic Control Centre (T.13b).
2. Northern Ring Road and the westward extension:
   a. Phase 1: Separations of grades at 304 to 306.
   b. Upgrading the link between 209 and 308 to 3 lanes.
   c. Construction of Northern link.
3. Upgrade of Hazaa bin Sultan Street.
4. Construction of new three-lane dual carriages with grade separations.

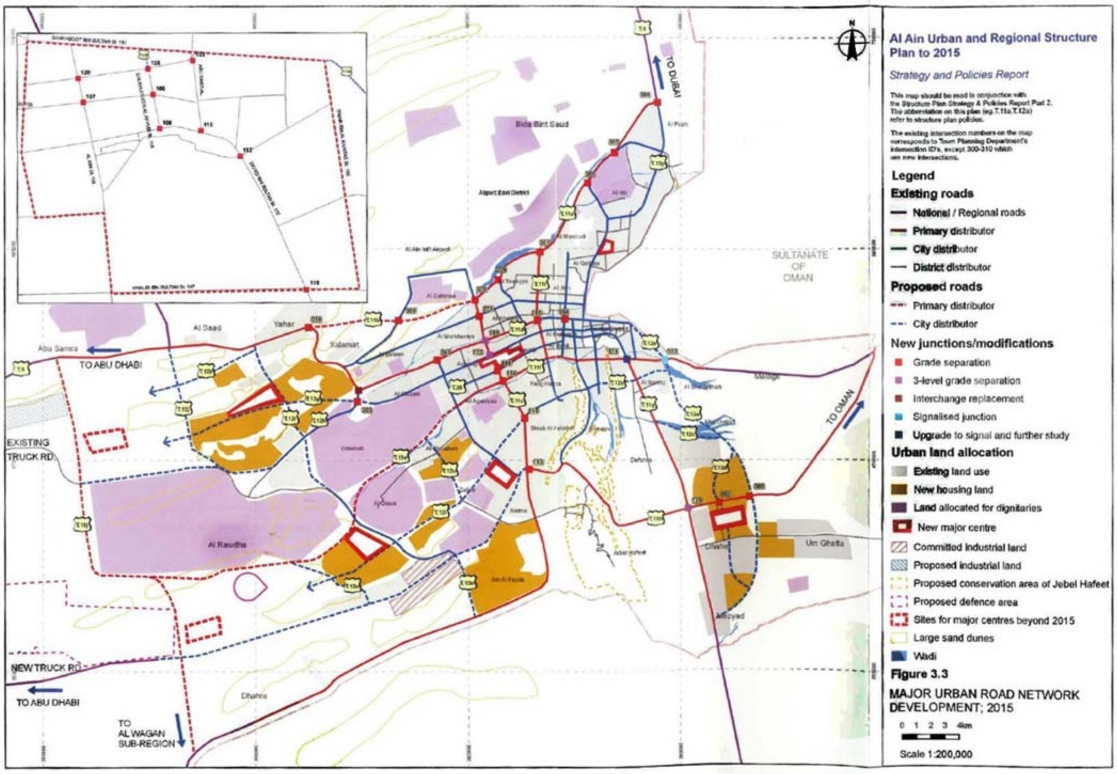


Figure 3.6. Urban and regional structure plan to 2015. Source: Al Ain Town Planning Department, 2001.

3.5. Conclusions

This chapter presented the main objectives of the 1986-2000 Master Plan for the maintenance of the traditional role of the city as a centre for educational, cultural and recreational activities of national importance; as the main agricultural producer of the

Emirate; and as an environmentally attractive garden city (Town Planning Department of Al Ain, 1986). Additionally, economic diversification was included to provide stable conditions for local businesses, agricultural self-sufficiency in those products for which it was suited, and the maintenance of a high level provision of services. Residential land comprised community facilities and other uses associated with housing such as health care centres, mosques, schools, or neighbourhood centres (Hadjri, 2006).

New residential areas were proposed with the objective to infill vacant lots within the extant built environment and to expand in several new directions: north of Qattara and Hili up to Al Foha; from the edge of the current urban area along the new Abu Dhabi road to the north of *wadi* Tawia and toward the west clover-leaf intersection; South from Zakhir to Al Faydah; extension of Sarooj; and finally, adjacent to the Mezyad road to the industrial area. Housing policies addressed the existing stock (old government housing and spontaneous housing areas), and the new citizen housing both for government houses and private dwellings. According to Selim and Gamal (2007), the government defined the need for citizen housing: in 2000, private households needed at a minimum a completed house on a 45 m * 45 m plot free of cost or a plot of 60 m * 60 m to construct a house with further financial assistance from the government.

In the case of agricultural land, and despite unfavourable climate conditions and water and soil constraints, proposals were issued to increase its area with the objective to settle the local population and promote commercial and traditional farms concentrating on date palms and fodder rather than vegetable fields. Finally, a regional road hierarchy at national, regional and local level was proposed; the most important national roads were the Dubai Road (E66) and the Abu Dhabi Road (E22).

Derived from the Master Plan of 2003-2015, the Urban Structure Plan aimed at achieving six goals: social and economic prosperity, natural resources conservation, efficient and convenient transport systems, enhancement and preservation of the environment, conservation of the historic and landscape value, and effective engineering utility systems (Al Ain Municipality Town Planning, 2007). The combination of these six aims constitutes the "primary" goal used in locating and forecasting future needs for employment, housing, related road traffic, and community facilities. It would help in minimizing traffic congestion and environmental congestion by building elevated grade-segregated junctions and new road networks, reinforce existing and new communities, enhance and conserve natural resources for sustainability purposes, and increase the attraction of Al Ain for investments in tourism and other sectors. In the case of agricultural land, the vision was to limit the allocation of farms and the reduction of subsidies for saving water resources and reducing groundwater pollution.

Finally, according to the summarized master plans, Al Ain seemed a quite well-planned city from the mid-1980s to 2014. Nonetheless, its urban growth has not been exempt from criticism. For instance, Ben Hamouche (1999) argued that the 1986 Master Plan was governed by the daily practices of the Town Planning Department, turning it into a servant plan without legal power and major effect on the urban development traditionally characterized by empty spaces separating the different settlements and making urban development proceed in a leap-frog fashion. Urban planning was thus used as a tool for promoting urban growth rather than for controlling and limiting expansion. To contrast this argument, the next chapter will analyse LUCC changes and landscapes dynamics from 1984 to 2014 in Al Ain city. In each period, the integration of the existing fragmented urban areas and the continuity and cohesion of the town's urban structure at different stages of future growth will be examined, together with the densities of new housing and the tendency towards scattered areas of isolated development.

3.6. Chapter bibliography

Al Ain Town Planning Department (2001) *Al Ain Urban and Regional Structure Plan to 2015*. Executive Summary. Strategy and Policies Report. Al Ain.

Association of New Jersey Environmental Commissions (1997) *The Master Plan: smart growth, the master plan and environmental protection*. Available at: http://www.anjec.org/pdfs/SG_MasterPlan.pdf

Ben Hamouche, M. (1999) Opting for growth: a strategy for Al Ain. *Habitat International*, 23, 303-317.

Hadjri, K. (2006) An analysis of the spatial structure of a new desert town: Al Ain, United Arab Emirates. *Urban Design International*, 11, 3-19.

Selim, G.M., Gamal, M. (2007) Neighborhoods and residential communities. The case of Al Ain UAE. *Housing Symposium*, 3, 343-361.

Town Planning Department of Al Ain (1986) *Master Plan for the region of Al Ain. Final Report, Volume 1. Regional strategy and urban development plan*. Town Planning Department, Al Ain, UAE.

Town Planning Department (1985) *The Master Plan and Traffic and Transportation Study for Al Ain and its Region, volume 1*, Al Ain. UAE.

4.1. Introduction

Given the need to improve the knowledge about urban trajectories and forms in Al Ain city, this chapter has two objectives: to investigate LULC changes from 1984 to 2014 and to understand the consequences of LULC changes from a landscape point of view. The study period was divided into three segments: from 1984 to 1990, from 1990 to 2000 and from 2000 to 2014. Our methodology to map and quantify LULC changes differed from previous studies, combining remote sensing (RS) and GIS techniques to obtain historical data from the 2014 back to the 1980s and establish the LULC at the beginning of each segment. The spatial scales of study selected to understand the landscape consequences were the district (a group of communities or neighbourhoods) and the sector (a group of districts). The purpose of the landscape analysis was to distinguish which spatial characteristics showed the LULC changes according to the following configurations: aggregated pattern, linear pattern, leapfrogging or nodal pattern (Aguilera et al, 2011). The changes were mainly urban, including residential, services and industrial, and agricultural land.

4.2. Integration of GIS and RS for land-use analysis

A Geographical Information System (GIS) is a technology dedicated to capturing, storing, manipulating, analysing and presenting all types of geographical or spatial data (Burrough, 1998). The abbreviation is also used to refer to the broader academic disciplines of Geographical Information Science (GIScience). GIS technology has many applications in the fields of engineering, management, planning, transport and telecommunications (Longley et al., 2005; Yagoub, 2006; Cellone et al., 2016; Machado et al., 2017). In this regard, GIS and location intelligence applications are the foundation of many location-enabled services. Such services rely on both visualization and analysis to correlate unrelated data, using location as the primary index variable. Several spatial datasets (e.g. lines, polygons and points), either in raster or in vector, can be combined to develop a new output dataset.

On the other hand, remote sensing (RS) is the process of acquiring information about a phenomenon or object without having physical contact with it (Campbell, 1996). The technique involves the active or passive use of satellite sensor technologies to classify objects on the Earth, relying on the propagation of electromagnetic radiation signals. Active RS involves the transmission of signals from satellites or aircrafts whereas passive RS only records data (Jensen, 1996). The RS data, including spatial resolution, global coverage, and revisit capabilities, may be effectively used as a tool for both monitoring and evaluating LULC changes at specific timepoints (Serra et al., 2003; Rogan and DongMei, 2004; Abd El-Kawy et al., 2011; Leh et al., 2013). Further processing based on different techniques is possible to enhance the quality of generated images.

The quantity, as well as the quality, of satellite images depends on their resolution. Four different types of resolution can characterize any remote sensor: spatial, spectral, radiometric, and temporal resolution. Spatial resolution involves the direct representation of the Earth's surface coverage for every pixel shown in an image. Spatial resolution relies on the sensor's instantaneous area of view. This refers to the area of the earth's surface through which the sensor can receive signals of electromagnetic radiation, as determined by the angle and height of the imaging platform. For instance, if the satellite generates imagery with a spatial resolution of 30m (as is the case for Landsat), the corresponding coverage on the ground for every pixel is 30m by 30m (900m^2).

Spectral resolution denotes the ability of sensors to detect the component features of wavelength intervals, or bands, in the electromagnetic spectrum. It is based on the interval size of a given wavelength and the intervals being scanned. Multispectral sensors resolve two or more bands falling within a spectrum (e.g., green, near infrared, infrared). Radiometric resolution refers to the sensitivity to changes in brightness, and represents the magnitude of grayscale levels imaged by the sensor. Traditionally, it has 8-bit radiometric values ranging from 0-255. Finally, temporal resolution refers to the time between image collection periods. It is based on the satellite-calculated time required to repeat its generally elliptical orbit around the Earth.

Technical limitations often result in a trade-off in the measurement of the four types of resolution. Improving one type of resolution may reduce the precision of another. For instance, an increase in spectral resolution could result in the decline of spatial resolution. Geostationary satellites (e.g. Meteosat) have low spatial resolution but deliver good temporal resolution, and sun-synchronous satellites (e.g. Landsat) produce medium/high spatial resolution but low temporal resolution.

Some authors have used RS images to detect the urban growth of cities because they offer a cost-effective and time-saving alternative compared to other conventional methods such as surveying (Patino & Duque, 2013). During the last 40 years, significant advances in sensor technologies have improved spatial, spectral and temporal resolution and coverage of satellite imagery. Nevertheless, the current very-high spatial resolution of optical sensors is not appropriate for many urban applications due to the high financial cost and the lack of a sufficient archive of imagery. For this reason, some researchers study urban growth over short time periods, as in the case of Moeller and Blaschke (2006) who tested the feasibility of using Quickbird imagery to monitor urban changes in the Phoenix Metropolitan Area from 2003 to 2005. In order to avoid such problems, other authors have used a combination of aerial photographs and RS images to detect urban growth. A clear example is provided by Yagoub (2004), who monitored the urban expansion of Al Ain city between 1976 and 2000. However, this approach can produce problems in complex legends due to the use of different sources and techniques, such as combining photointerpretation and automatic classifications.

The best option to detect urban growth with a long temporal perspective is the use of Landsat series. For instance, Issa and Shuwaihi (2012) used Landsat data (MSS, TM and ETM+) to characterize Al Ain urban development from 1972 to 2000 using automatic classifications. Nevertheless, as the authors acknowledge, accurate mapping of urban areas is not an easy task at 30-meter pixel resolution because the heterogeneous nature of urban environment produces mixed pixels, the main source of mapping errors. For this reason, they used a semi-automatic method, intervening manually by adjusting the ambiguous pixels according to their knowledge of the study area.

In this PhD thesis, change detection for Al Ain city from 1984 to 2014 was conducted using Landsat-5, Landsat-7 and Landsat-8 images, selected for their spatial, spectral, radiometric and temporal resolution. Images from different dates, free of clouds and of haze, were processed and analysed to aid in extracting detailed LULC information:

- Landsat 5 image for May 15, 1984
- Landsat 5 image for August 25, 1990
- Landsat 7 image for November 27, 2000
- Landsat 8 image for November 26, 2014

On the other hand, the combination of GIS and RS techniques can assist in change detection (Stuttard, 1992). In this case, GIS provided the right system to capture necessary data from images, while RS offered a mechanism for obtaining the images from satellites in space. The two techniques needed to be coordinated for effective results because techniques of analysis require detailed comparisons.

4.3. Vector map of Al Ain: LULC change detection analysis

The method used in this research to analyse LULC dynamics is a combination of GIS and RS data, trying to avoid the issues mentioned above. The data from "Al Ain Town Planning", at 1:1000 scale for 2014, is a base map obtained from *in situ* surveys and aerial photographs. This GIS vector cover not only shows physical features of the natural environment, but also provides a clear analysis of most of the human features of interest, like buildings, roads and houses (Figure 4.1). Additionally, current LULC categories are visible, such as industrialization, businesses, and residential places. This offers a higher level of detail than RS techniques alone.

The vector base map from 2014 was opened on the first satellite image from 1984 to retain only the oldest polygons using the "computer-aided photo interpretation of false-colour images" technique (European Environment Agency, 2016). Visual interpretation was clearly the best approach to avoid a large number of misclassifications (Shahraki et al., 2011). This method is considered the best way to capture information on urban LULC trends (Akbari et al., 2003) and makes possible the generalization and distinction between different LULC categories as well as the identification of relevant characteristics which are better distinguished by their visual form and pattern rather than by their spectral signal.

Figure 4.1. A fragment of 2014 base LULC map from Al Ain city. Source: Al Ain Town Planning Department.

Therefore, LULC characteristics (both physical and human features, including agricultural plots, houses, and industrial centres represented as polygons in the vector base map) were visually compared with the raster data, allowing the elimination of polygons/features not present in 1984 (Figure 4.2). When the 1984 raster data covered less than 50% of the 2014 vector data, the polygon was already removed; if equal or above 50%, it was maintained. Therefore, the remaining features reflect the land-uses from 1984 with a high reliability, avoiding the need to create new polygons or modify the original ones. This was repeated successively for the next target years (1990, 2000 and 2014). After that, a map was drawn to represent all the changes identified (Figure 4.3).

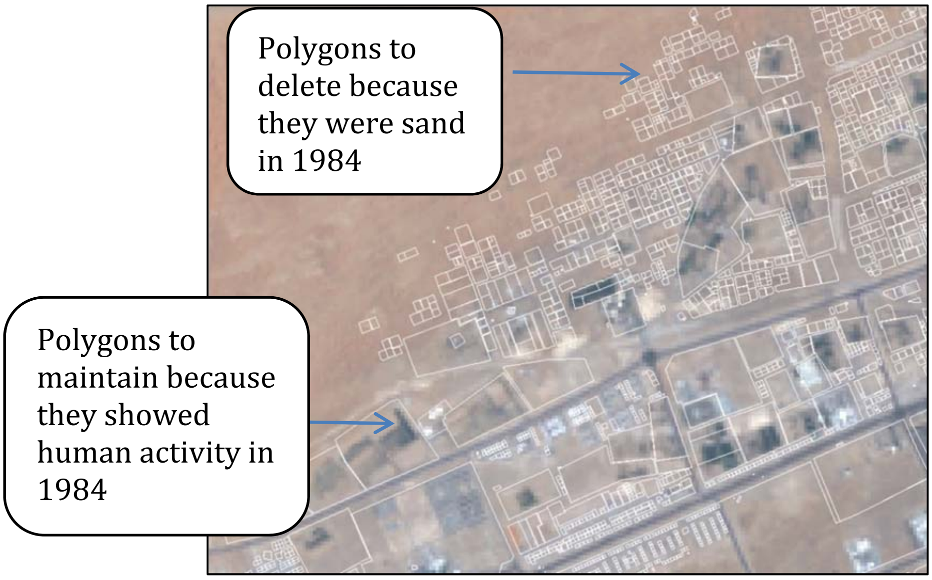


Figure 4.2. A visual overlay of 2014 base vector map (in white) and 1984 RS image; some polygons were maintained because they showed human activity and others deleted because they were sand. The final vector corresponded to the 1984 base map. Source: own elaboration from base map of Al Ain Town Planning and Landsat image.

4.4. LULC changes (1984-2014)

After grouping LULC into four categories –residential, services, industrial land, and agricultural and forest land– for analysis, agricultural land was the most extensive LULC from 1984 to 2014, followed by services, residential, and industrial land (Figure 4.3). The analysis also showed that the most important change between 1984 and 1990 was an increase in residential land, followed by services; between 1990 and 2000, the principal increase was in industrial land, followed by agricultural land. Finally, between 2000 and 2014 the changes were small, showing a clear reduction in the LULC expansion. In general terms, the main city expansion (Figure 4) follows the Abu Dhabi roads to the west (E-22 and E-30), the main road to the south (E-95) and the two chief roads to the north (E-66 and E-16).

As explained before, for a better understanding, an in-depth analysis by sectors and by districts (Figure 4.4) was applied to discriminate the land dynamics with more detail.

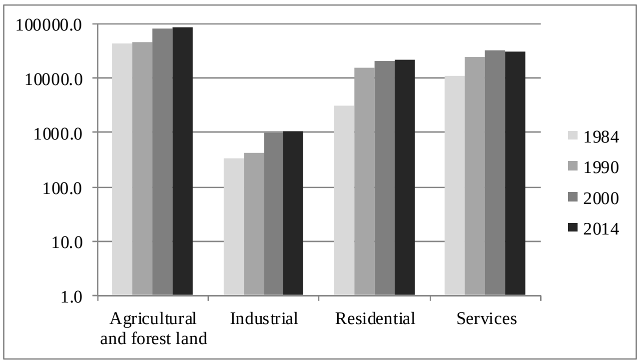


Figure 4.3. LULC changes 1984-2014, in hectares. Source: own elaboration from Al Ain Town Planning Base Map and Landsat data.

4.4.1. Urban growth by districts and by sectors

In the Eastern sector analysis, the districts of Defence, Malagit, Saa and Khatm Al Shikla showed no urban change (Figure 4.5a) whereas the biggest increases, corresponding to residential urban growth from 1990 to 2000, were in Jebel Hafeet, followed by Al Dhaher, Al Khrair, Um Ghaffa, and Mezyad (Table 4.1a). In the case of urban growth from services, the biggest increases were observed in Jebel Hafeet and in Al Daher in 1990-2000; in Um Ghaffa in 2000-2014 and in Mezyad and Al Khrair in 1984-1990.

In the Southern sector, the district of Abu Huraibah showed no urban change. In general, the urban growth of this sector was less intensive than in the Eastern sector. Al Wagan and Al Dhahra districts increased in residential LULC from 1990 to 2000, whereas the main increase in services was in Al Wagan and in Abu Krayyah from 2000 to 2014 (Figure 4.5b and Table 4.1.b).

In the Northern sector, all the districts were involved in urban growth, but less than 150 ha on average, and very few hectares in the case of Masakin and Al Ajban. All other districts showed a large increase in services and residential land from 1990 to 2000; the exception was Sweihan, where the increase was only in services (Figure 4.5c and Table 4.1.c).

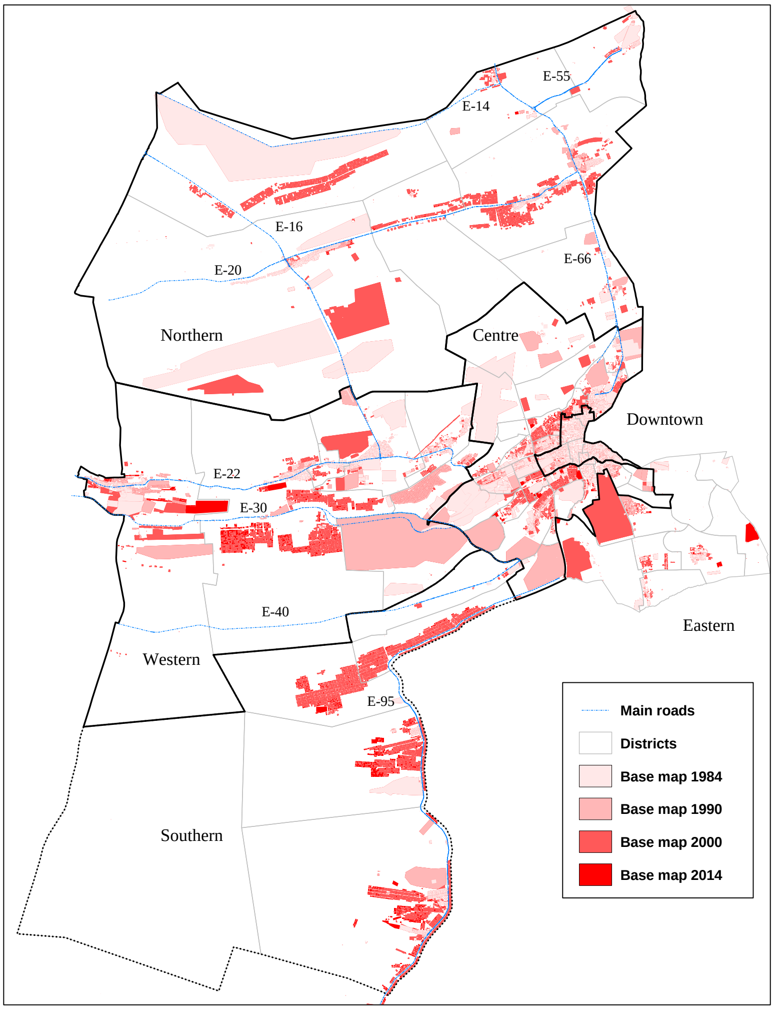


Figure 4.4. LULC changes by plots. The main road network is shown. Source: own elaboration from Al Ain Town Planning base map.

According to Figure 4.5d, the outer districts located around the Centre sector showed an urban growth practically equivalent to zero. These districts are Bida Bint Saud, Airport East, International Airport, Grebah, Al Qisais, Shiab Al Ashkhar, Al Aflaj and Al Shuwaimah. In general terms, the chief increase in the remaining districts was in services between 1984 and 1990 and in residential land between 1990 and 2000.

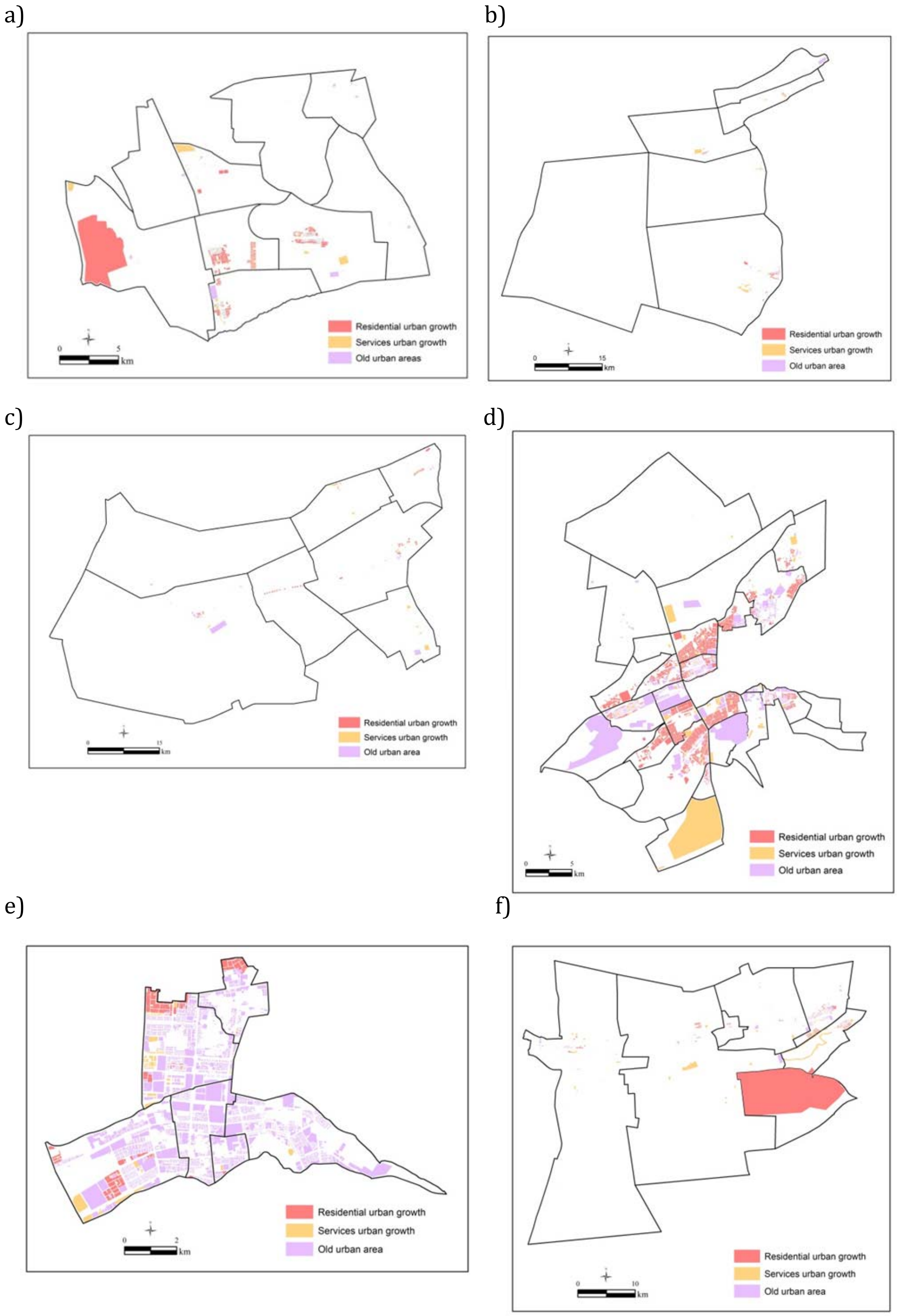


Figure 4.5. Urban growth (in hectares) of Eastern (a), Southern, (b), Northern (c), Centre (d), Downtown (e), and Western (f) sectors. Source: own elaboration from Al Ain Town Planning Base Map and Landsat data.

In the case of the inner districts of the Centre sector, the most important residential urban growth from 1984 to 1900 was in Al Khabisi and in Al Sarooj. Services increased the most in Al Maqam, Al Bateen and Ain Al Fayda, driven by the construction of a very big commercial mall (Table 4.1d). In the next decade, 1990-2000, a group of districts showed significant residential growth: Falaj Hazza, Al Markhaniya, Hili, Al Shuaibah, Al Masoudi, Zakhir, Al Agabiyaa and Al Towayya; the biggest increase in services was in Hili. In the period 2000-2014, four of these districts continued to show residential growth: Falaj Hazza (also in services), Al Shuaibah, Zakhir (also in services), Al Agabiyaa and Al Towayya.

In general, urban growth in the six Downtown districts was small, and occurred mostly between 1990 and 2000. For the period 1984-1990, one showed both residential and services growth (Al Jimi) and another (Al Muwaiji) had only residential growth (Figure 4.5e and Table 4.1e). From 1990 to 2000, four showed some residential growth: Al Jahili, Al Qattara, Al Jimi and Al Muwaiji. Finally, the main urban growth in the Western sector happened between 1984 and 1990, due to construction of the very large palace in Al Rawdha. In that period, only Remah showed an important increase in services. From 1990 to 2000, only Al Yahar showed some increase in residential land and services; from 2000 to 2014, the increase in urban growth was mainly in Remah and due to expansion of services (Figure 4.5f and Table 4.1.f).

a)

Eastern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Al Dhaher	20.0	0.9	20.4	4.5	111.1	22.5	193.2	30.4	0.4	3.6	90.7	18.0	82.1	7.9
Al Khrair	0.0	0.1	190.0	84.6	251.6	89.0	262.4	89.1	190.0	84.5	61.6	4.4	10.8	0.1
Jebel Hafeet	0.0	7.1	0.0	8.4	2082.1	72.4	2114.8	72.2	0.0	1.3	2082.0	64.0	32.7	-0.2
Mezyad	16.4	85.2	25.3	112.4	70.9	117.5	70.9	117.5	8.9	27.2	45.6	5.1	0.0	0.0
Um Ghaffa	55.8	10.2	59.4	19.9	116.3	25.5	143.4	72.4	3.6	9.6	56.9	5.7	27.0	46.9
Total	92.2	103.5	295.1	229.8	2632.0	326.9	2784.6	381.7	202.9	126.3	2336.9	97.1	152.7	54.8

b)

Southern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Abu Krayyah	0.0	0.1	0.0	0.0	7.9	11.1	25.8	150.7	0.0	0.0	7.9	11.1	18.0	139.6
Al Araad	0.0	3.6	3.0	5.2	3.6	6.4	11.1	26.4	3.0	1.6	0.6	1.2	7.5	20.0
Al Dhahra	0.0	0.0	0.0	0.6	21.3	24.2	21.3	26.1	0.0	0.6	21.3	23.6	0.0	1.9
Al Wagan	26.9	32.1	32.7	38.4	110.8	75.0	183.2	458.5	5.8	6.3	78.1	36.6	72.4	383.5
Industrial Town	0.0	143.1	0.0	143.1	0.0	143.1	0.0	143.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	26.9	178.9	35.7	187.3	143.6	259.8	241.5	804.8	8.8	8.5	107.9	72.5	97.9	545.0

c)

Northern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Al Ajban	0.0	0.7	0.0	0.5	6.3	4.1	6.3	4.1	0.0	-0.2	6.3	3.6	0.0	0.0
Al Faqa'a	0.4	3.5	5.4	14.0	36.2	27.4	38.6	32.7	5.0	10.5	30.8	13.4	2.4	5.4
Al Hayer	2.7	53.3	28.8	76.3	134.6	190.7	134.7	213.4	26.1	23.0	105.7	114.4	0.1	22.7
Al Shwaib	0.3	15.9	0.5	17.3	36.5	90.3	39.7	92.1	0.2	1.3	36.0	73.0	3.1	1.7
Masakin	0.0	1.4	0.0	3.5	0.4	51.9	0.4	56.5	0.0	2.1	0.4	48.4	0.0	4.6
Nahel Town	0.0	0.2	0.0	0.1	84.9	15.2	84.9	15.1	0.0	-0.1	84.9	15.1	0.0	-0.2
Sweihan	13.8	454.2	28.9	454.2	28.9	602.0	56.0	605.3	15.1	0.0	0.0	147.8	27.1	3.3
Total	17.2	529.2	63.5	565.9	327.8	981.7	360.6	1019.2	46.4	36.7	264.3	415.8	32.8	37.6

d)

Center sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Ain Al Fayda	1.0	1.1	1.0	2409.0	1.0	2409.0	1.0	2409.0	0.0	2407.9	0.0	0.0	0.0	0.0
Al Agabiyaa	0.0	67.6	0.0	67.7	244.0	86.3	357.9	96.9	0.0	0.0	244.0	18.6	113.9	10.6
Al Bateen	216.8	208.6	224.4	427.6	277.6	456.5	289.3	460.4	7.6	219.0	53.2	28.9	11.7	3.9
Al Dahmaa	0.0	0.0	0.0	0.0	0.0	6.0	0.0	6.0	0.0	0.0	0.0	6.0	0.0	0.0
Al Foah	10.8	47.0	11.2	52.0	11.2	146.0	69.9	147.0	0.4	5.0	0.0	94.0	58.7	1.0
Al Khabisi	172.3	10.7	265.6	14.8	290.9	25.6	320.5	32.2	93.3	4.0	25.4	10.8	29.6	6.6
Al Maqam	217.0	140.7	224.8	360.4	278.1	388.9	285.8	396.0	7.8	219.7	53.3	28.5	7.7	7.2
Al Markhaniya	80.0	11.4	82.7	11.4	259.9	8.5	265.6	8.5	2.7	0.0	177.1	-2.9	5.7	0.0
Al Masoudi	111.6	3.5	114.9	3.8	245.0	7.9	278.6	8.7	3.3	0.3	130.1	4.1	33.6	0.7
Al Mutawa'a	13.5	33.1	14.4	39.5	14.4	39.5	14.4	39.5	0.9	6.5	0.0	0.0	0.0	0.0
Al Sarooj	107.3	104.6	198.8	104.6	206.1	117.2	211.7	118.2	91.5	0.0	7.3	12.7	5.6	0.9
Al Shuaibah	3.7	0.1	7.9	0.2	187.9	3.9	319.0	7.0	4.2	0.1	180.0	3.6	131.1	3.2
Al Towayya	18.6	45.6	58.0	45.0	531.5	97.2	635.8	133.6	39.4	-0.6	473.5	52.2	104.3	36.4
Asharej	78.3	358.9	78.3	359.0	78.3	359.0	118.8	362.9	0.0	0.1	0.0	0.0	40.5	3.9
Falaj Hazza	0.7	138.0	1.2	141.7	325.1	176.9	389.0	231.5	0.5	3.7	323.9	35.2	63.9	54.6
Ghrebah	1136.3	232.6	1136.3	232.6	1136.3	232.6	1149.0	232.6	0.0	0.0	0.0	0.0	12.7	0.0
Hili	259.7	358.1	259.7	548.0	516.0	767.4	516.0	767.4	0.0	189.9	256.3	219.4	0.0	0.0
Neima	13.8	1.5	18.9	4.1	37.1	4.4	40.9	4.6	5.0	2.6	18.2	0.3	3.8	0.2
Sanaiya	11.4	152.8	11.1	152.8	11.1	152.8	11.1	217.9	-0.3	0.0	0.0	0.0	0.0	65.1
Shiab Al Ashkhar	0.1	903.6	0.0	929.3	0.1	960.0	0.1	960.0	-0.1	25.7	0.1	30.7	0.0	0.0
Zakhir	199.7	16.1	266.0	42.1	599.4	60.6	752.1	114.2	66.3	25.9	333.4	18.5	152.7	53.6
Total	2652.7	2835.6	2975.2	5945.5	5251.1	6506.1	6026.6	6754.0	322.4	3109.9	2276.0	560.7	775.4	247.9

e)

Downtown sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Al Jahli	111.6	3.5	114.9	3.8	245.0	7.9	278.6	8.7	3.3	0.3	130.1	4.1	33.6	0.7
Al Jimi	170.8	175.8	198.7	198.5	247.5	213.4	254.2	213.4	27.9	22.7	48.8	14.9	6.7	0.0
Al Mutaredh	105.1	150.1	106.0	150.1	106.0	147.6	106.0	150.1	0.9	0.0	0.0	-2.5	0.0	2.5
Al Muwaiji	312.4	86.8	364.7	86.6	391.3	107.0	403.3	108.1	52.3	-0.3	26.6	20.4	12.1	1.2
Al Qattara	64.4	35.4	64.6	35.4	98.9	35.4	101.1	35.6	0.2	0.0	34.3	0.0	2.1	0.2
Central District	182.7	389.4	182.7	394.0	181.0	388.9	182.7	394.0	0.0	4.6	-1.7	-5.2	1.7	5.2
Total	947.1	841.0	1031.6	868.4	1269.6	900.2	1325.9	909.9	84.6	27.4	238.0	31.8	56.3	9.8

f)

Western sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Abu Samra	0.5	8.9	11.2	9.0	9.9	9.7	10.3	9.7	10.7	0.2	-1.3	0.6	0.4	0.0
Al Khaznah	30.4	25.8	74.7	98.1	59.1	85.9	80.9	138.9	44.2	72.3	-15.6	-12.1	21.8	53.0
Al Rawdha	0.0	0.0	11681.7	0.4	11681.7	0.4	11681.7	1.2	11681.7	0.4	0.0	0.0	0.0	0.9
Al Saad	1.8	367.3	19.4	370.4	12.4	393.6	12.4	393.0	17.6	3.1	-6.9	23.2	0.0	-0.6
Al Salamat	35.0	66.6	100.5	543.7	148.7	481.8	148.7	481.8	65.5	477.1	48.2	-61.9	0.0	0.0
Al Yahar	152.4	67.4	161.0	87.9	259.3	151.7	263.7	165.1	8.6	20.5	98.2	63.7	4.5	13.5
Remah	13.4	36.4	13.0	250.6	15.7	258.8	58.9	525.5	-0.4	214.3	2.6	8.1	43.2	266.7
Total	233.5	572.3	12061.5	1360.2	12186.8	1381.8	12256.7	1715.3	11828.0	787.9	125.3	21.6	69.9	333.5

Table 4.1. Urban growth (in hectares) of Eastern (a), Southern (b), Northern (c), Centre (d), Downtown (e) and Western (f) sectors. R: Residential land; S: Services. Source: Own elaboration from Al Ain Town Planning Base Map and Landsat data.

4.4.2. Agricultural and industrial land growth by districts and by sectors

In the Eastern sector, the biggest agricultural growth was in Saa and in Jebel Hafeet from 2000 to 2014 and at a more reduced level in Um Ghaffa from 1990 to 2000 (Figure 4.6a and Table 4.2a). Industry growth in general was less expansive in surface area, occurring in Al Khrair and Malagit from 1984 to 1990 and in Al Khrair and Al Daher from 1990 to 2000. In the Southern sector, four districts increased in agricultural land from 1990 to 2000 (Al Dhahra, Abu Krayyah, Al Aradd and Al Wagan) whereas two had no increase (Abu Huraibah and Industrial Town) (Figure 4.6b and Table 4.2b). The industry increment was just located in the Industrial Town, mainly in 1990 to 2000. In the Northern sector, all the districts had huge increments of agricultural land in 1990 and 2000. In the case of Nahel Town district, the growth was mainly around the E-20 road (Figure 4.6c and Table 4.2c); industrial increase was practically nonexistent.

In the Centre subsector, only the districts around the Northern and the Southern areas of the inner city had a significant increase in agricultural land (Al Foah, Al Qisais, Al Shuwaimah, Bida Bint Saud, Hili and Zakhir) from 1984 to 1990. Between 1990 and 2000, there were small increments whereas from 2000 to 2014 the main increase was in Bida Bint Saud (Figure 4.6d and Table 4.2d). The only district with a substantial increment of industrial land was Sanaiya from 2000 to 2014. In the case of the Downtown subsector, any significant change in agricultural and industrial land was identified and, finally, in the Western subsector all the districts except Al Rawdha and Al Yahar experienced an increase of agricultural land, mainly from 1990 to 2000. The most noteworthy districts were Al Salamat, Remah and Al Khaznah, all of them around the E-22 and E-30 roads (Figure 4.6e and Table 4.2e). The districts with the greatest industrial increase from 1990 to 2000 were Al Saad and Remah.

Figure 4.6. Agricultural and industrial land growth (in hectares) of Eastern (a), Southern, (b), Northern (c), Centre (d), and Western (e) sectors. Source: own elaboration from Al Ain Town Planning base map and Landsat data.

a)

Eastern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	A	I	A	I	A	I	A	I	A	I	A	I	A	I
Al Daher	52.5	0.0	52.5	0.0	55.9	9.2	55.9	9.2	0.0	0.0	3.4	9.2	0.0	0.0
Al Khrair	0.0	0.0	3.1	11.6	3.1	21.7	3.1	21.7	3.1	11.6	0.0	10.1	0.0	0.0
Jebel Hafeet	0.0	0.0	0.0	0.0	164.9	0.1	165.0	2.5	0.0	0.0	164.9	0.0	0.1	2.4
Malagit	265.4	0.0	265.4	14.0	265.4	14.0	265.4	14.0	0.0	14.0	0.0	0.0	0.0	0.0
Mezyad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Saa	0.0	0.0	0.0	0.0	0.0	0.0	366.2	0.0	0.0	0.0	0.0	0.0	366.2	0.0
Um Ghaffa	195.6	0.0	196.4	0.0	213.8	0.0	213.8	0.0	0.8	0.0	17.4	0.0	0.0	0.0
Total	513.5	0.0	517.4	25.6	703.1	45.0	1069.3	47.4	3.9	25.6	185.6	19.4	366.3	2.4

b)

Southern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	A	I	A	I	A	I	A	I	A	I	A	I	A	I
Abu Krayyah	103.8	0.0	103.8	0.0	2311.9	0.0	2700.2	0.0	0.0	0.0	2208.1	0.0	388.4	0.0
Al Araad	1459.5	0.0	1481.6	0.0	3518.7	0.0	4415.0	1.1	22.1	0.0	2037.1	0.0	896.3	1.1
Al Dhahra	0.0	0.0	22.2	0.0	2695.5	0.0	2863.1	0.0	22.2	0.0	2673.3	0.0	167.6	0.0
Al Wagan	664.6	0.0	2224.0	0.0	4556.1	0.0	5469.6	2.2	1559.4	0.0	2332.1	0.0	913.5	2.2
Industrial Town	0.0	44.3	0.0	44.3	0.0	108.5	0.0	124.6	0.0	0.0	0.0	64.2	0.0	16.1
Total	2227.9	44.3	3831.5	44.3	13082.1	108.5	15447.9	127.9	1603.7	0.0	9250.6	64.2	2365.8	19.4

c)

Northern sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	A	I	A	I	A	I	A	I	A	I	A	I	A	I
Al Ajban	14711.3	0.0	14711.3	0.0	17617.9	0.0	17617.9	0.0	0.0	0.0	2906.5	0.0	0.0	0.0
Al Faqa'a	117.1	0.0	288.5	1.5	549.9	1.5	566.6	1.5	171.3	1.5	261.4	0.0	16.7	0.0
Al Hayer	762.4	1.5	1307.3	1.6	4320.3	1.1	4415.0	1.1	544.9	0.1	3013.0	-0.5	94.7	0.0
Al Shwaib	978.0	0.0	992.4	0.0	1150.4	0.0	1150.4	0.0	14.4	0.0	158.0	0.0	0.0	0.0
Masakin	496.5	0.0	1045.5	0.0	1283.6	0.0	1283.0	0.0	549.0	0.0	238.1	0.0	-0.6	0.0
Nahel Town	10.7	0.0	10.7	0.0	636.0	0.0	676.4	0.0	0.0	0.0	625.3	0.0	40.4	0.0
Sweihan	3649.1	0.0	3682.1	0.0	9834.2	0.0	9860.5	0.0	33.0	0.0	6152.0	0.0	26.4	0.0
Total	20725.1	1.5	22037.7	3.1	35392.2	2.6	35569.8	2.6	1312.6	1.6	13354.5	-0.5	177.6	0.0

d)

Center sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	A	I	A	I	A	I	A	I	A	I	A	I	A	I
Ain Al Fayda	0.0	59.4	0.0	59.4	0.0	59.4	0.0	59.4	0.0	0.0	0.0	0.0	0.0	0.0
Airport East	131.8	0.0	131.8	0.0	293.5	0.0	293.5	0.0	0.0	0.0	161.7	0.0	0.0	0.0
Al Agabiyaa	223.4	0.0	223.4	0.0	223.4	1.4	223.4	1.9	0.0	0.0	0.0	1.4	0.0	0.4
Al Bateen	482.7	0.0	482.7	0.0	513.9	0.0	513.9	0.0	0.0	0.0	31.2	0.0	0.0	0.0
Al Dahmaa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Al Foah	618.4	0.0	1374.5	0.0	1374.5	0.0	1374.5	0.0	756.1	0.0	0.0	0.0	0.0	0.0
Al Khabisi	61.9	0.8	66.3	0.8	66.3	0.8	66.3	0.8	4.3	0.0	0.0	0.0	0.0	0.0
Al Maqam	482.8	0.0	404.6	0.0	513.9	0.0	513.9	0.0	-78.2	0.0	109.4	0.0	0.0	0.0
Al Markhaniya	269.0	0.0	244.9	0.0	269.0	0.0	269.0	0.0	-24.0	0.0	24.0	0.0	0.0	0.0
Al Masoudi	21.7	0.0	21.5	0.0	190.0	0.0	193.5	0.0	-0.2	0.0	168.5	0.0	3.4	0.0
Al Mutawa'a	2.4	0.0	2.4	0.0	2.4	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Al Qisais	0.0	0.0	1823.8	0.0	1823.8	0.0	1823.8	0.0	1823.8	0.0	0.0	0.0	0.0	0.0
Al Sarooj	48.5	0.1	68.9	0.3	68.9	0.3	68.9	0.3	20.4	0.2	0.0	0.0	0.0	0.0
Al Shuaibah	102.4	0.0	107.6	0.0	111.3	0.0	110.4	0.0	5.3	0.0	3.7	0.0	-1.0	0.0
Al Shuwaimah	57.0	0.0	398.0	0.0	456.8	0.0	456.8	0.0	341.0	0.0	58.8	0.0	0.0	0.0
Al Towayya	43.1	0.0	43.0	0.0	43.0	0.0	53.8	0.0	-0.1	0.0	0.0	0.0	10.8	0.0
Asharej	147.4	0.0	145.9	0.0	156.5	0.0	154.5	0.0	-1.5	0.0	10.6	0.0	-2.0	0.0
Bida Bint Saud	212.6	0.0	1469.5	0.0	1469.6	0.0	2587.2	0.0	1256.9	0.0	0.1	0.0	1117.6	0.0
Falaj Hazza	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ghrebah	1737.8	0.0	1737.8	0.0	1737.8	0.0	1816.6	0.0	0.0	0.0	0.0	0.0	78.8	0.0
Hili	383.8	0.0	1208.8	0.0	1214.8	0.0	1218.2	0.0	825.0	0.0	6.0	0.0	3.4	0.0
Neima	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sanaiya	0.0	130.3	0.0	130.3	0.0	130.3	0.0	235.8	0.0	0.0	0.0	0.0	0.0	105.5
Shiab Al Ashkhar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zakhir	155.9	0.0	1178.2	0.0	1221.5	0.0	1224.9	0.0	1022.3	0.0	43.3	0.0	3.3	0.0
Total	5182.55	190.58	11133.66	190.81	11750.96	192.25	12965.37	298.21	5951.10	0.23	617.30	1.44	1214.41	105.96

e)

Western sector	1984		1990		2000		2014		Inc. 1984-90		Inc. 1990-2000		Inc. 2000-2014	
	A	I	A	I	A	I	A	I	A	I	A	I	A	I
Abu Samra	250.5	5.6	269.9	6.0	454.8	6.8	464.8	7.2	19.4	0.4	184.8	0.8	10.1	0.4
Al Khaznah	1743.9	0.1	4696.6	1.6	6559.2	0.1	8006.0	1.6	2952.7	1.5	1862.6	-1.5	1446.8	1.5
Al Rawdha	746.5	0.0	746.5	0.0	746.5	0.0	746.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Al Saad	2605.7	33.2	3685.1	33.2	6243.7	95.0	6243.0	95.2	1079.3	0.0	2558.7	61.8	-0.7	0.2
Al Salamat	0.0	0.0	1392.1	0.0	1392.1	0.0	1392.1	1.7	1392.1	0.0	0.0	0.0	0.0	1.7
Al Yahar	200.6	0.2	204.2	0.1	334.9	0.0	327.0	0.0	3.7	-0.1	130.7	-0.1	-8.0	0.0
Remah	601.5	2.3	833.3	2.3	5344.7	17.5	6539.7	19.5	231.8	0.0	4511.4	15.2	1195.0	2.0
Total	6148.7	41.3	11827.7	43.1	21075.9	119.4	23719.1	125.1	5679.0	1.8	9248.2	76.2	2643.2	5.7

Table 4.2. Agricultural and industrial land growth (in hectares) of Eastern (a), Southern (b), Northern (c), Centre (d), and Western (e) sectors. Source: own elaboration from Al Ain Town Planning Base Map and Landsat data.

4.5. Landscape results

This section summarizes the landscape analysis applied in this thesis, considering that a landscape is formed by a set of units distributed in space and linked by a series of flows (energy and materials). The physical properties such as size, shape and spatial distribution of the various units are the result of functional processes that take place at landscape scale. The discipline that developed the conceptual framework for understanding these processes is “Landscape Ecology”, which considers the landscape as a functional unit repeatable over a certain territory and comprising a set of interrelated ecosystems (Holt-Jensen, 1999).

“Landscape Ecology” has focused on three main aspects that define a landscape (Turner and Gardner, 1991): i) the structure, which tries to establish patterns of spatial distribution of the various components; ii) the function, which analyses the flow between components of the landscape; iii) the dynamic changes that would study the structure and function over time. The landscape units are the patches, defined as an area with homogeneous characteristics different from those around it. The main topological attributes are size, shape and number of patches and their disposition. Therefore, a landscape can be characterized by two elements: i) composition, which includes the various LULC and abundance of patches. Several quantitative measures characterize the composition of the landscape: the types of patches (patch richness), uniformity and variety (evenness and diversity), etc.; ii) configuration, or the spatial distribution of patches in the landscape (landscape pattern), which includes the patch shape, isolation, and contagion (the space between classes, as well as the mean patch size, density, etc. (McGarigal et al., 2012).

“Landscape Ecology”, therefore, is involved in the study of landscape patterns, interactions between patches in a mosaic and, finally, how these patterns and interactions change over time. As described by Turner (1989), the spatial patterns observed in the landscapes are the result of complex interactions between social, biological and physical forces. Most landscapes are influenced by LULC and the resulting mosaic landscape is a mixture of patches, the result of human and natural actions varying in size, shape and disposition in the territory. Several landscape indicators have been used over LULC applied in different countries, such as the USA (Luque, 2000; Nagendra et al., 2004), Spain, (Serra et al., 2008), and Senegal (Cabral and Lagos Costa, 2017). Luque, for example, concludes that forest fragmentation is perceptible in the mean reduction in patch area. In this sense, fragmentation or division of a homogeneous area into smaller pieces is seen as negative since it involves the loss of connectivity, the isolation of species, etc.

In this chapter, two landscape analyses will be described, one at polygon scale and the other one at pixel scale. The first one is developed using "Patch analyst", an extension to the ArcGIS® software system that facilitates the spatial analysis of landscape patches/polygons and the modelling of attributes associated with patches/polygons. The landscape metrics calculated were:

- Number of polygons: total number of patches for each individual class
- Mean patch size in hectares: average patch size for each individual class
- Total edge in meters: perimeter of patches for each individual class

According to Aguilera et al. (2011), landscape metrics (which refers exclusively to indices developed for categorical map patterns) can be a useful tool for planners to better understand and characterize urban processes and their consequences. Their work identified three spatial urban processes: aggregation, or the clustering of patches to patches of a larger size; compaction, or the formation of more compact patches as opposed to elongation, in which the shape of the patches is stretched out; and dispersion/isolation or an increased distance between patches of the same land-use type. In this case, a greater isolation indicates greater dispersion, due to urban sprawl. Four urban patterns were differentiated: aggregated, characteristic of urban growth in some Mediterranean cities where new urban areas are added into consolidated city, reducing dispersion or landscape fragmentation; linear, characteristic of urban growth around a road network, increasing aggregation and decreasing compaction; leapfrogging, characteristic of low-density residential areas with dispersed single houses, producing a decrease of aggregation and an increase of dispersion; and finally nodal, characteristic of urban growth near the main transportation nodes but affecting only industrial and commercial uses.

Morphological image processing is a customized sequence of mathematical morphological operators targeted at the description of the geometry and connectivity of the image components (Soeille and Vogt, 2009). Two software platforms were used to analyse the LULC changes from a landscape point of view. The first, "Patch Analyst", is an extension to the ArcGIS® software system that facilitates the spatial analysis of landscape patches and the modelling of attributes associated with patches, being an adaption of another software, "Fragstats". To examine landscape dynamics at class level, five landscape metrics assessing composition and configuration were calculated. Composition analysis included the number of patches/polygons and the mean patch size; configuration analysis included total edge, edge density and mean patch edge (McGarigal et al., 2012). The second was the Morphological Spatial Pattern Analysis (MSPA) from the Graphical User Interface for the Description of image Objects and their Shapes, the GUIDOS Toolbox software (Vogt, 2017). GUIDOS provides image-processing tools based on geometric concepts and can thus be applied to any kind of raster data. An algorithm to classify LULC classes in morphological terms is usually defined by a sequence of operators such as union, intersection, complementation and translation. From binary maps (presence and no presence of a specific LULC class), the package measures the shape, size and connectivity of the spatial patterns using a distance threshold. Using mathematical morphology (Soille, 2003), seven categories were quantified: core, islet, loop, bridge, perforation, edge and branch. Four were included in the analysis: core, islet, bridge and edge. Two other additional parameters were calculated: the Euclidean distance between features and the overall network connectivity.

Two general LULC categories were considered in this subsection: urban and agriculture. The urban polygons, labelled as residence and services, and agriculture and forestry plantations were included in the urban and agriculture categories, respectively. After converting the polygons to raster (with a pixel size of 10 m), core pixels were extracted, taking into account the inner part of a polygon occupying at least one pixel edge width (Soille and Voght, 2009). Areas with less than 1,000 pixels were considered small cores, until 4,600 medium and above large cores. In contrast, the islets pixels were defined as those polygons that do not contain any core. In consequence, an increase of core pixels was an indicator of compaction whereas an increase of islets pixels was an indicator of dispersion or isolation.

To analyse landscape connectivity of urban or agricultural land, the bridges, or connector pixels emanating from two or more connected cores, were included. Another parameter was the measurement of edge pixels, corresponding to the outer boundaries of core pixels. Two additional calculated parameters, considering the Euclidean distance, were the average distance value and the maximum distance found in the raster. Finally, the last two calculated parameters were entropy and "Equivalent Connected Area-Relative" (ECAR) The overall network connectivity, or ECAR, considers that a network is composed of cores and bridges whereas entropy is a descriptor of spatial fragmentation. According to Bhatta et al. (2010), entropy is perhaps the most widely used technique to measure the extent of urban sprawl integrating RS and GIS, considering that higher values of entropy indicate the occurrence of sprawl.

In the next subsections, the main results for the main LULC of urban and agricultural land at landscape scale are shown. The industrial land was not considered, given the limited area and sparse cover, compared with urban and agricultural LULC.

4.5.1. Urban landscape dynamics

At district scale, the landscape configuration of the Eastern sector showed an increasing number of polygons, both for residential land and urban services, as in the examples of Um Ghaffa and in Al Dhaher (Figure 4.7). The mean patch size increased greatly in residential land between 1990 and 2000 in Um Ghaffa and even more in Al Dhaher (Figure 4.8). In the case of services, the mean patch size evolution was irregular in Um Ghaffa and increased steadily in Al Dhaher. Finally, the dynamics of total edge were increased regularly in both cases, mainly from 1990 to 2000 (Figure 4.9).

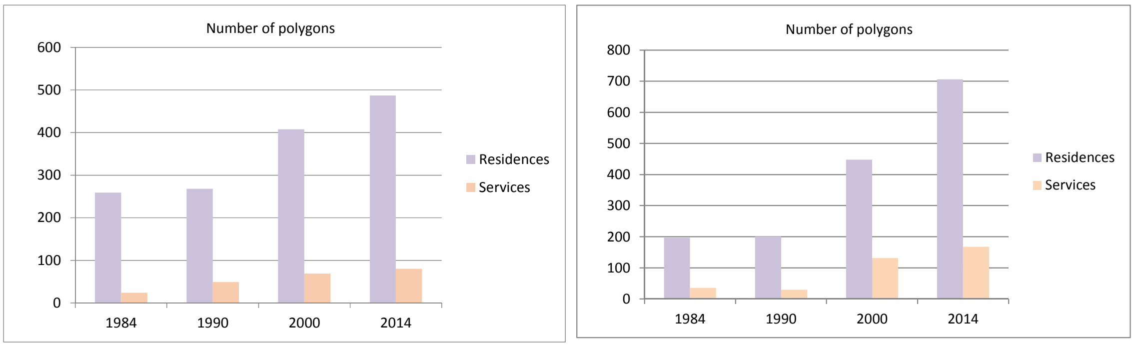


Figure 4.7. Number of urban polygons evolution in Um Ghaffa and in Al Dhaher.

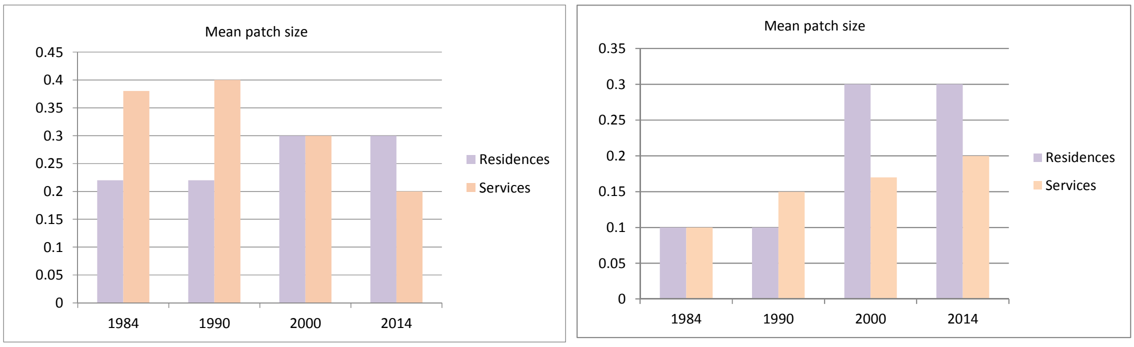


Figure 4.8. Mean patch size (in hectares) of urban changes in Um Ghaffa and in Al Dhaher.

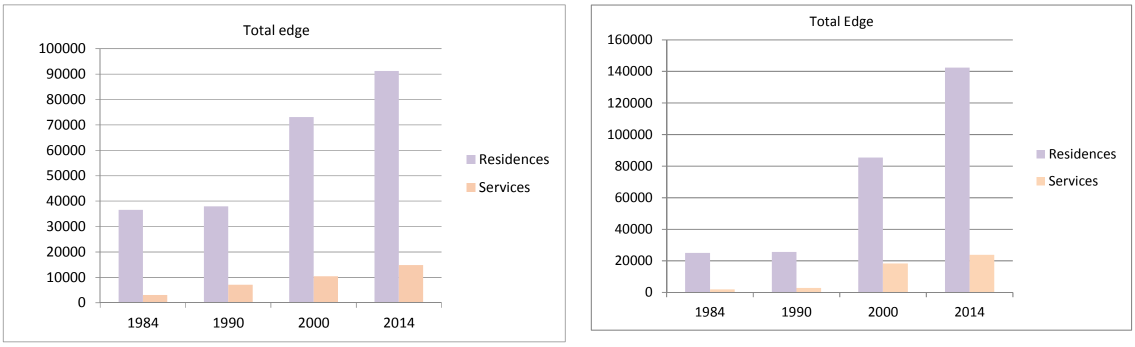


Figure 4.9. Total edge (in meters) urban changes in Um Ghaffa and in Al Dhaher.

At sector scale, large core areas increased greatly in the Eastern sector, mainly due to the extensive residential growth in Jebel Hafeet and the aggregation of new urban areas to the oldest (Figure 4.10); as a result, the small and medium core areas showed a decrease. The next three landscape parameters showed similar behaviour: a decrease of islets, edges and bridges from 1985 to 2014, as a consequence of urban aggregation and compaction. The average distance and the maximum distance were greater in 2014 compared with 1984, increasing from 5.9 to 30.6; 27.2 to 155.8, respectively. Finally, the core network connectivity (ECAR) was higher in 2014 (74%) compared with 1984 (50%) (Figure 4.11) whereas the entropy value in 2014 (2.08) was also higher than in 1984 (0.73). Therefore, the 2014 urban landscape of Eastern sector was more compacted and sprawled.

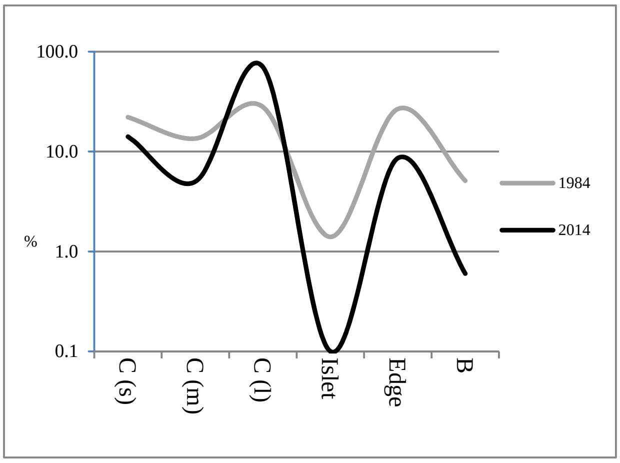


Figure 4.10. Urban landscape parameters (in percentage) of Eastern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

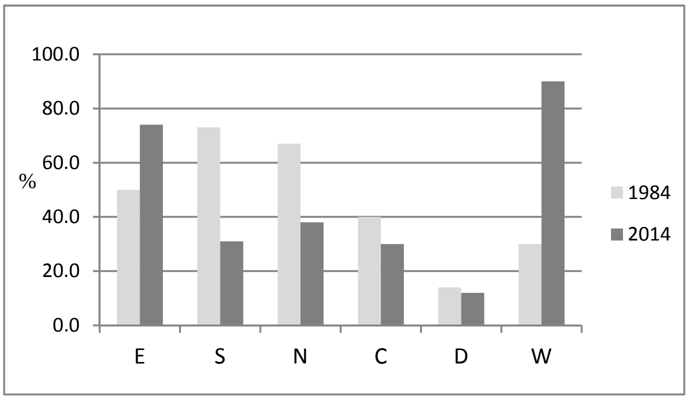


Figure 4.11. Urban Equivalent Connected Area Relative (ECAR) (in percentage) of Eastern (E), Southern (S), Northern (N), Centre (C), Downtown (D), and Western (W) sectors. Source: own elaboration.

At district scale of Southern sector, the landscape configuration in two representative districts, Abu Krayyah and Al Wagan, showed a clear increase in the number of polygons, their mean patch size and total edge, both for residences and services, mainly from 2000 to 2014. This evolution was more intense in Abu Krayyah due to the lack of urban land in 1984 and in 1990, showing a bigger mean patch size compared with Al Wagan (Figures 4.12, 4.13, and 4.14). In this sector, with less residential land but more services compared with the Eastern sector, the main difference between 1984 and 2014 was the steep increase of medium core areas as a result of new residential land and services (Figure 4.15). Therefore, a weaker process of aggregation was detected, confirmed by the similar values in islets, edges and bridges and by the weak decrease of average distance (10.5 to 8.4) and feeble increase of maximum distance (34.9 to 43.8) together with the ECAR that showed less connection from 1984 (73%) to 2014 (31%) (Figure 4.11). Finally, the entropy value in 2014 was just slightly higher (0.5) than in 1984 (0.2). Therefore, the urban sprawl in this sector was minimum, with a few more connections and similar aggregation.

Figure 4.12. Number of urban polygons evolution in Abu Krayyah and in Al Wagan.

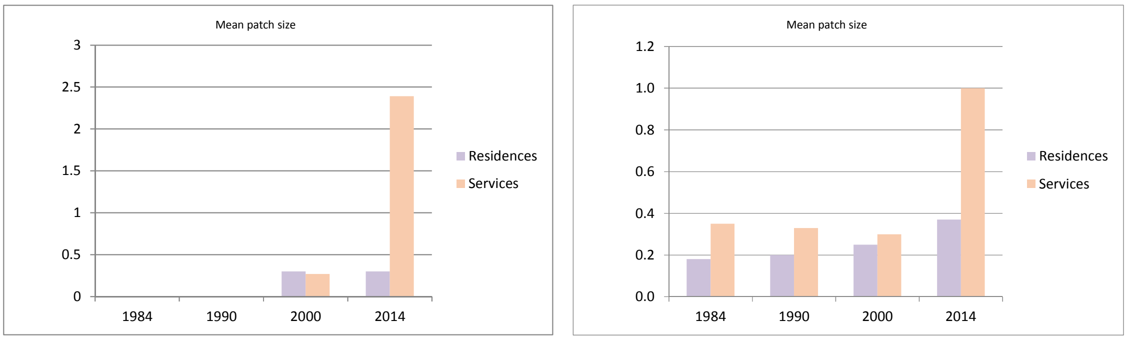
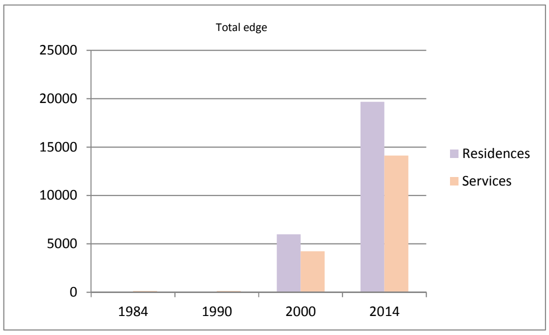


Figure 4.13. Mean patch size (in hectares) of urban dynamics in Abu Krayyah and in Al Wagan.



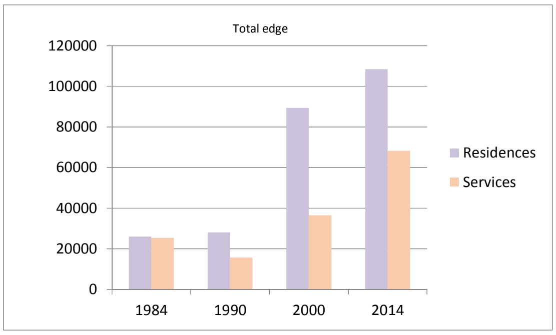


Figure 4.14. Total edge (in meters) evolution in Abu Krayyah and in Al Wagan.

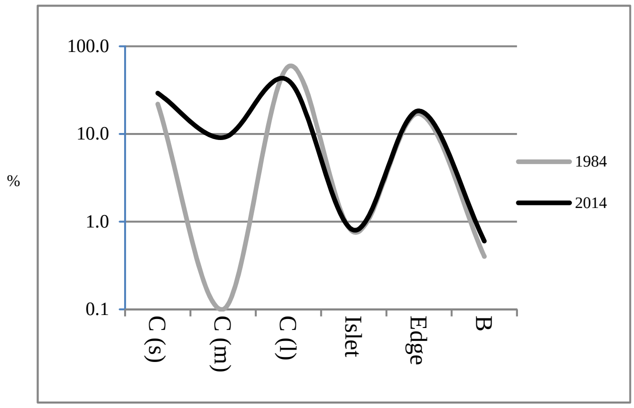
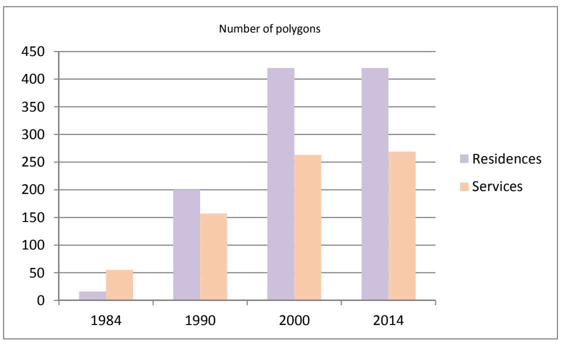


Figure 4.15. Urban landscape parameters (in percentage) of Southern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

The landscape configuration of two districts of the Northern sector, Al Hayer and Nahel Town, showed the increasing number of urban polygons and the bigger mean patch size of services in the case of the former and the fast increase of urban polygons between 1990 and 2000 in the latter, according to mean patch size and total edge (Figures 4.16, 4.17 and 4.18).



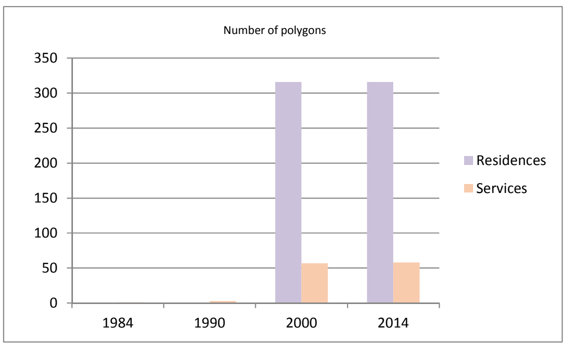


Figure 4.16. Number of urban polygons evolution in Al Hayer and in Nahel Town.

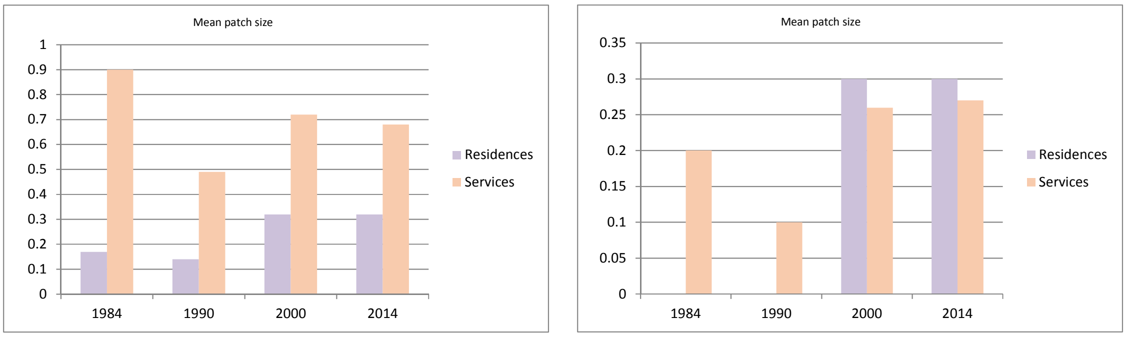


Figure 4.17. Mean patch size (in hectares) of urban dynamics in Al Hayer and in Nahel Town.

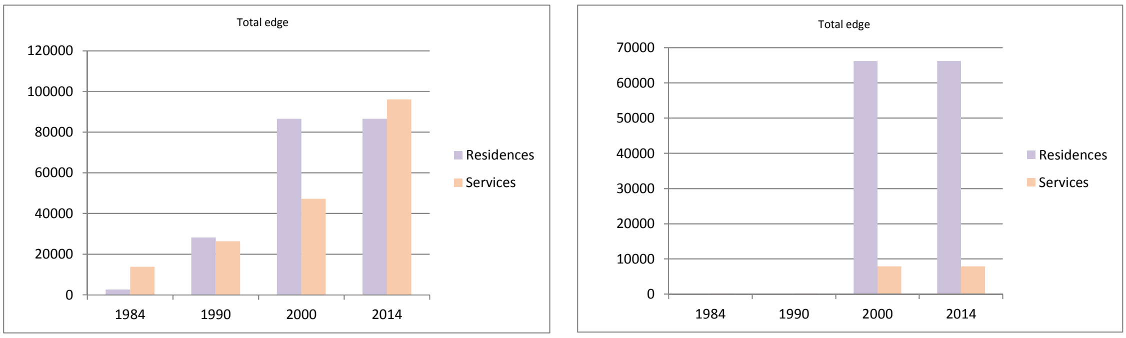


Figure 4.18. Total edge (in meters) of urban dynamics in Al Hayer and in Nahel Town.

In this Northern sector, with a predominance of services as in the Southern sector, the main landscape dynamics from 1984 to 2014 were the increase of all small and medium cores and, in consequence, the landscape became less compact (Figure 4.19). A weak increase of islets, edges and bridges was detected as a result of fragmentation, highlighting some residential increase around the main road network (very clear around E-16, E-66 and E-20). The next spatial metrics showed a decrease of average distance and an equal maximum distance whereas the ECAR indicated less connection from 1984 (67%) to 2014 (38%) (Figure 4.11). Finally, in 2014 entropy was slightly higher (0.37) compared with 1984 (0.11). Therefore, the urban sprawl in three districts of this sector was very limited.

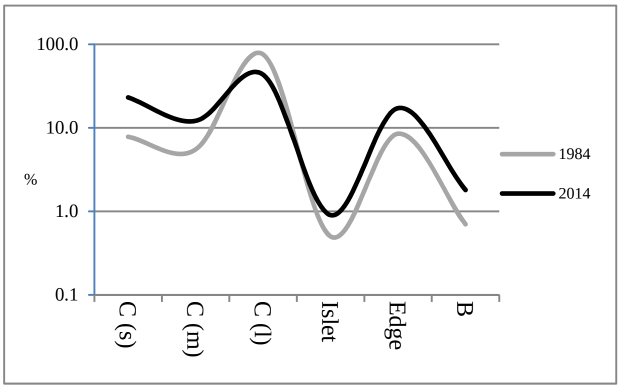
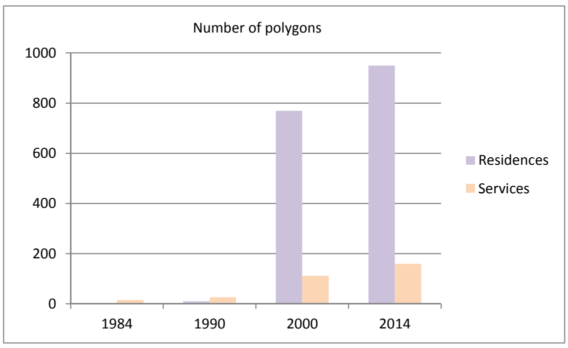


Figure 4.19. Urban landscape parameters (in percentage) of Northern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

The dynamics of landscape composition of two districts in the Centre, Falaj Hazza and Zakhir, are shown in the next figures. The former showed an important increase in residential land from 1990 to 2000 and a predominance of big polygons in services whereas the urban increase of the latter was progressive, with smaller mean patch size and total edge (Figures 4.20, 4.21 and 4.22). The analysis of this sector, characterized by extensive increase of residential land and services that resulted in a process of fill-in or land compaction (Photographs 4.1, 4.2, 4.3, 4.4), showed an increase of small cores, in a landscape dominated by large cores but with a bit less intensity than in 1984 (Figure 4.23). The islets and bridges decreased but the edge increased slightly, whereas the average distances also decreased slightly but the maximum distance increased, showing a process of dispersion. The ECAR value decreased from 1984 (40%) to 2014 (30%), equivalent to less connection (Figure 11), whereas the entropy indicated a clear increase of urban sprawl from 1984 to 2014 (2.79 and 4.93, respectively).



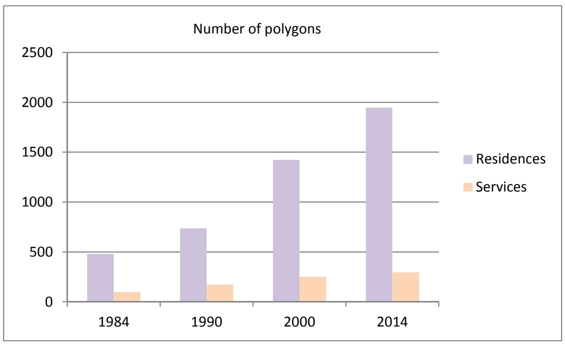
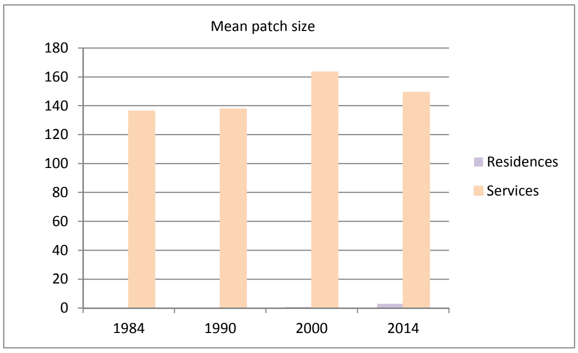


Figure 4.20. Number of polygons evolution in Falaj Hazza and in Zakhir.



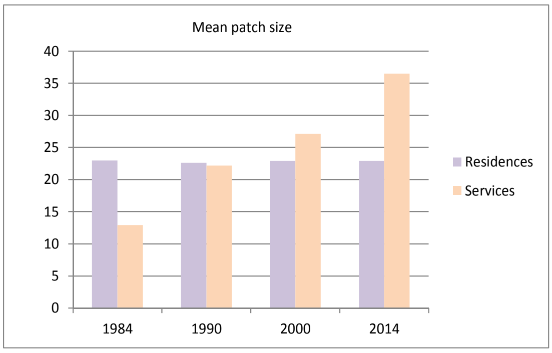
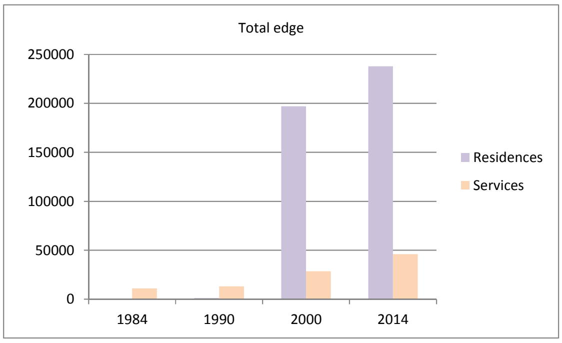


Figure 4.21. Mean patch size (in hectares) evolution in Falaj Hazza and in Zakhir.



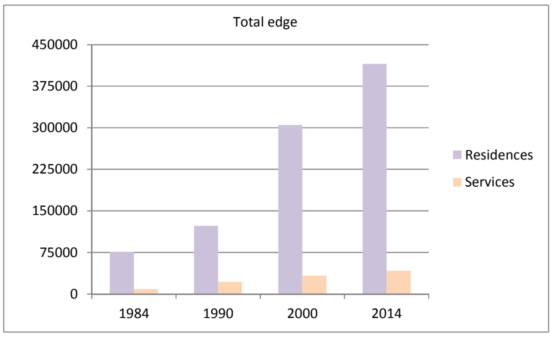


Figure 4.22. Total edge (in meters) evolution in Falaj Hazza and in Zakhir.

Photograph 4.1. Aluyoon village resort surrounded by industrial land in Sanaiya district, Centre sector. Source: Al Ain Municipality, 2009.

Photograph 4.2. Emirates shopping mall in the Centre sector. Source: Al Ain Municipality, 2009.

Photograph 4.3. Al Jahili Park and urban coalescence in the Centre sector. Source: Al Ain Municipality, 2009.

Photograph 4.4. Zoo and urban compaction of Falaj Hazza (wright), in the Centre sector. Source: Al Ain Municipality, 2009.

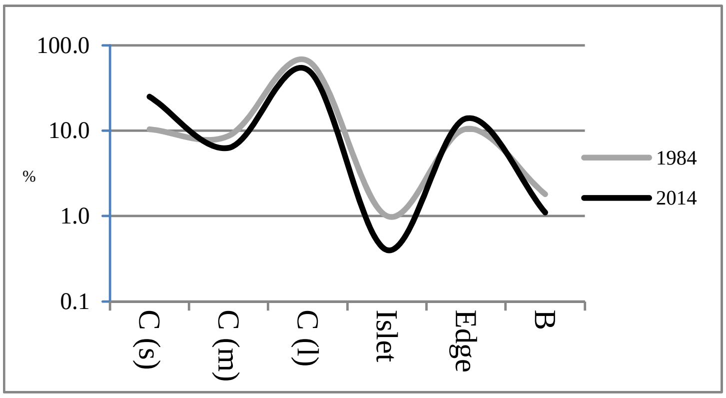


Figure 4.23. Urban landscape parameters (in percentage) of Centre sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

Al Qattara and Al Jimi, the two selected districts of the Downtown sector, showed some differences from a landscape point of view: the former had fewer polygons, with a bigger mean patch size and shorter total edge, compared with the latter where the size of services polygons were predominant (Figures 4.24, 4.25 and 4.26). In this sector, characterized by the slight growth of residential land and services given the lack of available new space (photograph 4.4), the number of small cores increased slightly whereas the medium cores decreased and the large core remained the same (Figure 4.27). This sector had the fewest changes at landscape scale, according to the size of cores, islets, edges, bridges, average distance, maximum distance and ECAR (Figure 4.11) and entropy (15.4 to 16.03), as a result of the slight compaction of small cores and feeble urban sprawl.

Figure 4.24. Number of polygons evolution in Al Qattara and in Al Jimi.

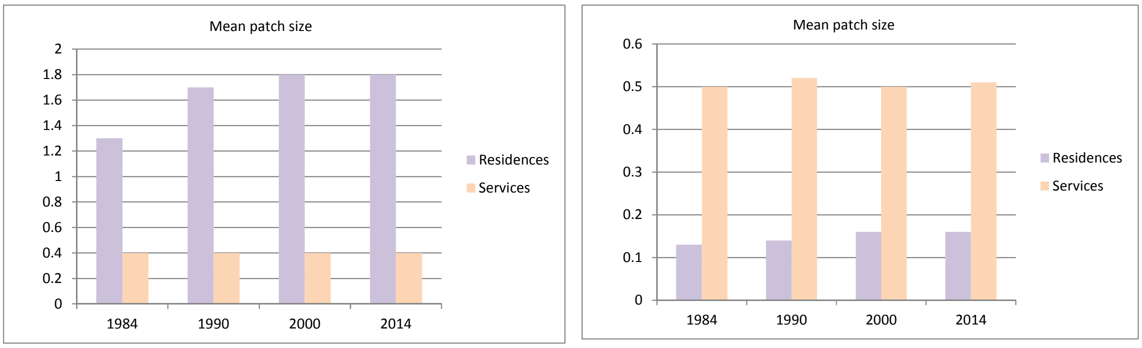


Figure 4.25. Mean patch size (in hectares) evolution in Al Qattara and in Al Jimi.

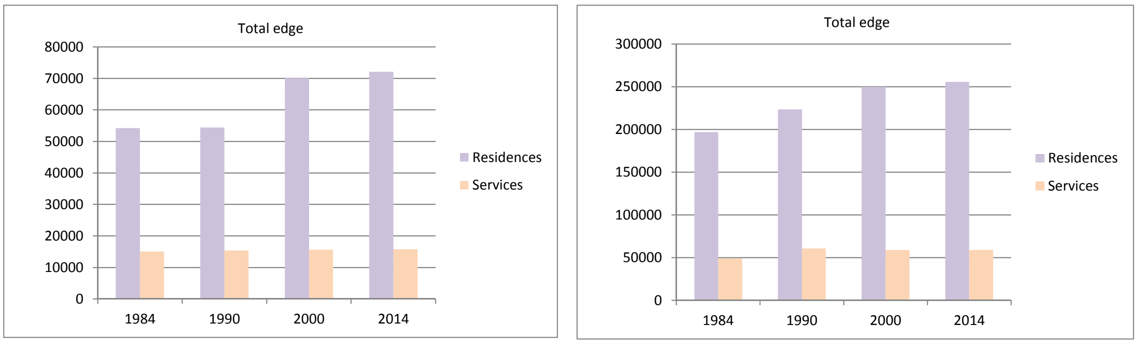


Figure 4.26. Total edge (in meters) evolution in Al Qattara and in Al Jimi.

Photograph 4.4. Al Ain Oasis and compact Downtown sector, Central District. Source: Al Ain Municipality, 2009.

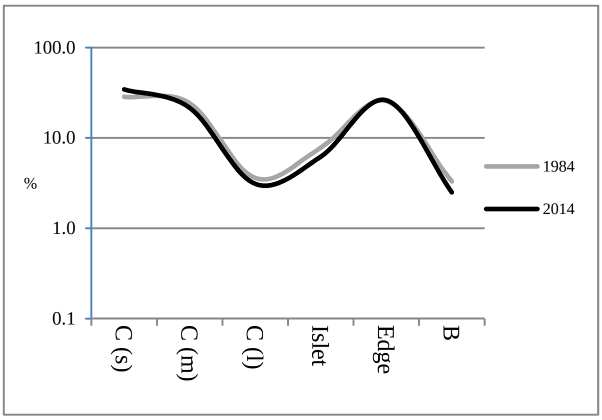


Figure 4.27. Urban landscape parameters (in percentage) of Downtown sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

Finally, Al Yahar and Al Khaznah were selected as representative districts in the Western sector. The mean patch size of the former was smaller than the latter, mainly in the case of services (Figure 4.28, 4.29 and 4.30). In this sector, there was a decrease in the small and medium cores whereas there was an increase in large cores, showing less fragmentation (Figure 4.31). There was a decrease in islets, edges and bridges, showing more compaction. A clear increase of average distance and maximum distance appeared, with more landscape connectivity detected according to the ECAR increase from 1984 (30%) to 2014 (90%), and a clear process of urban sprawl according to the entropy values (0.57 in 1984 and 1.21 in 2014).

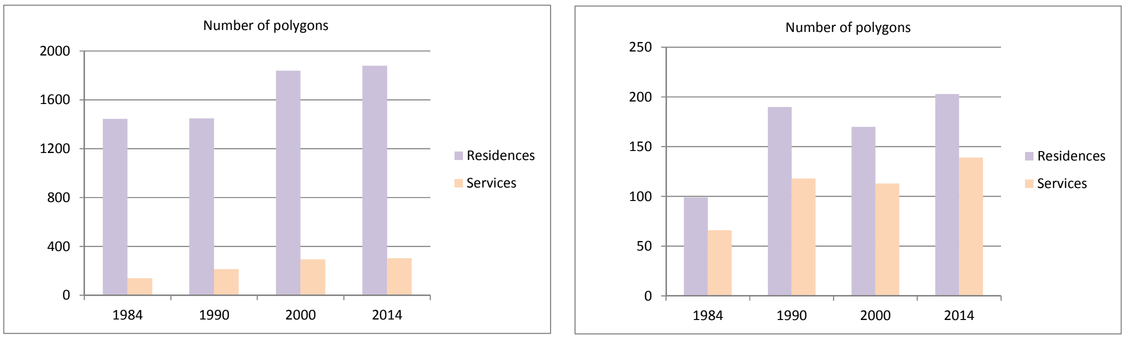


Figure 4.28. Number of polygons evolution in Al Yahar and in Al Khaznah.

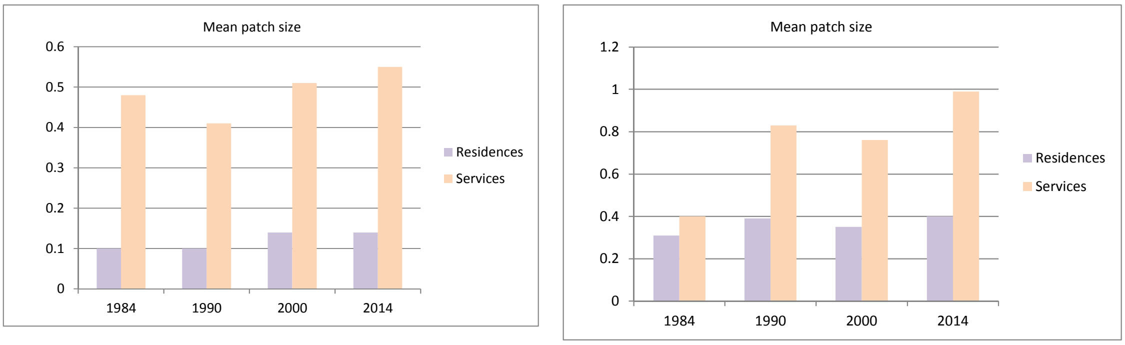


Figure 4.29. Mean patch size (in hectares) evolution in Al Yahar and in Al Khaznah.

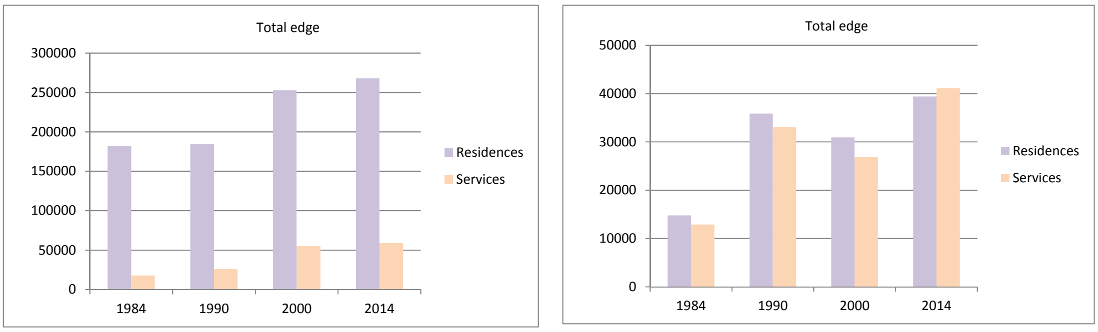


Figure 4.30. Total edge (in meters) evolution in Al Yahar and in Al Khaznah.

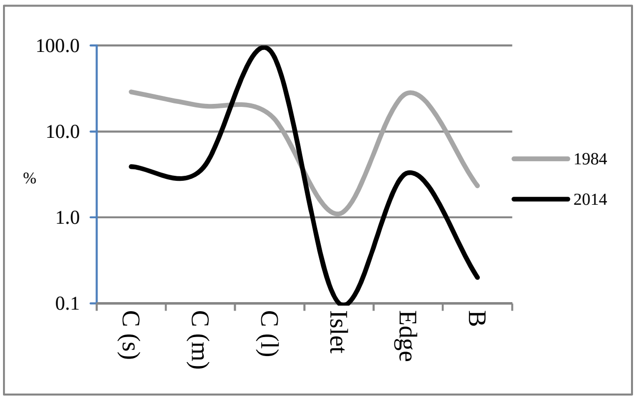


Figure 4.31. Urban landscape parameters (in percentage) of Western sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

4.5.2. Farm landscape dynamics

In this subsection the islet indicator was not considered because all the values were very small, indicating the lack of isolated agricultural polygons. The selected districts for the Eastern sector were Um Ghaffa and Al Dhaher. The latter showed fewer polygons and bigger mean patch size, although a trend toward more fragmentation was observed, compared with the former district (Figures 4.32, 4.33 and 4.34). In this sector, a few changes were detected corresponding to the small decrease of medium cores and the slight increase of small and large cores (Figure 4.35). The average distance and the maximum distance increased as a result of dispersion, whereas the ECAR increased from 1984 (50%) to 2014 (74%) (Figure 4.36), and the entropy value remained very similar (from 0.70 to 0.71), likely as a result of a leapfrogging pattern rather than urban sprawl.

Figure 4.32. Evolution of agricultural and industrial polygons in Um Ghaffa and in Al Dhaher.

Figure 4.33. Mean patch size (in hectares) of agricultural and industrial changes in Um Ghaffa and in Al Dhaher.

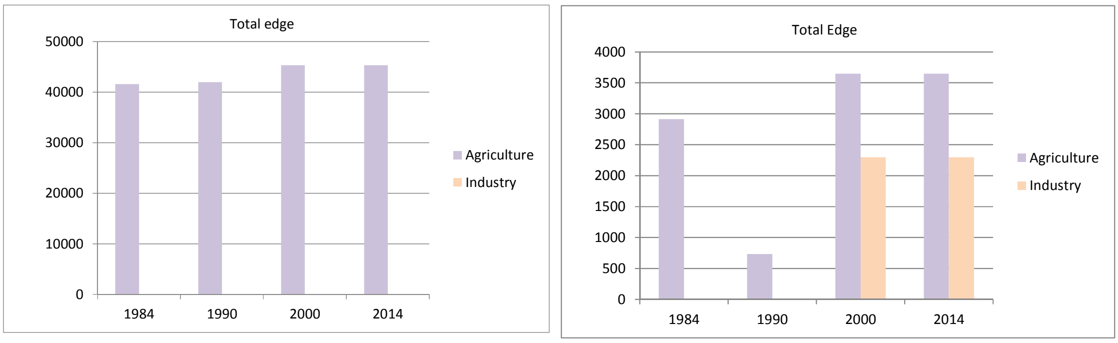


Figure 4.34. Total edge (in meters) of agricultural and industrial changes in Um Ghaffa and in Al Dhaher.

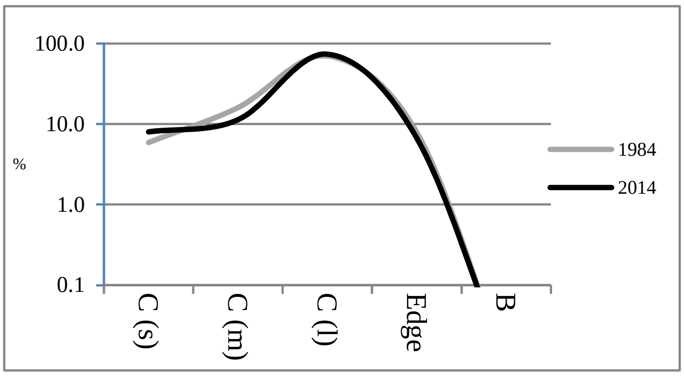


Figure 4.35. Agricultural landscape parameters (in percentage) of Eastern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

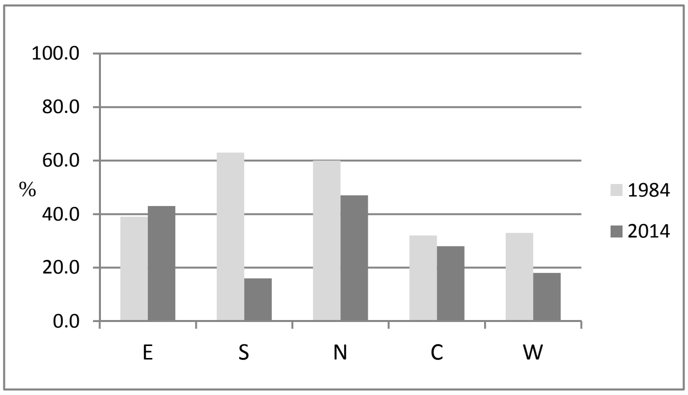
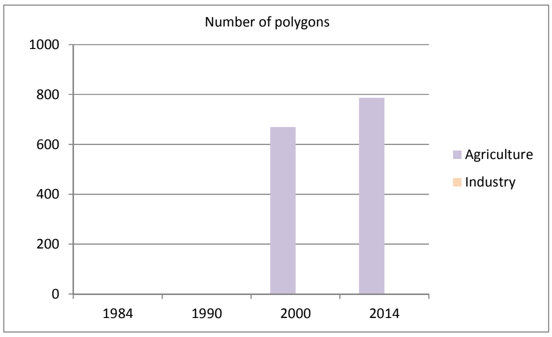


Figure 4.36. Agricultural Equivalent Connected Area Relative (ECAR) (in percentage) of Eastern (E), Southern (S), Northern (N), Centre (C), Downtown (D), and Western (W) sectors. Source: own elaboration.

The dynamics of landscape composition of two selected Southern sector districts, Abu Krayyah and Al Wagan, are shown in the next figures. The former showed an important increase in agricultural land from 1990 to 2000 and a predominance of big polygons, whereas the mean patch size of agricultural polygons of the latter was irregular but decreased from 2000 (Figures 4.37, 4.38 and 4.39). The farm dynamics of this sector were characterized by a large increase of small cores compared with the decrease of medium and large cores (Figure 4.40) with an increase of edges and bridges. As a consequence, there was less average distance but more maximum distance, producing more compaction. Finally, the ECAR showed a decrease from 1984 (63%) to 2014 (16%) as a consequence of less connectivity (Figure 4.36), and the entropy showed a very clear process of sprawl (from 0.53 in 1984 to 4.06 in 2014).



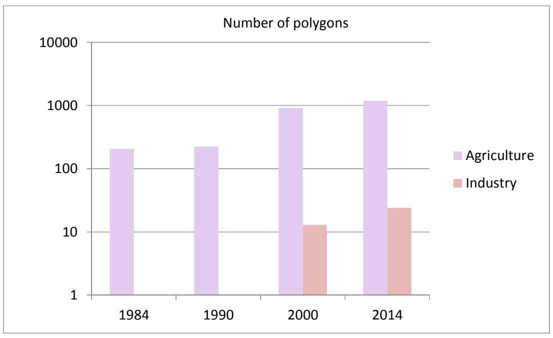


Figure 4.37. Evolution of agricultural and industrial polygons in Abu Krayyah and in Al Wagan.

Figure 4.38. Mean patch size (in hectares) of agricultural and industrial changes in Abu Krayyah and in Al Wagan.

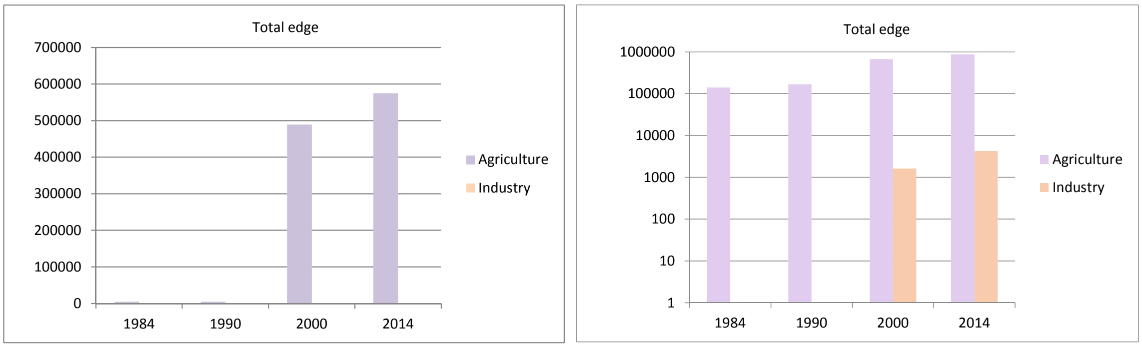


Figure 4.39. Total edge (in meters) of agricultural and industrial changes in Abu Krayyah and in Al Wagan.

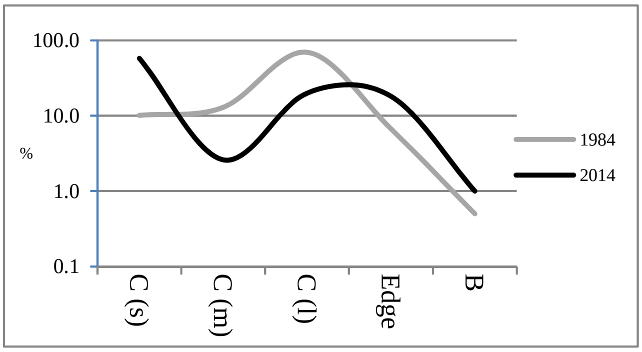


Figure 4.40. Agricultural landscape parameters (in percentage) of Southern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

For the Northern sector Al Hayer and Nahel Town were selected as representative districts. In both cases, an increase in the number of polygons occurred in 2000 with similar mean patch size, whereas the total edge showed an important increase, mainly from 2000 (Figures 4.41, 4.42 and 4.43). In this sector, there was an increase of small and medium cores and a small decrease in large cores (Figure 4.44). There was also a weak increase of bridges with less average distance and equal maximum distance; as a result, there was slightly more compaction. The ECAR indicator decreased from 1984 (60%) to 2014 (47%) as a consequence of less connectivity, whereas the entropy was higher in 2014 (0.8 versus 2.9), increasing the sprawl.

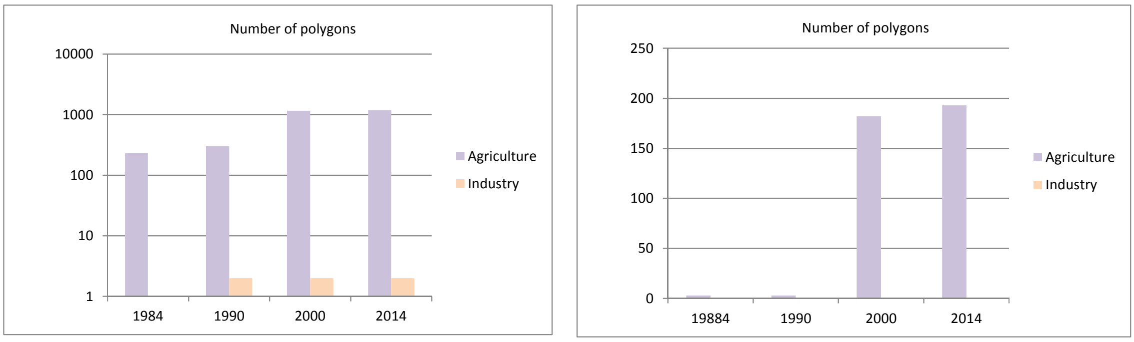


Figure 4.41. Number of agricultural and industrial polygons evolution in Al Hayer and in Nahel Town.

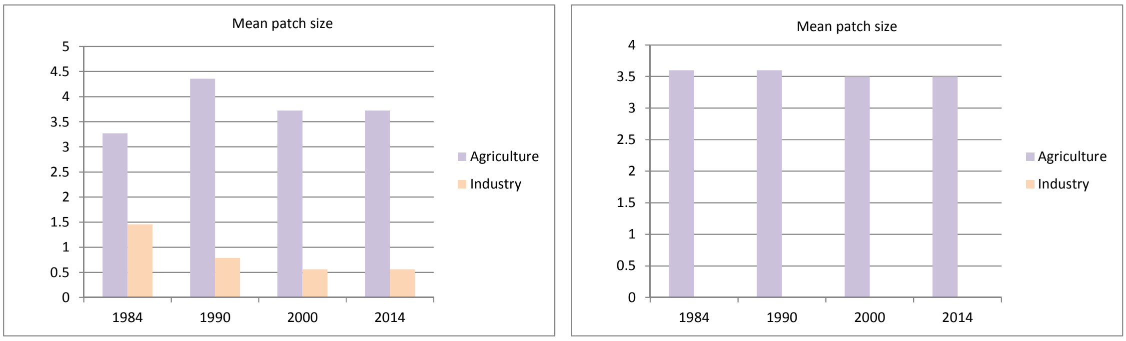


Figure 4.42. Mean patch size (in hectares) of agriculture and industry dynamics in Al Hayer and in Nahel Town.

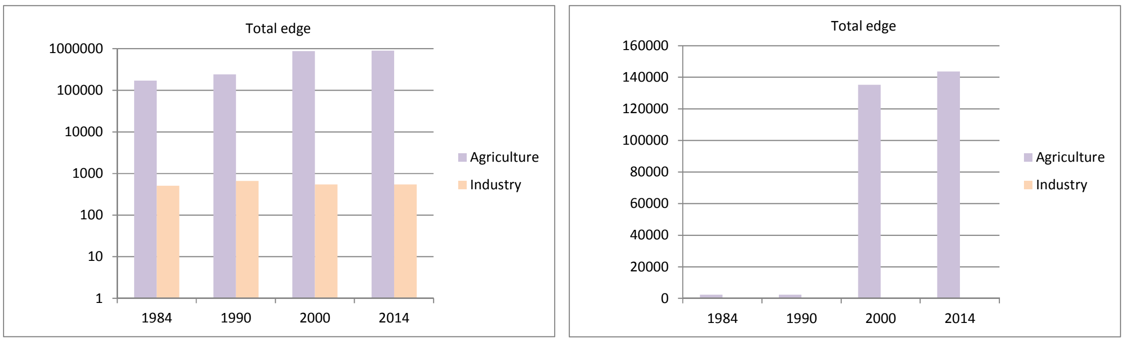


Figure 4.43. Total edge (in meters) of agriculture and industry dynamics in Al Hayer and in Nahel Town.

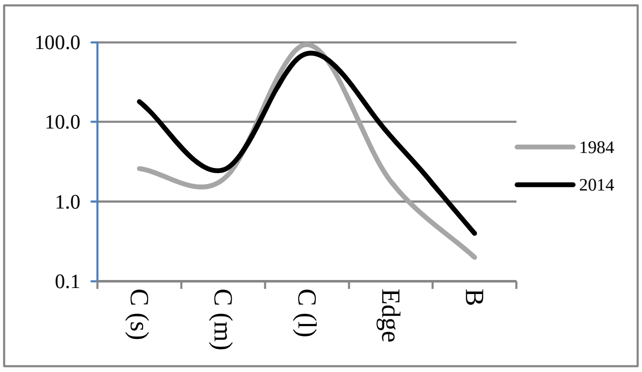
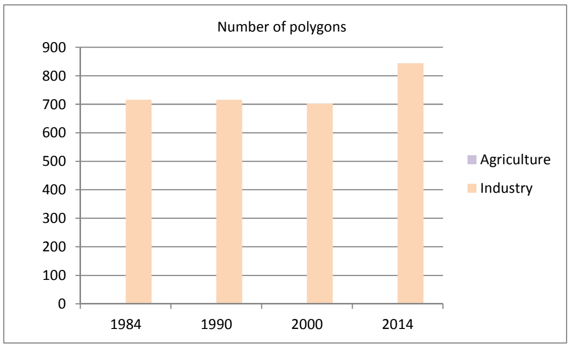


Figure 4.44. Agricultural landscape parameters (in percentage) of Northern sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

The districts selected from the Centre sector, Sanaiya and Zakhir, showed different dynamics: the former an increase of industrial land (photograph 4.1) characterized by a high number of polygons of small size, whereas the latter saw an increase of agricultural land, characterized by a small number of polygons and their large size (Figures 4.45, 4.46 and 4.47; photograph 4.5). In this sector, there was a decrease of small and medium agricultural cores and a small increase of large cores, a decrease of edges and bridges and an increase of average distance and maximum distance, causing less compaction (Figure 4.48). The ECAR showed a decrease from 1984 (32%) to 2014 (28%), producing less connectivity (Figure 4.36) and increasing the sprawl slightly, according to the entropy increase (1.63 versus 2.05).



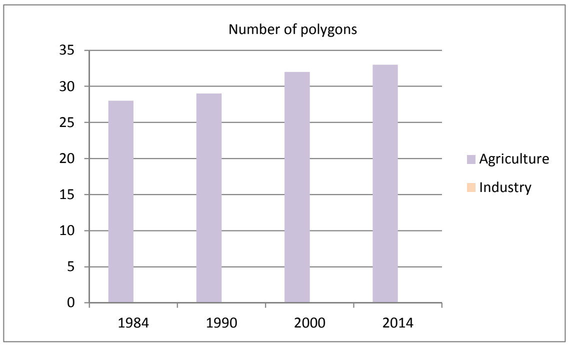
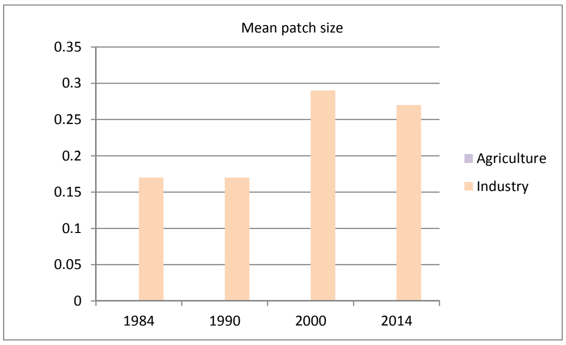


Figure 4.45. Number of agricultural and industrial polygons evolution in Sanaiya and in Zakhir.



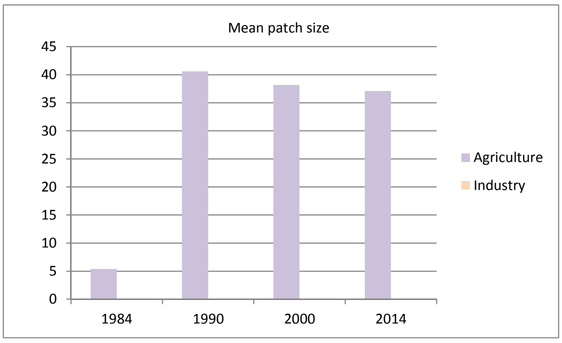
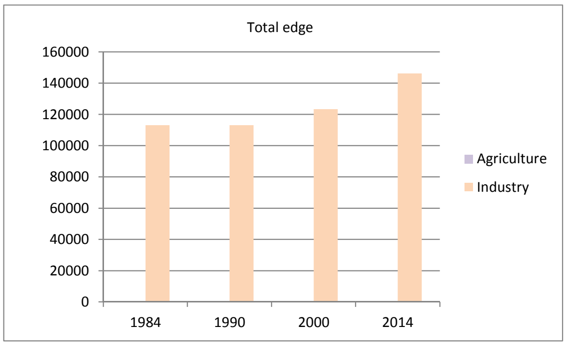


Figure 4.46. Number of agricultural and industrial polygons evolution in Sanaiya and in Zakhir.



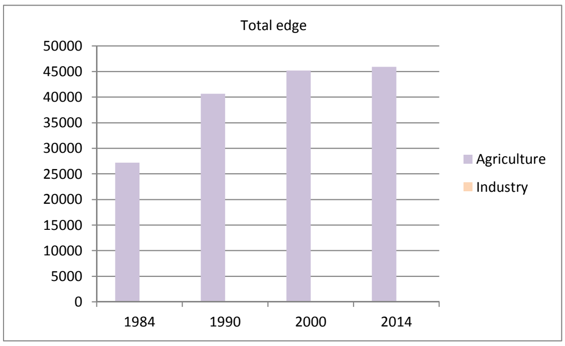
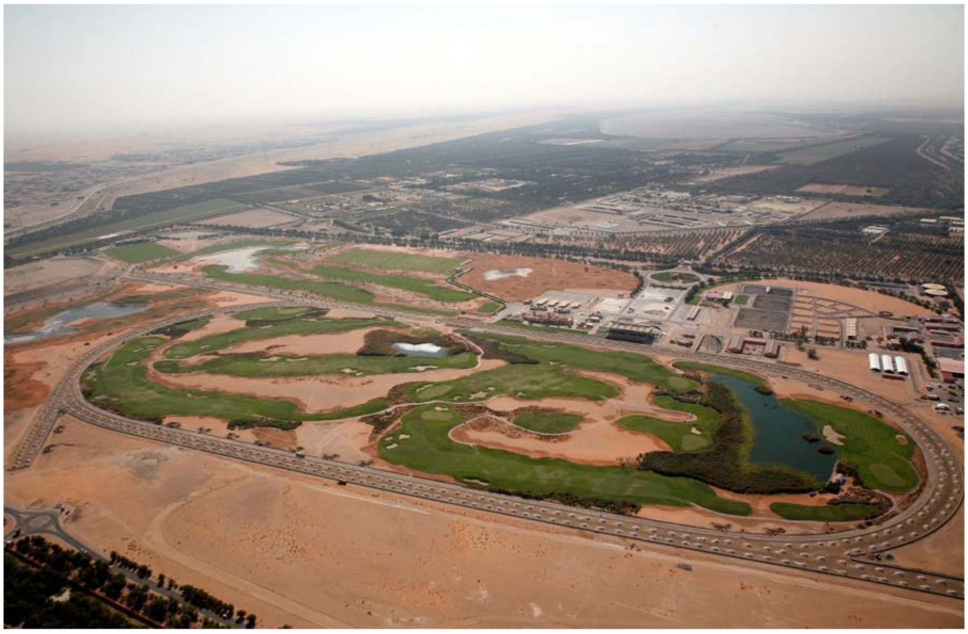


Figure 4.47. Total edge (in meters) of agriculture and industry dynamics in Sanaiya and in Zakhir.



Photograph 4.5. At the bottom, extensive agricultural fields of Al Maqam and Grebah, in the Centre sector. In front: the Nakheel Resort. Source: Al Ain Municipality, 2009.

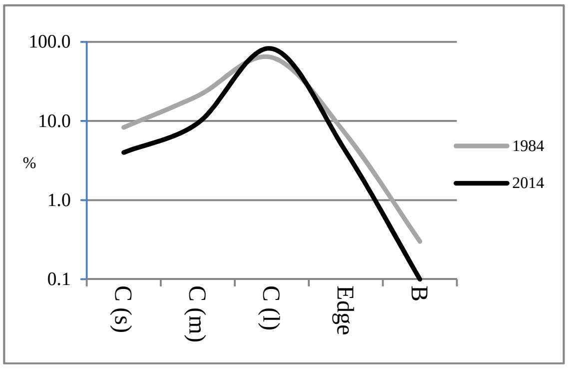


Figure 4.48. Agricultural landscape parameters (in percentage) of the Centre sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

In the Downtown sector, the agricultural and industrial land measures showed very similar values in all the years; given the lack of available new space, no landscape changes were detected.

Finally, Saad and Remah, the selected districts for the Western sector, showed some differences although both displayed agricultural and industrial land: in the former, the number of polygons and the total edge were smaller and its mean patch size was bigger (Figures 4.49, 4.50 and 4.51). In this sector, the main landscape differences were the increase of small cores and the decrease of medium and large cores with very similar edges and bridges, whereas there was an increase of average distance and maximum distance as a clear process of dispersion (Figure 4.52). The ECAR showed a decrease from 1984 (33%) to 2014 (18%), equivalent to less connectivity (Figure 4.36) and the entropy a large increase, from 1.84 in 1984 to 5.35 in 2014, as a result of intensive sprawl.

Figure 4.49. Number of agricultural and industrial polygons evolution in Saad and in Remah.

Figure 4.50. Mean patch size of agricultural and industrial polygons evolution in Saad and in Remah.

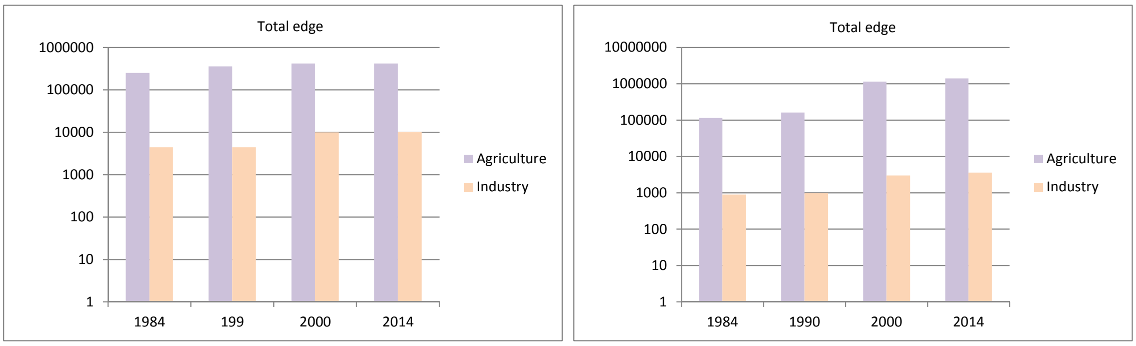


Figure 4.51. Total edge (in meters) of agriculture and industry dynamics in Saad and in Remah.

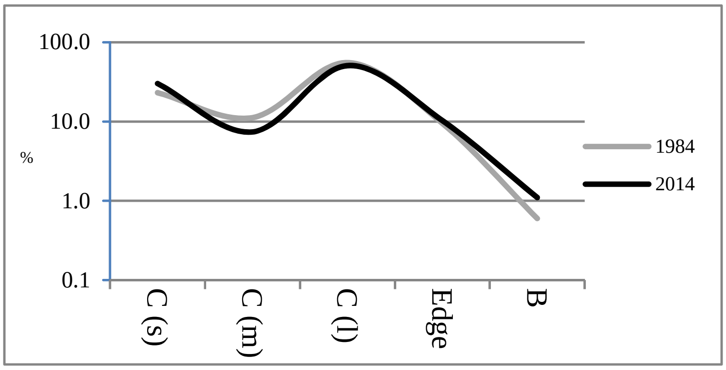


Figure 4.52. Agricultural landscape parameters (in percentage) of the Western sector. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

4.6. Conclusions

From an urban viewpoint, a particularity of Al Ain, compared with Dubai or Abu Dhabi cities, is that urban growth has been horizontal rather than vertical. In consequence, this city offers a specific example of urban sprawl, clearly differing from the Dubai urban brand or from other urban development forms. According to the analysis of LULC changes, urban growth of Al Ain City was not uniform either in space or in time. In the period 1984-1990, the Western sector showed the maximum increase in residential land and services, and the Centre sector had the maximum increase in services. In the period of 1990-2000, the maximum increase in residential land was in the Eastern (2,336.9 ha), Centre (2,276 ha) and Downtown sectors (107.9 ha), whereas the maximum increase in residential land and services occurred in the Northern sector (264 and 415 ha, respectively). The maximum increase in 2000-2014 happened in services in the Southern (545 ha).

From our results, it can be deduced that Al Ain city has experienced rapid urban growth since the 1980s, which in some sectors may be defined as a sprawled development with increased population and housing. Urban development has been widespread following the directions of the Al Ain Town Planning Department (and since 2007, the Urban Planning Council), as explained in chapter 3: housing and services management and zoning, and other directives such as urban plot size or the building height, restricted to a maximum of four floors (El Araby et al., 2004). As a result, the city retains some atmosphere of a country town with greenery along the streets, public gardens and oases, all within the urban centre. According to Selim et al. (2007), by the time of the 1986 Master Plan approximately 80 percent of all dwellings were located in the urban area; in 2001, this figure had dropped to 65 percent as a consequence of the construction of government housing outside the urban area. These developments reinforce the results obtained in this research regarding urban sprawl.

A second population process analysed in this PhD thesis is the migration of local residents outside the city centre in order to gain more comfort and space. This migration proceeded from the Centre to the West, following a sprawling pattern, as previously reported. According to Yagoub (2006), the districts with the highest densities were located between valleys (*wadis*) in the past, but this natural factor together with sand dunes no longer constrained development; the master plans were the most important factor in urbanization. In addition, Yagoub attributes the main stream of population toward the West to the attraction of Maqam Palace, UAE University, the Tawam hospital and transportation access to Abu Dhabi. In contrast, Eastern expansion was constrained by the political boundary of the Oman Sultanate and by the Jebel Hafeet Mountain in the South.

Simultaneously with residential land growth (and the subsequent high demand for workers), a rapid increase in cultural, recreational and educational activities was reported, producing a large increment in the services sector. Besides local Emiratis, this situation attracted a high number of foreign workers from India, Pakistan, Bangladesh, Egypt, Jordan, Palestine, Iran, Sri Lanka, Philippines, and the United Kingdom, among others (Elessawy and Zaidan, 2014). Most migrants either temporarily or permanently move to the city to seek employment, start businesses or work for existing enterprises. The Downtown and Centre districts were more affected by this process because there are several nodal points for services, such as the Al Ain Mall, which provides employment opportunities for residents and foreigners. Other service industries that attract workers include car sales, repair factories, and craft shops, together with other utility services such as the Al Noor Hospital and the Oasis Hospital, which are recognized for providing quality healthcare to residents and to other people from all over the world. Likewise, schools and higher educational institutions provide quality education and training to local and international students.

According to our results, the increase in agricultural land also was not uniform either in space or in time. The Western sector had the largest growth in agricultural land between 1984 and 1990 and an even greater increase between 1990 and 2000. The second main growth area was the Northern sector between 1990 and 2000, and the third was the Southern sector between 1990 and 2000. In the Centre sector, the largest growth was between 1984 and 1990; the main increase in the Eastern sector occurred between 2000 and 2014. Therefore, agricultural land growth was very important in the study period.

In most of the world, urban growth proceeds at the expense of agricultural land. This LULC conversion has been very clear in Mediterranean countries such as Spain (Gallardo and Martínez-Vega, 2016), Italy (Salvati and Sabbi, 2011) or Greece (Salvati et al., 2013). For instance, a recent study in the Barcelona metropolitan area (Spain) concludes that in 52 years (from 1957 to 2009), 76 percent of total agricultural land was lost (19,872 ha), of which 12,812 ha were converted to urban land (Serra et al., 2017). The main reasons for such strong agricultural abandonment were the globalization of agricultural markets, the increase in land price, due to urban pressures, crop fragmentation, and the ageing of farmers. In Turkey, Esbah (2007) established this conversion in the Aegean Sector from 1986 to 2002, together with the isolation of small patches of formerly agricultural land because of new roads and housing developments. Other examples of agricultural land decline and spatial fragmentation due to urban growth can be found in China's Hubei Province from 1996 to 2009 (Liu et al., 2015) or Ray City, Iran, from 1956 to 2013 (Assar Khaniki et al., 2015). Therefore, Al Ain constitutes an exception to the general trend of agricultural land as the main loser in the face of urbanization because there has been a massive conversion of barren land to agricultural land (UAE Ministry of Information and Culture, 2006). As a result, in 2006 the UAE was one hundred per cent self-sufficient in dates and fish, whereas the needs for vegetables, meat, fresh milk and eggs were met at rates of 58, 31, 83 and 39 per cent, respectively. A similar situation to Al Ain is Yazd City, Iran, where the transformation of barren land to agricultural production was the second major LULC change from 1975 to 2009, leading to the cultivation of saffron, pistachio, wheat, barley, and leafy vegetables (Shahraki et al., 2011). Nevertheless, the Al Ain Master Plan of 1986 was very explicit about agricultural self-sufficiency in those products for which it was suited, while in Yazd the agricultural increase was more related to rural immigration and population growth.

In the case of industry, increments were very restricted and localized. The Centre sector had the largest industrial increase, mainly between 2000 and 2014. Sanaiya district had the highest activity level, ranging from motor manufacturing companies to art centres. Other sectors experiencing industrial increase were the Western and the Southern between 1990 and 2000. Factories involved in processing and manufacturing have attracted significant numbers of foreign workers, mainly men.

The analysis of spatial metrics showed two sectors, Eastern and Western, with similar urban landscape areas and simultaneously a process of sprawl, much clearer in the latter sector. Two other sectors with similar dynamics were the

Southern and the Northern, with very limited sprawl, more similar to a leapfrogging urban pattern. A particularity of the Northern sector was the linear pattern of Nahel Town around the road network. Finally, in the Downtown sector the changes were small given the lack of available new space, whereas in the Centre there was a clear urban land compaction (filling in vacant land). Therefore, one of the main aims of the 1986 master plan to integrate the extant fragmented urban areas was achieved in the city centre and in some zones of the new residential areas. In this sense, the framework based on the idea of urban growth phases, diffusion and coalescence will multiple waves over different time periods (Dietzel et al., 2005; Nassar et al., 2014) seems to have been successful in these sectors. Finally, the agricultural land results showed important landscape differences: its increase was isolated in the Eastern sector, associated with linear patterns in the Northern and Southern sectors, restricted to vacant land to the north and south in the Centre and sprawled throughout the Western sector.

4.7. Chapter bibliography

Abd El-Kawy, O.R., Rød, J.K. Ismail, H.A., Suliman, A.S. (2011) Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Applied Geography*, 31, 483-494.

Afifi, A. A., Clark, V. (1996) *Computer-Aided Multivariate Analysis*. London, Chapman & Hall.

Aguilera, F., Valenzuela, L.M. Botequilha-Leitão, A. (2011) Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish Metropolitan area. *Landscape and Urban Planning*, 99, 226-238.

Akbari, H., Shea Rose, L., Taha, H. (2003). Analyzing the land cover of an urban environment using high-resolution orthophotos. *Landscape and Urban Planning*, 63(1), 1-14.

Assar Khaniki, Z., Darabi, H., Irani-Behbahani, H. (2015) Integrated analysis of urban landscape fragmentation (Case study: historical-religious city of Ray). *International Journal of Environmental Research*, 9, 511-522.

Bhatta, B., Saraswati, S., Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography*, 30, 731–740.

Burrough, P.A. (1998) *Principles of geographical information systems*. Oxford, Oxford University Press.

Cabral, A.I.R., Lagos Costa, F. (2017) Land cover changes and landscape pattern dynamics in Senegal and Guinea Bissau borderland. *Applied Geography*, 82, 115-128.

Campbell, J.B. (1996) *Introduction to Remote Sensing*. Taylor & Francis Ltd, London, 2nd edition.

Cellone, F., Carol, E. and Tosi, L. (2016) Coastal erosion and loss of wetlands in the middle Río de la Plata estuary (Argentina). *Applied Geography*, 76, 37-48.

Dietzel, C., Herold, M., Hemphill, J.J. & Clarke, K.C. (2005) Spatio-temporal dynamics in California's Central Valley: empirical links to urban theory. *International Journal of Geographical Information Science*, 19, 175-195.

Elessawy, F., Zaidan, E. (2014). Living in the move: Impact of guest workers on population characteristics of the United Arab Emirates (UAE). *The Arab World Geographer*, 17, 2–23.

Esbah, H. (2007) Land use trends during rapid urbanization of the city of Aydin, Turkey. *Environmental Management*, 39, 443-459.

European Environment Agency (EEA) (2016). U*rban sprawl in Europe*. Joint EEA-FOEN report, nº 11. Copenhagen.

Gallardo, M., Martínez-Vega, J. (2016). Three decades of land-use changes in the region of Madrid and how they relate to territorial planning. *European Planning Studies*, 24, 1016–1033.

Holt-Jensen, A. (1999) *Geography. Its history & concepts*. Sage, London.

Issa, S. and Shuwaihi, A.L. (2012) Characterization of Al Ain city urban growth using multi-temporal remote sensing data and GIS. *International Geoinformatics Research and Development Journal*, 3, 1-17.

Jensen, J.R. (1996) *Introductory digital image processing: a remote sensing perspective*. Upper Saddle River, Prentice Hall.

Leh, M., Bajwa, S. and Chaubey, I. (2013). Impact of land use change on erosion risk: an integrated remote sensing, geographic information system and modeling methodology. *Land Degradation & Development*, 24, 409-421.

Liu, Y., Luo, T., Liu, Z., Kong, X., Li, J. & Tan, R. (2015) A comparative analysis of urban and rural construction land use change and driving forces: implications for urban-rural coordination development in Wuhan, Central China. *Habitat International*, 47, 113-125.

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. (2005). *Geographical Information Systems and Science*. England, John Wiley & Sons Limited.

Luque, S., 2000. Evaluating temporal changes using Multi-spectral Scanner and TM data on the landscape of a natural reserve: the New Jersey Pine Barrens, a case study. *International Journal of Remote Sensing* 21, 2589–2611.

Machado, P.G., N.A.M. Rampazo, Picoli, M.C.A., Miranda, C.G., Duft, D.G., de Jesus, K.R.E. (2017) Analysis of socioeconomic and environmental sensitivity of sugarcane cultivation using a Geographic Information System. *Land Use Policy*, 69, 64-74.

McGarigal, K., Cushman, S. A., Ene, E. (2012) *FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps*. Computer software program produced by the authors at the University of Massachusetts, Amherst. Retrieved October, 2014, from http://www.umass.edu/landeco/research/fragstats/fragstats.html

Moeller, M.S., Blaschke, T. (2006) *Urban change extraction from high resolution satellite image*. ISPRS Technical Comm. II Symposium. Vienna, 151-156.

Nagendra, H., Munroe, D.K., Southworth, J. (2004) From pattern to process: landscape fragmentation and the analysis of land use/land cover change. *Agriculture, Ecosystems and Environment*, 101, 111-115.

Nassar, A.K., Blackburn, G.A. & Whyatt, J.D. (2014) Developing the desert: the pace and process of urban growth in Dubai. *Computers, Environment and Urban Systems*, 45, 50-62.

Patino, J.E., Duque, J.C. (2013) A review of sectoral science applications of satellite remote sensing in urban settings. *Computers, Environment and Urban Systems*, 37, 1-17.

Rogan, J., DongMei C. (2004) Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*, 61, 301-325.

Salvati, L., Sabbi, A. (2011) Exploring long-term land cover changes in an urban region of southern Europe. *International Journal of Sustainable Development & World Ecology*, 18, 273-282.

Salvati, L., Sateriano, A., Bajocco, S. (2013) To grow or to sprawl? Land cover relationship in a Mediterranean city region and implications for land use management. *Cities*, 30, 113-121.

Serra, P., Saurí, D., Salvati, L. (2017) Peri-urban agriculture in Barcelona: outlining landscape dynamics vis à vis socio-environmental functions. *Landscape Research*, 43, 613-631.

Serra, P.; Pons, X., Saurí, D. (2008) Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, 28, 189-209.

Serra, P.; Pons, X.; Saurí, D. (2003) Post-classification change detection with data from different sensors. Some accuracy considerations. *International Journal of Remote Sensing*, 24, 3311-3340.

Shahraki, S., Saurí, D., Serra, P., Modugno, S., Seifolddini, F., Pourahmad, A. (2011) Urban sprawl pattern and land use change detection in Yazd, Iran. *Habitat International*, 35, 521-528.

Soeille, P., Vogt, P. (2009) Morphological segmentation by binary patterns. *Pattern Recognition Letters*, 30, 456-459.

Soille, P. (2003) *Morphological image analysis: principles and applications*. Second ed. Springer-Verlag, Berlin/Heidelberg/New York.

Stuttard, M. 1992. GIS and remote sensing. In: Cadoux-Hudson, J.; Heywood, I. (Ed). *Geographic information 1992-93*. Taylor & Francis, London, 173-182.

Turner, M.G., Gardner, R.H. (Ed) (1991) Quantitative methods in landscape ecology. The analysis and interpretation of landscape heterogeneity. *Ecological Studies*, 82. Springer-Verlag, New York.

Turner, M. (1989). Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics*, 20, 171-197.

UAE Ministry of Information and Culture (2006). *UAE Yearbook 2006*. London: Trident Press Ltd.

Vogt, P., (2017) *Guidos Toolbox* (Graphical User Interface for the description of image objects and their shapes): Digital image analysis software collection available at the following web site: http://forest.jrc.ec.europa.eu/download/software/guidos

Yagoub, M.M. (2004) Monitoring of urban growth of a desert city through remote sensing: Al-Ain, UAE, between 1976 and 2000. *International Journal of Remote Sensing*, 25, 1063-1076.

Yagoub, M.M. (2006) Application of remote sensing and geographic information systems (GIS) to population studies in the Gulf: a case of Al Ain city (UAE). *Journal of the Indian Society of Remote Sensing*, 34, 7-21.

5.1. Introduction

The objective of this chapter is to examine the spatial consequences at district scale of LULC changes, applying a multivariate statistical analysis in order to understand the spatial dynamics of urban (services, industry and residential land) and agricultural sprawl with respect to the 62 analysed districts of Al Ain. Although similar approaches have been used in previous studies, this study makes a contribution in three aspects. First, the work is based on an empirical case showing the spatial implications of planning from a dynamic perspective, using a synthesizing methodology, factor analysis, and consideration of a high number of variables. Second, a combination of demographic, LULC and geographic variables has been introduced. This approach incorporates information provided from different sources and allows a more robust evaluation of spatial planning. Therefore, instead of analysing a specific spatial topic (industrial agglomeration, for example), this chapter analyses general LULC trends as a result of planning management at district scale. The third contribution is the application of an innovative multivariate statistical analysis that allows advanced comparisons of district-level changes.

5.2. Factor statistical analysis at district scale: data description

The spatial dynamics of Al Ain city were analysed at district level using the methodology previously applied by Serra et al. (2013, 2014), including census data and spatial analysis using GIS techniques. Given the lack of census data at district level before 2005, two years were considered, 2005 and 2010, using the same variables for both periods. The available variables were the following (Table 5.1): number of local and non-local people by sex; kilometres of main roads; and area (in hectares) of government employment houses, company camps, private housing polygons, public housing polygons, shopping centres, retail shops, religious facilities, recreation facilities, general industry, light industry, heavy industry, agricultural land, poultry farms, palm land, and commercial buildings.

The LULC were extracted from the Base Map for Al Ain 2014 (Al Ain Municipality) for 2005 and for 2014 that included the administrative boundaries of the 62 districts that conform Al Ain region, excluding Al Qua'a and Um Elzumol (see annex 1).

Variables	Source	Measurement units
Population by sex and origin		
Local males	Statistical censuses	Absolute number
Local females	Statistical censuses	Absolute number
Non-local (foreign workers) males	Statistical censuses	Absolute number
Non-local (foreign workers) females	Statistical censuses	Absolute number
Land-use at plot level and at district scale		
Government employment houses	Base maps	Hectares
Shoping centers	Base maps	Hectares
Retail shops	Base maps	Hectares
Commerce buildings	Base maps	Hectares
Religious facilities	Base maps	Hectares
Recreation facilities	Base maps	Hectares
General industry	Base maps	Hectares
Light industry	Base maps	Hectares
Heavy industry	Base maps	Hectares
Company camps	Base maps	Hectares
Farm land	Base maps	Hectares
Poultry	Base maps	Hectares
Palm land	Base maps	Hectares
Private houses	Base maps	Polygons
Public houses	Base maps	Polygons
Extracted from GIS techniques		
Lenght of main roads	Own elaboration	Kilometers

Table 5.1. Variables included in the statistical analysis, 2005 and 2010. Sources: Statistics Center of Abu Dhabi for census data; Al Ain Municipality and own elaboration.

5.3. Statistical Analysis

Factor analysis (FA), in general, and principal component analysis (PCA), in particular, are among the most common statistical methods applied in planning and socioeconomic studies (e.g., Nunes, 2002; Monastiriotis, 2009; Nosvelli and Musolesi, 2009; Salvati and Carlucci, 2016). The objective of FA is to obtain comprehensible new factors that express the essential information contained in a set of variables. Each of those variables is represented as a linear combination of a smaller set of common factors plus a unique factor assigned to each of the original variables (Afifi and Clark, 1996).

The equation is:

$$X_1 = w_{F1} + w_{F2} + \ldots + w_{Fp} + u_1$$

where X_1 is the standardised original variable, *w* the factor loadings of *Fp* common factors that describe the linear combination, and u_1 the unique factor specific to each original variable. The four steps used in FA include a correlation test of original variables, extraction of common factors, computation of a factor matrix, and calculation of factor score coefficients.

Two different tests were considered to assess the first requirement (i.e. the original variables must be correlated in order to share common factors): Measure of Sampling Adequacy (MSA) and the Kaiser-Meyer-Olkin (KMO). The MSA compares the correlation coefficients with the partial correlation coefficients for each original variable whereas KMO is a global test of the model and requires values above 0.6 to be considered appropriate for FA (Norušis, 1994).

The next step was the extraction of common factors, according to the eigenvalue criterion (namely, the variance explained by each common factor, being gradually smaller from the first to the last); the eigenvalue is usually greater than one because the variance of a standardised variable is equal to one (Hakstian *et al.*, 1982). The next criterion was communality, indicating the proportion of variance between original variables explained by the selected common factors. Values near one indicate that common factors retained the main information of original variables; values near zero indicate the opposite.

The third step was to obtain the factor matrix that shows the weight of each retained common factor in relation to each original variable, a value known as factor loading. These values can be near +1 or -1, reflecting a high weighting, or near zero, indicating little relationship. To obtain a more defined factor matrix that is easier to interpret, a common operation is to rotate the factor matrix using, as in our case, the Varimax rotation, an orthogonal rotation of each factor intended to get high loadings in just a few variables and the rest near zero (Norušis, 1994).

The last step was to calculate the final values for each common factor and municipality using factor score coefficients. To analyse regional changes over a period of time (5, 10, 15 or 20 years, for example), usually the comparison is made after applying different (and individual) FA as in Burinskienė and Rudzkienė (2004). Nevertheless, this option may complicate the interpretation of results because the number of main factors and their loadings can change from one time period to another (as happened when we tried this option) and therefore the comparison becomes meaningless. Consequently, once the factor score coefficients from the first period of analysis were obtained, they were applied to the standardised original variables from the second period. In this PhD research, the factor score coefficients were first obtained for the most recent period (2010) and then applied to the oldest period for which data were available (2005), with the objective of relying on the robustness of this method. The equation to quantify the value for each factor from the 2010 study period was:

$$F_1 = s_1^{t_1} x_1^{t_1} + s_2^{t_1} x_2^{t_1} + \ldots + s_p^{t_1} x_p^{t_1}$$

where F_1 is the corresponding value of the first common factor for a given individual and $s_p^{t_1}$ are the factor scores corresponding to p original variables $x_p^{t_1}$ from 2010. The following equation (3) was used to calculate the factor score coefficients for the 2005 data:

$$F_1 = s_1^{t_1} x_1^{t_2} + s_2^{t_1} x_2^{t_2} + \ldots + s_p^{t_1} x_p^{t_2}$$

where F_1 is the corresponding value of the first common factor for a given individual, $s_p^{t_1}$ are the factor scores corresponding to 2010 and $x_p^{t_2}$ are p original variables for 2005.

To synthesise the analysis of changes (and to avoid examining an excessive number of maps), the next step was to calculate the difference between the two time periods in the final values for each factor, in order to group the districts with similar dynamics (Sharaf and Serra, 2016).

5.4. Results of statistical analysis

Factor analysis results show that all the communalities, after the PC extraction, were above 0.5 (table 5.2) and that the KM0 value was 0.65. This test validated the application of principal component analysis because the original variables were sufficiently correlated to share common factors and each principal component retained more than the half of the original variance.

Variables	Communalities	
	Initial	After extraction
Local males	1	0.959
Local females	1	0.956
Non-local (foreign workers) males	1	0.841
Non-local (foreign workers) females	1	0.911
Government employment houses	1	0.925
Shoping centers	1	0.756
Retail shops	1	0.817
Commerce buildings	1	0.513
Religious facilities	1	0.95
Recreation facilities	1	0.949
General industry	1	0.855
Light industry	1	0.817
Heavy industry	1	0.756
Company camps	1	0.906
Farm land	1	0.834
Poultry	1	0.576
Palm land	1	0.788
Private houses	1	0.677
Public houses	1	0.808
Distance from main roads	1	0.827

Table 5.2. Initial communalities and values after principal component extraction.

According to 2010 data, six components were retained, covering 82.1% of total variance (21.3, 17.8, 13.5, 11.0, 10.1 and 8.4, respectively). After the *Varimax* rotation, these principal components were labelled PC1-PC6, as follows (Table 5.3): PC1, "foreign workers associated to commercial services" because the main related variables according to PC loadings were 'non-local men', 'non-local women', 'shopping centres', 'commerce buildings' and 'palm land' (the city centre has oases of palm land as well as commercial buildings); PC2, "local people associated to private and public housing" because the chief related variables were 'local men', 'local women', 'private houses' and 'public housing'; PC3, "industry" because the main associated variables were 'general industry', 'light industry' and 'heavy industry'; PC4, "rural activity" because the main variables were 'agricultural land', 'poultry', and 'distance from main roads'; PC5, "houses of big public and private companies" because the main variables were 'government employment houses', and 'company camps'; and PC6, "religious and recreational facilities" because the main variables were 'religious facilities' and 'recreational facilities'.

	Principal component					
Variables	**1**	**2**	**3**	**4**	**5**	**6**
Local males	0.03	0.97	-0.08	-0.09	-0.05	0.08
Local females	0.03	0.97	-0.08	-0.09	-0.05	0.08
Non-local (foreign workers) males	0.64	0.10	0.51	0.15	0.38	0.06
Non-local (foreign workers) females	0.81	0.50	-0.02	-0.03	-0.02	0.06
Government employment houses	-0.01	-0.06	-0.03	0.17	0.94	-0.01
Shoping centers	0.87	0.04	-0.03	-0.02	-0.03	0.00
Retail shops	0.87	0.20	-0.05	0.14	0.02	0.04
Commerce buildings	0.70	-0.08	-0.04	-0.09	-0.06	-0.03
Religious facilities	0.26	0.43	-0.01	0.05	-0.02	0.83
Recreation facilities	-0.07	-0.03	-0.01	-0.07	-0.03	0.97
General industry	0.00	-0.04	0.92	0.05	-0.05	0.06
Light industry	-0.07	-0.12	0.89	0.07	-0.03	-0.05
Heavy industry	-0.06	-0.12	0.08	-0.03	0.25	-0.04
Company camps	-0.03	-0.06	0.17	-0.07	0.93	-0.05
Farm land	-0.07	-0.10	-0.19	0.88	0.12	0.01
Poultry	-0.07	-0.04	0.19	0.72	-0.08	-0.05
Palm land	0.88	0.03	-0.02	0.08	0.00	0.08
Private houses	0.52	0.61	-0.09	-0.12	-0.07	0.07
Public houses	0.12	0.88	-0.07	0.08	0.00	0.05
Distance from main roads	0.22	0.00	0.09	0.87	0.10	0.01
Total variance (%)	21.30	17.80	13.50	11.00	10.10	8.40

Table 5.3. Final results from loading matrix. In grey, the values > 0.51 and in soft grey the values between 0.25 and 0.51.

The next figures show the results for PC1-PC6 for 2010 and the differences between 2010 and 2005. The classification choice was the "Quantile" option, showing six classes for the 2010 results and five classes for differences in principal components. Figure 5.1a shows PC1, "foreign workers associated to commercial services", being the districts with the highest values located inside the Downtown region together with some districts of the Centre region and in the western part of the Eastern. This emplacement indicated the importance of commercial services and the related population around the city centre, where oasis palm land is mainly located.

With respect to principal components (Figure 5.1b), the 10 districts with an increase in PC1, "foreign workers associated to commercial services" were Al Salamat, Al Maqam, Asharej, Alagabiyaa, Zakhir, Falaj Hazza, Al Dhaler, Al Jimi, Al Towayya and Al Masoudi. In point of fact, Al Ain has a higher proportion of Emirati nationals and non-locals, compared to local citizens. The residents are citizens of countries such as India, Pakistan, Eritrea, Ethiopia, Somalia, Bangladesh, Sri Lanka, Philippines, the United Kingdom, and many other jurisdictions across the Arab world (Elessawy and Zaidan, 2014). The majority of employees, either tour or permanently, move to the city for purposes of seeking employment, starting up their businesses or working for the existing enterprises in the area. Also, the unique socio-economic development in the Persian Gulf confirms that Al-Ain, as opposed to the other towns and cities of the UAE, is generally more tolerant to its neighbors and temporary residents.

a) b)

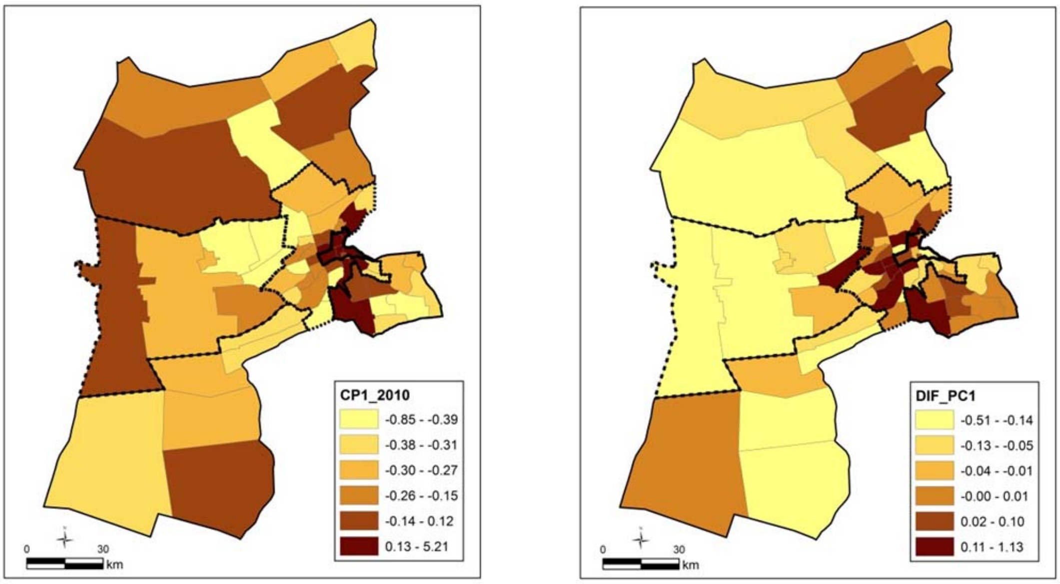


Figure 5.1. Results for 2010 PC1 "foreign workers associated to commercial services" (a) and for PC difference (b).

Accordingly, the Al Ain district map shows that Al Qattara and some other districts around the Central District were dominated by foreign workers in the years 2005 and 2010, respectively. It is fundamental to underscore the support of the relationship between workers and commercial services in the city. Investors and employers, therefore, find the Centre sector a good place to set up their businesses, factories, and companies. Given the feeling of safety, there is no apprehension about establishing companies in Al Ain. Accordingly, expatriate workers and the locals feel safe while going about their business. There is also a feeling of job security for employees who work in such companies. In view of all this, it is very likely that the companies are there to stay. In addition, one can feel secure about living with his or her family. Actually, this is reckoned as one of the factors that encourage people to move into the city.

Another reason for the activity and workers in the city is commerce and industry. Likewise, there are several service centers in the city, such as the Al Ain Mall in the Central District (Photograph 2.10). Ultimately, urban parts of Al Ain, such as Central District, are regarded as 24-hour economies. The malls and other consumer goods companies respond effectively to the household needs of the residents and provide employment opportunities to both locals and foreigners. Furthermore, other service industries including car sales, machinery mechanics, and specialized artisans are located in the areas of Al Qattar and Central District, which have attracted local citizens and foreigners equally.

In addition, social amenities and utility services have supported the relationship between economic activities and workers in the city. In this case, hospitals such as Al Noor and Oasis (Photograph 2.9) are recognized for providing quality healthcare in cardiology to residents and other patients from all over the world. By the same token, schools and higher education institutions provide quality education and training to local and international students; most of these are private schools that usually cater to the needs of expatriates, like New York Film Academy, Al Ain English-Speaking School, Al Dhafra Private School in the Al-Manaseer area, and Al Ain International School.

The Central District also houses the eastern zone headquarters of the Abu Dhabi education authority, the Abu Dhabi Education Council. Moreover, the residents enjoy clean water, a contrast to the water quality problems common in most cities of the world. With State-owned Etisalat and private communication companies, adequate telephone, cell phone and Internet services are provided in the city. Additionally, road networks in the UAE are excellent, busses operate within and outside the city, and taxi services are plentiful and affordable. For drivers with an American or European license, transferring to the UAE one is not a complicated process.

The relationship between businesses and workers is influenced by the law on business ventures. In this context, the general rules of investments in the United Arab Emirates are favorable to foreigners. Investments in free trade zones give foreign investors 100% foreign ownership of the enterprise, 100% import and export tax exemptions, and 100% repatriation of capital and profits. Accordingly, they are privileged with corporate tax exemptions of up to 50 years, no personal income taxes, assistance with labor recruitment, and additional support services like sponsorship and housing. The above factors, coupled with UAE culture, provide a pristine environment and even a permanent residence for a business venture.

Figure 5.2 shows the location of “local population in private and public housing” (PC2). In 2010, private and public housing were mainly provided in Al Mawaiji, Al Maqam, Al Salamat, Al Yahar, Zakhir, and Um Ghaffa districts, with a number of the residents living in these areas (Figure 5.2a). However, there is a distinction between two classes of people in these regions: those who own their homes and those who pay rent or mortgage to the government and estate owners. The regions offering public housing are a consequence of the government’s efforts to improve living conditions through the housing programs begun in the early 1970s. The enormous wealth and small population of the country, combined with a desire for rapid development, resulted in building a number of urban communities and offering them to the citizens. However, the population has increased over time, exerting pressure on the available housing and some who are able to build houses or buy homes do so in the urban areas. It is also important to note that private housing also dominates in the rural regions of the district and a variety of services are offered in this area, including shopping malls, grocery shops, salons, and retail shops.

a) b)

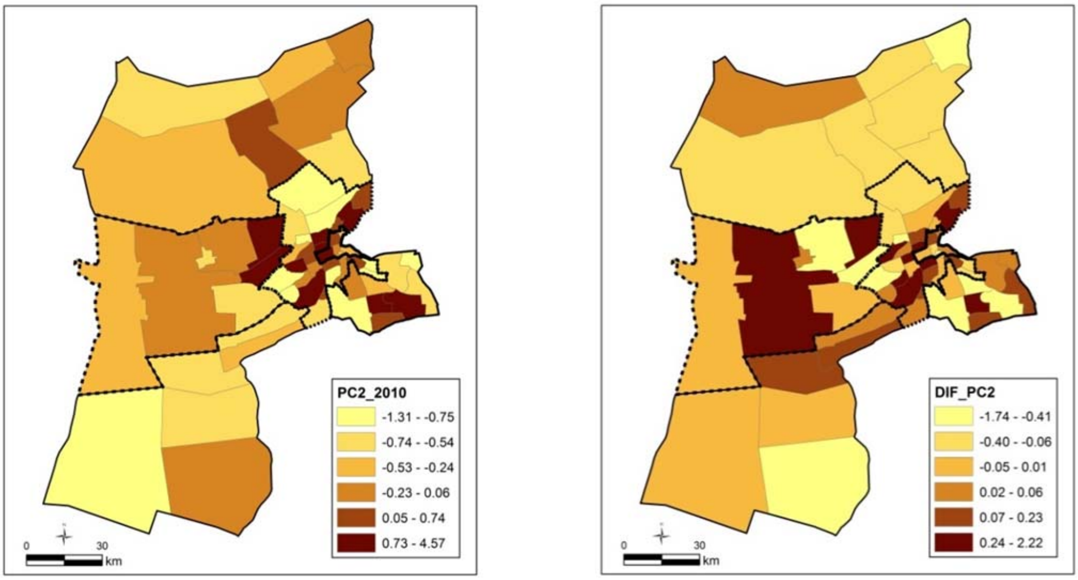


Figure 5.2. Results for 2010 PC2 “local population in private and public housing” (a) and for PC difference (b).

The districts with the highest increase in “local population in private and public housing” (PC2) were located around the city centre and in some districts of the Western and Eastern regions very close to the Centre region, with the exception of Remah: Hili, Al Foah, Al Towayya, Falaj Hazza, Zakhir, Al Shuaibah, Asharej and Al Bateen (Figure 5.2b). This is an indication that the other areas have grown into commercial centers and there may be relocation, whereby the citizens and foreigners are likely to move out to the other towns for the fundamental goal of developing their businesses. In the city, it is also common to find that two or three workers share the rent of one housing unit. Previously, the government built free public housing for locals; notably, the government now offers loans for locals to build their own homes. This is usually in the interest of cutting costs in lieu of the rather high costs of rental housing.

Figure 5.3a shows the situation of “industry” (PC3) in 2010; the districts with the highest values were located outside the city centre and along the E-22 and E-30 roads (Al Saad, Industrial Town and Sanaiya).

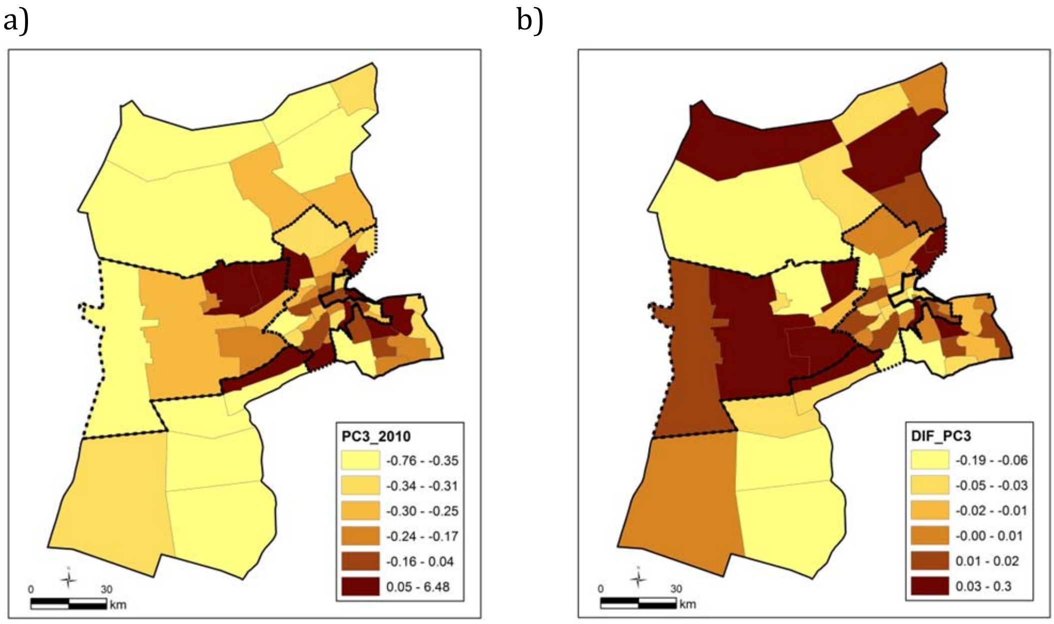


Figure 5.3. Results for 2010 PC3 “industry” (a) and for PC difference (b).

The districts with the highest increase in “industry” scores (PC3) were Remah, Al Rawdha, Industrial Town, Al Yahar, Al Markhaniya, Sanaiya, Al Sarooj, Al Khrair, Hili, Al Foah, Al Hayer and Al Ajban (Figure 5.3b). In both 2005 and 2010, many industries dominated in the Sanaiya region, as confirmed with the map indicators. The industries range art centers to motor manufacturing, including Al Futtaim, Al Majid, Premier, Liberty Abu Dhabi Automobiles, Hyundai, Al Habtoor Royal Cars, Eastern and Galadari Automobiles (Mazda). Sanaiya is, by far, the most industrialized region of Al Ain, producing some of the most trusted and popular motor models in the world. Although one of the richest zones of Al Ain, a few challenges could soon be facing the region, such as air and water pollution as a result of industrial processes.

The situation of “agricultural activity” (PC4) is shown in Figure 5.4. The districts with the highest values in 2010 are mainly located outside the city centre and inside the Southern, Western and Northern regions (5.4a), as reported in chapter 4. The districts with the highest increase in principal component scores were Abu Krayyah, Al Araad, Al Wagan, Al Yahar, Al Khrair, Al Shuwaimah, Al Mutaredh and Al Khabisi, corresponding to the Western, Southern and Eastern sectors (Figure 5.4b).

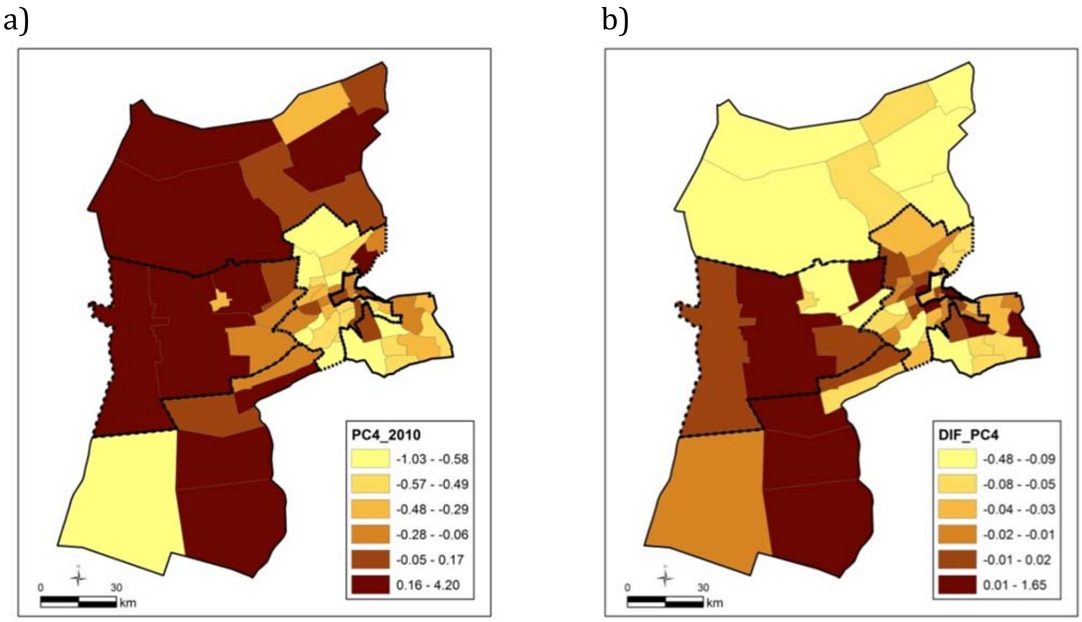


Figure 5.4. Results for 2010 PC4 “agriculture” (a) and for PC difference (b).

Figure 5.5 shows the location of “big public and private companies” (PC5), with the highest values mainly in the large districts outside the city centre (5.5a and 5.5b). Finally, Figure 5.6a shows the location of “religious and recreational facilities” (PC6), mainly around the city centre and in the north and south. According to the difference in principal components (Figure 5.6b), the districts with the highest increase in “religious and recreational facilities” scores were Al Araad, Al Wagan, Zakhir, Sanaiya, Hili and Al Towayya.

a) b)

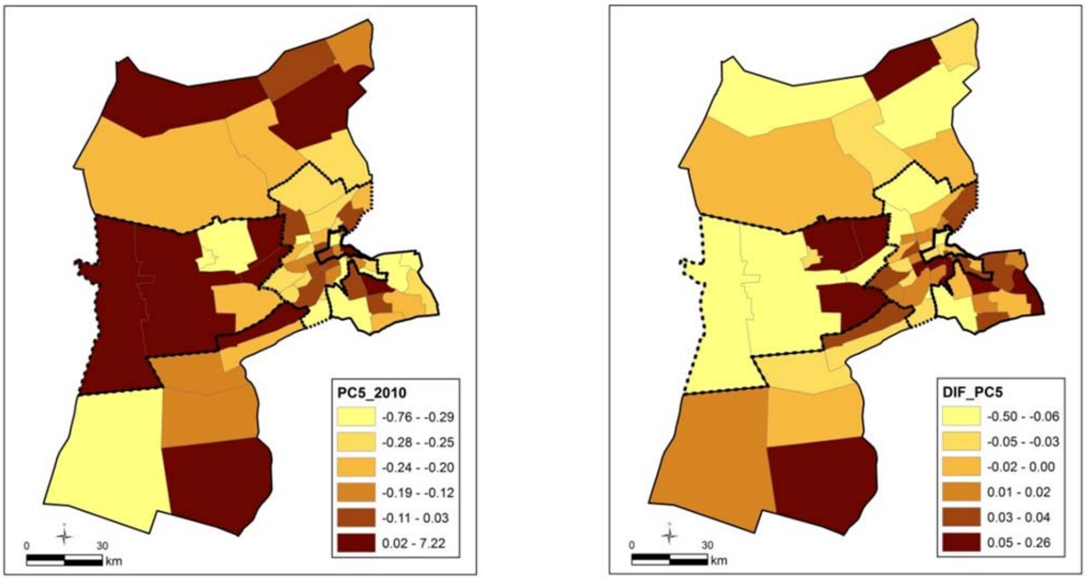


Figure 5.5. Results for 2010 PC5 “houses of big companies” (a) and for PC difference (b).

a) b)

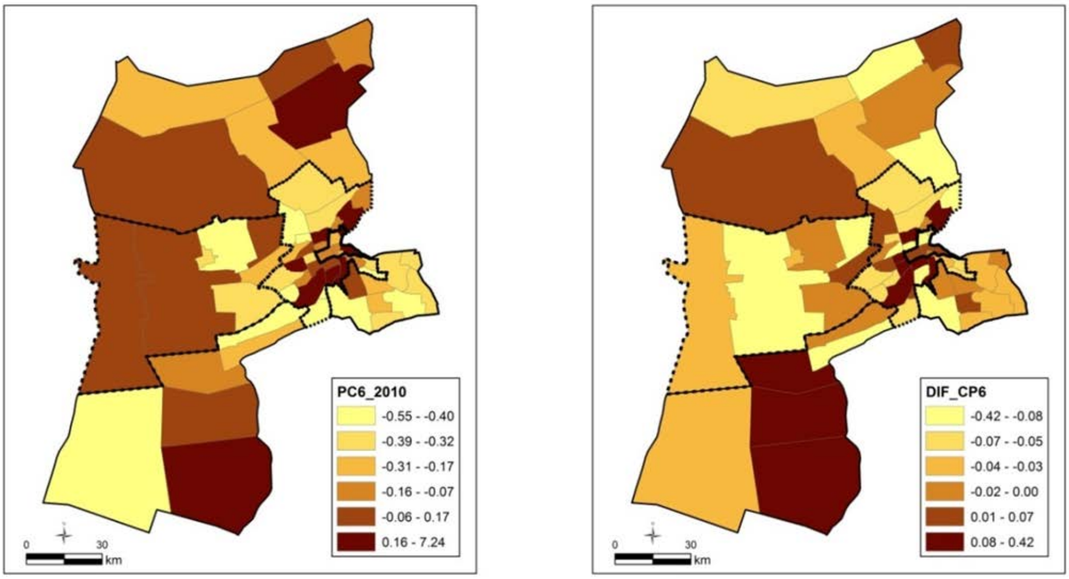


Figure 5.6. Results for 2010 PC6 “religious and recreational facilities” (a) and for PC difference (b).

5.5. Conclusions

This chapter comprehensively analyses and highlights the spatial consequences at a district scale of LULC changes through multivariate statistical applications. It also describes the spatial dynamics of urban regions such as industry and residential land use, and the agricultural sprawl evident in the 62 districts of Al Ain. Rapid urban development sprawl began during the 1980s and can be attributed to the constant migration of local residents from the Downtown to the Central District and to the West. The statistical analysis associated the development with the growth of private and public housing, the integration of religious facilities, and the presence of foreign workers in Al Ain. These factors allowed stakeholders to gain more space and comfort, and augmented the appeal of the developing service sectors located in the West such as Maqam Palace, UAE University or Tawam Hospital. Besides the local Emiratis, the service sector development, mainly in the Downtown sector where the palm oasis is located, has attracted a huge number of foreign workers from India, Pakistan, and Egypt, among other countries. Additionally, both women and men stated that they were attracte to the improved private housing and religious facilities in the region.

The multivariate statistical assessment of LULC indicates that in Al Ain the improvement of commercial services has augmented the presence of foreign workers. The highest values were located inside the Downtown sector together with some districts of the Central sector and in the western part of the Eastern sector. Notably, the placement illustrated the importance of commercial services and the related population within the city center, especially where the palm oasis is situated. In addition, it is important to underline the relationship between workers and commercial services in the city. These aspects have prompted investors to identify the Central District as a convenient place to establish business, factories, and organizations. Additionally, the suitable situation serves also as an indicator for other districts that have developed their commercial services, and thus with a potential for housing relocation. Both citizens and foreigners are bound to shift and settle with the intent of establishing and developing their businesses. Finally, in the case of agricultural activity from 2005 to 2010, the sprawl to the West and South was related to the distance from the main roads and the results showed also the lack of increment in the North sector.

The rapid urban sprawl has enhanced commerce and industries in Al Ain, fulfilling the household needs and offering employment opportunities for both foreigners and locals. Social amenities and services such as health care facilities, communication, transportation, and learning institutions have highly developed. The services have been propelled by the presence of diverse economic activities and sufficient manpower from both local and foreign workers in the city.

The present research successfully combined the evaluation of LULC changes, demographics, and geographic variables in the robust evaluation of spatial planning. However, constant urban expansion in future decades is bound to cause adverse environmental effects; therefore, continued caution in urban planning is recommended, as described in the next chapters.

5.6. Chapter bibliography

Afifi, A. A., Clark, V. (1996) *Computer-Aided Multivariate Analysis*. London, Chapman & Hall.

Burinskienė, M., Rudzkienė, V. (2004) Comparison of spatial-temporal sectoral development and sustainable development strategy in Lithuania, *International Journal of Strategic Property Management*, 8, 163-176.

Elesssawy, F., Zaidan, E. (2014) Living in the move: impact of guest workers on population characteristics of the United Arab Emirates (UAE). *The Arab World Geographer*, 17, 2-23.

Hakstian, A. R., Rogers, W. T., Cattell, R. B. (1982) The behavior of number of factors rules with simulated data. *Multivariate Behavioral Research*, 17, 193–219.

Monastiriotis, V. (2009) Examining the consistency of spatial association patterns across socio-economic indicators: an application to the Greek regions. Empirical Economics, 37, 25-39.

Norušis, M. J. (1994) *SPSS Professional Statistics 6.1*. Chicago: SPSS Inc.

Nosvelli, M., Musolesi, A. (2009) Water consumption and long-run socio-economic development: An intervention and a principal component analysis for the city of Milan. *Environmental Modeling and Assessment*, 14, 303–314.

Nunes, P. A. L. D. (2002) Using factor analysis to identify consumer preferences for the protection of a natural area in Portugal. *European Journal of Operational Research*, 140, 499–516.

Salvati, L., Carlucci, M. (2016) Patterns of sprawl: the socioeconomic and territorial profile of dispersed urban areas in Italy. *Regional Studies*, 50, 1346-1359.

Selim, G.M., Gamal, M. (2007) Neighborhoods and residential communities. The case of Al Ain UAE. *Housing Symposium* 3, 343-361.

Serra, P., Vera, A., Tulla, A. and Salvati, L. (2014) Beyond urban–rural dichotomy: Exploring socioeconomic and land-use processes of change in Spain (1991–2011). *Applied Geography*, 55, 71-81.

Serra, P., Vera, A. and Tulla, A.F. (2013) Spatial and Socio-environmental Dynamics of Catalan Sectoral Planning from a Multivariate Statistical Analysis using 1980s and 2000s Data. *European Planning Studies*, 22, 1280-1300.

Sharaf, S.A., Serra, P. (2016) *Land-use dynamics in Al-Ain city (United Arab Emirates): a spatial statistical analysis at district scale*. 2nd Annual International Conference on Geography, 6-9 June 2016, Athens, Greece. Athens Institute for Education and Research.

6.1. Introduction

In this chapter the main driving mechanisms of LULC changes and landscape transformations and their socio-environmental consequences will be analysed. The inclusion of driving forces for analysing LULC changes is a common task in spatial research (Yagoub 2004; Geist et al., 2006; Chowdhury, 2006; Serra et al., 2008; Pineda Jaimes et al., 2010; Wu and Zhang, 2012; Nunes, 2012; Schmitt-Harsh, 2013; Meneses et al., 2017; among others). According to Verburg et al. (2004), the selection of driving forces is very much dependent on the theoretical and behavioural assumptions used in modelling LULC system. Those models that integrate the analysis of different LULC conversions, as in the case of Al Ain city, commonly use a long list of driving forces, especially when large areas are analysed because of the higher LULC diversity.

On the other hand, three different approaches to quantify the relations between LULC change and its driving forces can be applied. The first approach applies economic models based on economic input-output analysis, the second uses econometric models and statistical techniques, and the third relies on expert knowledge and, when quantitative information is not available, the development of qualitative modelling. This PhD thesis takes the third approach.

6.2. Al Ain driving forces

The LULC and landscape dynamics are modelled as a function of a selection of socio-economic and biophysical variables that act as "driving forces" of change. According to Tian et al. (2017), the driving mechanisms and the characteristics of urban expansion are variable in different settings and countries. They are generally subdivided in three groups (Turner II et al., 1995): socio-economic drivers, biophysical drivers and proximate causes (land management variables). Socio-economic drivers can include demographic, economic, technological, sociocultural and institutional causes (van Vliet et al., 2015). According to European Environment Agency (EEA) (2016), the most important socio-economic variables are transport infrastructure (road density and railway density), demography (population density and age structure), economic situation (GDPc and employment ration), governmental effectiveness and changes in lifestyle (e.g. household size and car ownership). On the other hand, biophysical factors do not drive LULC changes directly but they can influence LULC allocation decisions, for instance through soil quality, topography or solar radiation (Verburg et al., 2004; Serra et al., 2008; Nunes, 2012). These factors do not change over time and cannot be modified in general but are considered in planning (EEA, 2016).

A crucial element of driving forces to consider is the scale of analysis. According to ESPON (2010), three scales and five domains are differentiated:

- Macro level, corresponding to political and economic paradigms that shape the nature of the urban societies.
- Meso level, where much of the discourse about the causes of urban sprawl can be found.
- Micro level, which captures the decisions of individual actors in the urban system.
- Society, economy, governance, transport and land, the main domains related to changes in the main functions of urban regions: population, transport, tourism, manufacturing, and knowledge and decision-making in the private and public sectors. At macro and meso scales, the society domain can include population growth and declining household size whereas at micro scale individual decisions, housing preferences and quality of life can be factors to consider. In the economy domain at macro scale, globalization and economic growth can be the main factors whereas at meso and micro scales rising living standards, price of land, and competition between local administrations can be contemplated. In the case of governance, international regulations at macro scale, governmental legislations at meso scale, and enforcement of existing master plans at micro scale can be envisaged. In the transport domain, at macro scale the cost of fuel and transport costs in general should be considered, whereas at meso and micro scales some of the factors to include are private car ownership, the availability of roads and public transport. Finally, in the land domain, the

local geography and the environment are causes to contemplate at meso and micro scales.

Urban growth is a universal phenomenon which is a result of the population increase as well as infrastructure and economic projects. It is indisputable that Al Ain is among the fastest growing cities in the Arabian Peninsula. It has developed from a desert oasis into a thriving modern city within four decades (Statistics Centre Abu Dhabi (2013). The driving forces of urban growth and LULC changes in Al Ain region include oil in the Abu Dhabi Emirates, the city's physical and geographical location, government developmental policies (master plans), economic and social development, population growth and family patterns, road construction, water availability, transport infrastructures and tourism (Figure 6.1). Therefore, the level of urban sprawl is mainly a function of demographic and socio-economic drivers (Elsheshtawy, 2011). While many cities around the globe are developed at the expense of agricultural land, in Al Ain the growth is based on the conservation of agricultural land (oases) and the reclamation of the desert, as shown in this PhD thesis. It is imperative to note that the income from oil is a significant driver for the city's development, but even more important is the resolve of the UAE government to initiate policies in support of development.

6.3. Driving forces of LULC changes

6.3.1. Oil in the Abu Dhabi Emirates

The development of Al Ain city and its rapid transformation from a desert region to one with a growing economy has been made possible by the revenue from oil exports (Tourenq and Launay, 2008). As explained in chapter 2, oil development in the Abu Dhabi Emirates from 1962 greatly contributes to the world's reserves, and there is little doubt that it will continue to provide sufficient income for both economic development and the expansion of social amenities within the region of Al Ain. Whereas there is no oil in the city of Al Ain, the effects of the oil in Abu Dhabi city are felt across the entire region.

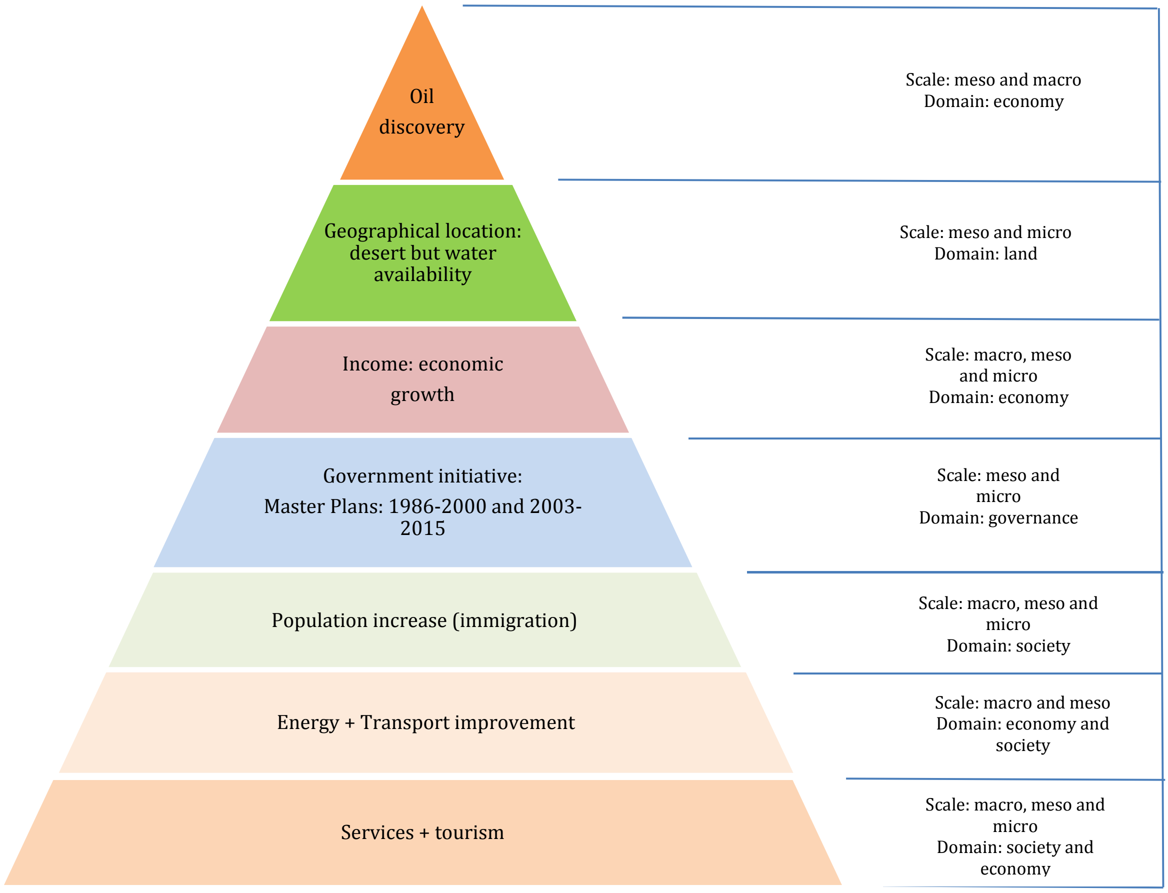


Figure 6.1. Driving forces of LULC changes in Al Ain. Source: Own elaboration.

The oil industry contributes to Al Ain city's economic growth in two main ways. First, the energy industry is a vital sector of the economy since it creates jobs and value through extraction, transformation and distribution of energy goods and services across the region. In a sense, the energy sector has contributed to the growth of Al Ain city by creating employment opportunities, investing in varied sectors of the economy and purchasing of services and goods. Second, the oil industry strengthens the entire economy as it is the driver for almost all goods and services, playing a crucial role in the construction, transportation and manufacturing sectors. Oil-related jobs can be categorized as having direct, indirect and induced impact. Direct jobs are held by those workers who are contracted or employed by oil firms to produce oil products for customers. Indirect jobs refer to the positions created in industries and firms that provide the oil companies with services and goods. Induced impacts are generated by household spending that results from indirect and direct impacts from an economic activity. Therefore, induced effects arise when workers from the oil industry plus its suppliers spend their salaries and other earnings in the community. In this regard, individuals who are working in the oil sector spend their funds and create demand for services and goods.

6.3.2. Geographical location

With its position at the junction of two major trade routes, the city of Al Ain occupies an important location as a market centre and stopping point for vehicles transporting merchandise across the UAE to India and Iran (Yagoub, 2006). Its physical geography, inserted in an oasis area with fresh groundwater and comparatively deep loamy soils, has promoted an agricultural system that meets the needs of the local population and satisfies the demands of those transporting goods across the region (Ahmed, 2017). Moreover, the proximity and the open-borders policy that is practiced between Buraimi District, in the Sultanate of Oman, and Al Ain have promoted economic activities within the city. Al Ain has also become a hub for the Omanis who rely on the city for their shopping, work and the education of their children.

The city of Al Ain is endowed with varied natural resources unlike other cities in the UAE, a factor that has greatly contributed to the increased settlement, investment and economic growth. Largely, the city is known for its palm plantations and oases that have attracted the interest of locals within the city. Over time, the presence of oases has improved the city's temperatures and contributed to its landscape. Trade caravans usually converged in the city before proceeding with their journeys to other parts of the Middle East. As the trade caravans settled, other businesses emerged, which further improved the economic status of the city (Chowdhury et al., 2015).

6.3.3. Economic development

It is important to note that the entry of new industry players and an increase in demand for services and goods has greatly improved the potential of the city and aided its economic growth. Better incomes for the residents improve their economic status, and this has a key impact on the city's development. Table 6.1 shows the evolution of GDP from 2004 to 2013, where the economic increase is clearly visible. Similarly, high demand for services and goods has opened the market for new players and this has created additional job opportunities (Tables 6.2 and 6.3).

Indicator	**2004**	**2009**	**2010**	**2011**	**2012**	**2013**
GDP (Million AED)	291.1	546.5	639.9	846.6	909.7	931.7
GDP oil (%)	50.7	51.0	49.6	57.3	57.1	54.9
GDP non-oil (%)	49.3	49.0	50.4	42.7	42.9	45.1
GDP per capita (Thousand AED)	221.4	293.1	352.2	391.7	394.5	380.4

Table 6.1. GDP evolution at current prices in the Abu Dhabi Emirate. Source: Statistics Center of Abu Dhabi 2016.

Labour Force (15 years and over)	**1985**	**1995**	**2001**	**2005**	**2011**
Local	22 358	43 183	71 651	85 838	132 000
Non-local	275 048	489 698	604 896	729 473	1 311 800
Total	297 406	532 881	676 547	815 311	1 443 700

Table 6.2. Evolution of labour force from 1985 to 2011. Source: SYB, 2017.

Employee by nationality	**1985**	**1995**	**2001**	**2005**	**2008**
Local	21 579	40 981	60 753	75 518	86 272
Non-local	272 945	484 476	588 589	711 220	803 145
Total	294 524	525 457	649 342	786 738	889 418

Table 6.3. Changes in employment by nationality from 1985 to 2008. Source: SYB, 2010.

Apart from the increase in the residents' purchasing power, better salaries have also contributed to the emergence of new housing. In fact, the application for housing mortgages in the city has doubled over the last decade (Statistics Center Abu Dhabi, 2016). Besides, difficulties that are associated with credit default have been reduced due to the present favorable economic situation within the city. Usually, housing in Al Ain is affordable and in close proximity to other important social amenities, such as learning institutions, health facilities, and recreational sites, as shown in this PhD thesis. Most of the housing projects that have been funded by the government have been occupied immediately after completion. The higher income of both private and government sector employees has always been the main reason for increased demand for housing (Abu Dhabi Housing Authority, 2016). Apart from the housing demand for purchase, the higher incomes have also influenced the expansion of rental units.

Higher income levels in the city of Al Ain have also contributed to better government revenues. It is indisputable that an increase in revenues from income attributed to higher salaries has provided the government with more money to initiate vital development projects. Expansion of the housing, transport and educational infrastructure has been witnessed due to increased government revenues (Statistics Center Abu Dhabi, 2016). Definitely, an increase in the residents' income has had a positive impact on the city's economic growth and development.

6.3.4. Government development policies

As explained in chapter 2, the first promise from Sheikh Zayed, the first president of UAE, was to make the nation a "green haven", which means the government was determined to make several changes in the land to suit their vision. Consequently, the government has managed the transformation of a desert area into an agricultural land such that currently Al Ain is considered the food-basket of the country. However, this transformation did not come automatically as the government has injected a lot of funds to ensure that the vision of the city is achieved. The commitment by the government has helped in financing mega projects such as reclamation of desert land and construction of infrastructure and irrigation projects. These and other projects have contributed in one way or another to LULC changes shown in this research. The government is also determined to make the country most well developed in the region, which explains why it injects a lot of funds into development projects. Although the availability of oil in the region makes it possible to finance these projects, it takes determination by the government to channel the funds to development and not use them for personal gain.

Through the Al Ain Municipality and the Town Planning Department, the government designed two master plans, as explained in chapter 3, presenting various policies to contribute to the growth of the city. The Urban Planning Council identified planning opportunities in all the 64 districts that form Al Ain and has embarked on the process of managing all the construction processes associated with the rapid increase in population (Ahmed, 2017). It is incontestable that these master plans have played a key role as a driving force for growth and development, proposing new ways to develop and leverage the economic opportunities while at the same time promoting agricultural activities and preserving cultural heritage. Developed through cooperation between international planning specialists, the Municipality, government representatives, and the city's residents, the Master Plans contain policies on land use, building heights and densities, infrastructure, quality housing and transportation. At the same time, the government development policies ensure a high quality of life for the residents by providing sufficient community facilities, such as hospitals and schools, along with various plazas and parks. The Council also works alongside the Abu Dhabi Culture and Tourism Authority, Al Ain Surface Transportation Master Plan (STMP), and utility providers who are working to deliver on the city's current and future demands for water and power.

To increase agricultural land, the master plans have promoted the investment of money earned from oil in building dams and desalination plants to develop the land given by the government to Emiratis to create their own farms, along with providing subsidies for machinery and fertilizers and price guarantees for produce. Finally, through Plan Al Ain 2030, the government is also working to develop Al Ain into an environmentally, economically, and socially sustainable city (Tourenq and Launay, 2008). The policies focus on five diverse initiatives including intelligent use of the available land, increase in the density of buildings and the city centre, creation of a surface tram system, preservation of surrounding agricultural areas, and the protection of designated environmental zones.

6.3.5. Population increase

One of the first and foremost reasons for urban growth is an increase in population, which may be rapid due to natural increase or migration to urban areas. In many cases, the most significant reason is the movement of people from rural to urban zones within the country and/or the international migration for labour reasons. Push factors, or conditions in the place of origin which are perceived by migrants as detrimental to their well-being, economic security, or job opportunities, as well as pull factors, or the circumstances in new places that attract people to move there, should be considered. According to Bhatta (2010), cities are perceived as places where people can have a better life because of better opportunities and services, and higher salaries. These better conditions attract poor people from rural areas inside and outside a country; this situation can be clearer in case of worsening environmental conditions as in droughts or floods. In cities, basic and specialty services, job opportunities, entertainment (restaurants, theatres, etc.), and education are more available.

According to chapter 2, population in Al Ain has grown rapidly in the last four decades; this has significantly contributed to the progress of the city. The city's population has continuously increased as a result of the migration and settling of individuals who provide the work force for industries and business units (Elsheshtawy, 2011). In consequence, the growth in population has noticeably improved the economic potential of the city. The government measures of subsidies, family aid and an advanced health care system have also contributed to the increased population. The growth in population has been accompanied by a change in family settlement behaviour patterns, pushing for more houses in the city. The families were divided into smaller groups, particularly as a result of the government grant for new houses for each married man and for divorced or widowed women. For instance, it was not allowed to construct buildings with more than four floors; housing policies addressed both the existing stock (old government housing and spontaneous housing areas) and new citizen housing both for government houses and private dwellings. According to Selim and Gamal (2007), the government defined the need for citizen housing; in the 2000s, for example, private households needed at least a completed house on a 45m * 45m plot free of cost or a plot of 60m * 60m on which to construct a house with further financial assistance from the government.

Urban expansion can also be attributed to the intra-city and intra-emirate migration. The opportunities available in Al Ain city have attracted more people. For instance, an increase in job opportunities has acted as the main pull factor into the city. This has been complemented by the government investment in education, health care, housing and the transportation network in order to support the general quality of life.

6.3.6. Improvement of infrastructures

Through the Department of Transport (DoT) in Abu Dhabi, the government has initiated road projects in the city of Al Ain in order to improve its outlook and connectivity. As new businesses emerge in the city, the construction of a reliable road network improves their impact and provides new impetus for the development of the city. By establishing the Transportation Management Center (TMC), the UAE initiated a process of making sure that information is gathered, examined and disseminated to improve the transportation and communication network within the city. This initiative opened the city to investors who have significantly contributed to the growth of Al Ain. Better movement of services and goods has boosted business operations and growth. Other transportation networks that have been developed include the metro bus and train system (Abu Dhabi Department of Transport, 2009), which has enhanced cross-border transportation and opened Al Ain city to the neighbouring regions. Apart from its contribution to the construction of roads and other transport systems, the government has also improved the housing sector and enhanced the welfare of the residents within the city (Ahmed, 2017). Through the Emirati Housing Corporation, the government initiated the development of affordable houses in Jebel Hafeet in Al Ain. It built more than 1,500 units with well-developed roads, sewage and rainwater systems. As such, an increase in settlement within the city has provided the region with competent and affordable labour; this contributes to the growth and expansion of Al Ain.

Additional construction projects have been initiated across the city with the support of the government to solve housing challenge. An example has been the Al Gharaibah project that provided accommodation for more than 1,000 homes for the residents of Jebel Hafeet mountain. The government has also facilitated the construction of villas with the support of private investors in other parts of the city. Access to affordable housing has undoubtedly contributed to the growth and development of Al Ain.

6.3.7. Services and tourism

As shown in this PhD thesis (chapters 2, 3, 4 and 5), the services sector has increased in all the districts, mainly in commercial and utility services and social amenities. In the case of tourism services, the city of Al Ain has attracted a significant number of tourists over the past two decades and many Emirati nationals have holiday houses. There is little doubt that the city is a popular weekend destination for many individuals and families from the capital and it has rapidly developed as an important tourist site (Elsheshtawy, 2011). Located in the southern part of the UAE, Al Ain is the only city in the region that is not bordered by a coastline. Nonetheless, it has various geographical features that have contributed to its growth and expansion over the years. Apart from being a route to other parts of the Middle East, such as Oman, in 2011 the city became the first in the UAE to be considered by the United Nations as a heritage site. The attractiveness of the city has been attributed to its unique geographical features, and these have increased tourism and international investment leading to the city's expansion. Tourists from other parts of the UAE and the Middle East have considered Al Ain city as a favourable destination compared to other cities in the region. Certainly, revenues from tourists who are interested in enjoying the friendly and serene environment within the palm plantations have increased and this contributes to the city's growth and development. The Sheikh Zayed Palace Museum, a former residence of Sheikh Zayed, has become a vital tourist attraction within the city. The museum holds the rich history of the city and the country's leadership, and therefore has been of interest to tourists. The interior of the museum has been improved to reflect the status of the Sheikh. Al-Jahili fort has been classified as a world heritage site and this contributes to the popularity of Al Ain city in the UAE (Abu Dhabi Authority for Culture and Heritage, 2018).

The Al Ain Zoo is also a tourist attraction that has drawn more visitors. One of the largest animal enclosures in the UAE, it is famous for its oryx, Arabian antelope and the African gazelle (Elsheshtawy, 2011). Other animals that have made the zoo more famous include lions, pumas, tigers, jaguars and leopards. It is imperative to note that the number of tourists visiting the zoo has greatly increased and this has contributed to the city's economic growth and development. Other features that contribute to tourism within the city include the camel racing, public gardens, Hili Archeological and Mubazzarah parks, and the valleys and dunes like the Salimi Valley.

6.4. Socio-environmental consequences of horizontal urban sprawl

The analysis of socio-environmental consequences of the horizontal urban sprawl of Al Ain is needed to understand its particular growth of planned urban sprawl, with affordable housing and public services (religious, cultural, etc.) and its impact on the environment. As a consequence of the specific driving forces of Al Ain, the socio-environmental consequences also will be unique.

All the LULC changes, landscape dynamics and socioeconomic transformations analysed, together with natural constraints, have produced some negative socio-environmental consequences that should be considered in future expansion. A model based on sprawled extension is considered a threat for urban sustainable development since it implies a strong increase in land taken, water and energy consumption, clearer when the sprawl is uncontrolled and uncoordinated (Bhatta, 2010). Many experts urge careful consideration of these impacts in order to make land use more sustainable. For instance, the Joint EEA-FOEN Report (EEA, 2016) notes that urban sprawl is a growing and serious problem worldwide that impacts environments and socio-economic structures (Table 6.4). However, so far, no country in Europe has truly established effective quantitative limits for urban sprawl, although some countries have established targets aimed at reducing the rate of land uptake for built-up areas.

Theme	Environmental consequences
Air pollution	Higher air pollution and noise
Energy and climate change	Higher energy consumption and higher greenhouse gas emissions per person
Flora and fauna	Loss of habitats for native species and spread of invasive species
	Increased road mortality of wildlife and destruction of burrows
	Increased fragmentation of the landscape: barrier effect, habitat fragmentation, disruption of migration pathways, impediment of dispersal, isolation of populations, degradation of ecological networks and loss of existing green infrastructure
Geomorphology	Local alterations of dunes and soil salinity
Landscape	Changes in the character and identity of the landscape
Local climate	Variability in temperature and modification of humidity conditions
LULC	Land uptake, removal and alteration of vegetation, soil sealing
	Overgrazing can lead to loss of habitat, loss of vegetation and soil erosion which ultimately leads to the destruction and degradation of natural plant community
Water	Increased water consumption
	Hydrological alterations, modification of surface water courses
	Total transfer of natural flow within the traditional *aflaj* system
	Water pollution
Theme	**Social impacts and quality of life**
Low-density housing	Desired place to live for many people because low-density housing offers more privacy and larger garden areas than densely built-up parts
	Higher proportion of single households leads to a more resource-intensive living style
Social interaction	Greater segregation of residential development based on income
	Longer commuting times and a reduction in social interaction

Table 6.4. Some impacts of urban sprawl in Al Ain. Source: Adapted from EEA (2016) and Hennig et al. (2015).

According to EEA (2016), urban sprawl affects biodiversity, reducing the amount of habitat available for wildlife because human disturbances are more spatially distributed in areas with high levels of sprawl. The development of residential and industrial areas destroys or degrades existing habitats, including micro habitats essential for many insects and plant species, and directly reduces species richness. Abu Dhabi has a remarkable number and variety of plant and animal species; according to the Environment Agency of Abu Dhabi (2008) sand, especially when it is stable, provides a favourable substrate for plant growth in warm, arid to semi-arid climates because sand sheets act as reservoirs for water in the short to medium term. Although the vegetation coverage becomes patchy, a number of important communities can be encountered; for instance, the ghaf tree (*Prosopis cineraria*), the samr tree (*Acacia tortilis*), the sedge (*Cyperus conglomeratus)*, or shrubs such as the *Haloxylon salicornicum* or the harma (*Rhazya stricta*). In the case of terrestrial reptiles, the majority of species are lizards, followed by snakes and amphisbaenids. These biological resources are extremely fragile, and in the last few decades many habitats and species have come under severe threat, primarily due to the rapid rate at which the Emirate has developed. For instance, of the 48 species of terrestrial mammals in UAE, two are now extinct in the wild, the Arabian oryx (*Oryx leucoryx*) and the wild goat (*Capra aegagrus*), although the former it is being reintroduced in selected areas (Environment Agency of Abu Dhabi, 2008); two are probably extinct, the Arabian wolf (*Canis lupus arabs*) and the striped hyena (*Hyaena hyaena*); seven are close to extinction in the wild, the Arabian tahr (*Hemitragus jayakari*), Arabian leopard (*Panthera pardus nimr*), mountain gazelle (*Gazella gazella cora*), sand fox (*Vulpes cana*), Gordon's wildcat (*Felis silvestris gordoni*); and six are considered endangered because of their restricted habitat and/or low populations: Brandt's hedgehog (*Hemiechinus hypomelas*), muscat mouse-tailed bat (*Rhinopoma muscatellum*), Rüppell's fox (*Vulpes rueppelli*), sand cat (*Felis margarita*), Egyptian spiny mouse (*Acomys cahirinus*), and the Arabian jird (*Meriones arimalius*) (Tourenq and Launay, 2008).

Another consequence of urban sprawl is the fragmentation and isolation of habitats produced by the transportation networks that connect built-up areas. In fact, the intensification of human mobility produces more traffic congestion as a consequence of a transport system based on private cars, and more ubiquitous air pollution (Abu Dhabi Department of Transport, 2009; Hadjri, 2006). Given the increasing number of roads, as explained in chapters 2 and 3, the traffic-related wildlife mortality can increase or impede the movement of animals in the landscape, or reduce the probability of animals to find mates, increasing the likelihood of inbreeding, reducing the genetic diversity and the ability to resist stochastic events, and leading to higher extinction rates (EEA, 2016). Additionally, this situation can be worse in case of uncontrolled off-road driving because it can produce the destruction of burrows.

With an increasing number of livestock (camels, goats, etc.), as reported in chapter 2, overgrazing can lead to loss of habitat and vegetation, along with soil erosion which ultimately leads to the destruction and degradation of the natural plant community. Whereas in the past the pastoral nomadism was the main form of animal husbandry, being the stocking density dictated by the natural carrying capacity of the land, nowadays large herds remain in relatively small areas for extended periods, denuding the natural vegetation and decreasing palatable species such as the *Rhanterium epapposum*.

Another negative impact to consider is that urban and agricultural sprawl contributes more easily to the invasion of habitats of the native flora and fauna by non-native species because the border between built-up areas and the open landscape is wider. The competition for food and space between native and introduced species may cause severe consequences on the local wildlife and environment. Examples of alien species are the rock hyrax (*Procavia capensis)* and common myna (*Acridotheres tristis*), listed as one of the 100 most invasive species of the world (Environment Agency Abu Dhabi, 2008). Other alien species are the ring-necked parakeet (*Psittacula krameri*), or plants such as the mesquite (*Proposis juliflora*) or the ushar (*Calotropis procera*).

As shown in this PhD thesis, a large increment in population growth, agricultural activity (agricultural sprawl supported by government subsidies) and afforestation occurred during the 40 years analysed. As a consequence, water demand also augmented significantly, as explained in chapter 2, with a high average consumption per capita (Chowdhury et al., 2015). From an agricultural point of view, one negative impact is soil salinity worsened by water scarcity: according to Abdelfattah (2009), 90 percent of agricultural farms were affected by soil salinization, with a more degraded situation in irrigated agriculture because water in 68 percent of farms was very strongly saline. As also reported in chapter 2, the main source is groundwater (with a depth of about 30 m) but according to Ali Suleiman (2007) 82% of groundwater samples were considered brackish water, and therefore not suitable for human consumption, because of their high total dissolved solids (TDS) concentrations which far exceeded the limits recommended. The reduction of ground water has caused numerous shallow wells to go dry and the almost total cessation of natural flow within the traditional *aflaj* system (Environment Agency Abu Dhabi, 2008). In consequence, there is an increasing reliance on other water resources, such as desalination and re-use of treated wastewater, as explained in chapter 2. With water use now being 26 times larger than the total annual renewable water resources of the Emirate, there is an urgent requirement to implement Integrated Water Resources Management in order to achieve sustainable development within the water sector. To make the water potable, it must be processed at one of the two main aquifers at Al-Foah. The process of making the water potable is expensive and requires a lot of energy output which adds to the city's carbon footprint and further compromises the integrity of the environment. As the water demands continue to increase, urban planners have to come up with innovative means of guaranteeing sufficient potable water. Already, studies have been conducted to assess the feasibility of increasing the number of desalination plans within the region.

According to Ali Suleiman (2007), one of the issues associated with urban sprawl in Al Ain revolves around sand dunes. About 75 percent of the entire UAE landmass is covered in various types of sand dunes such as linear, traverse, star, and barchanoid. Al Ain mostly has linear dunes. One way the city has managed to overcome these barriers is by reinforcing the dunes with artificial structures so that the dunes are more stable and land space for buildings can increase. However, these artificial structures present a range of ecological problems, including loss of native species diversity and the spread of introduced species. The challenge, therefore, is to reinforce the dunes in an ecologically-friendly manner. According to Mohammed et al. (2017), this can be done by combining ecological principles with engineering designs that are probably the most promising solution for the current urban sprawl, with terms such as green or eco-engineering. Yet, even with the best technology available, many of the dune areas are simply not feasible for building. The consequence is that the land is not appropriate for urban sprawl initiatives and other alternatives have to be found, many of which pose their own set of environmental and ecological issues.

From a social point of view, the negative effects comprise longer commuting times and higher spatial segregation of social classes, health effects due to the heat island effect and air pollution (Serra et al., 2014) and the altered perception of the landscape scenery and its character due to the increasing penetration of built-up areas (table 6.1). Nevertheless, other effects as urban sprawl correspond to the desire for affordable single houses with a garden and more privacy. People often prefer to have more space for themselves than apartment buildings offer, with a large garden and the possibility for children to play outside, rather than to be close to their place of work. Therefore, families tend to leave inner cities and move to the outskirts, in order to provide natural space for as their children develop (EEA, 2016).

6.5. Conclusions

The growth and development of the city of Al Ain can be attributed mainly to the oil revenues from 1962 and its physical location and geography. It is indisputable that these factors have promoted economic growth within the city through the creation of job opportunities. Moreover, the government development policies with some master plans have stimulated initiatives such as the provision of quality housing, investment in the education sector and other social amenities, the construction of roads and the availability of a favourable business environment. All these driving forces have produced a significant population increase and the specialization in services and tourism. A particularity of the region, compared with other world cities, is the conservation and expansion of agricultural land, highly subsidized with the objective to reach agricultural self-sufficiency in those products for which it is suited, as explained in chapter 4.

On the other hand, Al Ain shares some socio-environmental issues similar to other world cities with urban sprawl. Mandeli (2008) has pointed out the distorted nature of urbanization, which has caused the same problem internationally, and made it the central political issue in most developing countries. These include the leapfrog development, proliferation of scattered settlements, unregulated population growth, shortage of affordable housing, insufficiently funded public services and increasing social differences, overly long commuting times, traffic congestion, and severe ecological problems. Therefore, Al Ain shares some of these socio-environmental issues but also has some particularities given its specific desert environment and driving forces. The reduction and fragmentation of habitat available for wildlife, the overgrazing, the invasion of non-native species, the increase of water demand, the soil salinization or the issues associated to sand dunes can be some of them. From a social point of view, the negative effects comprise longer commuting times and higher spatial segregation of social classes, health effects due to air pollution and the altered perception of the landscape scenery and its character.

In conclusion, the research has shown that urban sprawl in Al Ain has been significant and is expected to continue to create challenges and opportunities for the UAE. The goal, therefore, has to be to overcome the challenges and find innovative means, through employing the best science and technologies, to protect the natural environment and still meet the needs of the population.

6.6. Chapter bibliography

Abdelfattah, M.A. (2009) Land degradation indicators and management options in the desert environment of Abu Dhabi, United Arab Emirates. *Soil Horizons*, 50, 3-10.

Abu Dhabi Authority for Culture and Heritage. (2018). Al Ain Oasis and City. Retrieved from https://www.abudhabi.ae

Abu Dhabi Department of Transport (2009) Surface Transport Master Plan. A vision for connecting Abu Dhabi. The Plan. Abu Dhabi.

Abu Dhabi Housing Authority (2016). Housing services. Abu Dhabi.

Ahmed, K. G. (2017). Designing sustainable urban social housing in the United Arab Emirates. *Sustainability*, *9*, 1413-1435.

Ali Suleiman, S. Y. (2007). *Geophysical and hydrogeological studies of Al-Foah Area, North Al Ain, United Arab Emirates (UAE)*. Theses of United Arab Emirates University, Paper 74.

Bhatta, B., Saraswati, S., Bandyopadhyay, D. (2010) Urban sprawl measurement from remote sensing data. *Applied Geography*. 30, 731-740.

Chowdhury, R. K., El-Shorbagy, W., Ghanma, M., El-Ashkar, A. (2015). Quantitative assessment of residential water end uses and grey water generation in the city of Al Ain. *Water Science and Technology: Water Supply*, *15*, 114-123.

Chowdhury, R.R. (2006) Landscape change in the Calakmul Biosphere Reserve, Mexico: Modeling the driving forces of smallholder deforestation in land parcels. *Applied Geograhy*, 26, 129-152.

Elsheshtawy, Y. (Ed.). (2011). *The evolving Arab city: tradition, modernity and urban development*. London: Routledge.

Environment Agency of Abu Dhabi (2008) *Terrestrial environments of Abu Dhabi, United Arab Emirates*. Abu Dhabi.

European Environment Agency (EEA) (2016). *Urban sprawl in Europe*. Joint EEA-FOEN Report. EEA Report Nº 11. Federal Office for the Environment FOE, Swiss Confederation.

European Spatial Planning Observation Network (ESPON) (2010) Future orientations for cities. The ESPON 2013 Programme. European Union, ESPON & ULB.

Geist H., McConnell W., Lambin E.F., Moran E., Alves D., Rudel T. (2006) Causes and trajectories of land-use/cover change. In: Lambin E.F., Geist H. (Eds) *Land-Use and Land-Cover Change. Global Change* - The IGBP Series. Springer, Berlin, Heidelberg.

Hadjri, K. (2006) An analysis of the spatial structure of a new desert town: Al Ain, United Arab Emirates. *Urban Design International*, 11, 3-19.

Hennig, E.I., Schwick, C., Soukup, T., Orlitová, E., Kienast, F., Jaeger, J.A.G. (2015) Multi-scale analysis of urban sprawl in Europe: towards a European de-sprawling strategy. Land Use Policy, 49, 483-498.

Jaeger, J. A., Bertiller, R., Schwick, C., & Kienast, F. (2010). Suitability criteria for measures of urban sprawl. *Ecological Indicators*, *10*, 397-406.

Mandeli K.N. (2008) The realities of integrating physical planning and local management into urban development: A case study of Jeddah, SaudiArabia. Habitat International, 32, 512-533.

Meneses, B.M., Reis, E., Pereira, S., Vale, M.J., Reis, R. (2017) Understanding driving forces and implications associated with the land use and land cover changes in Portugal. Sustainability, 9, https://doi.org/10.3390/su9030351

Mohammed, M., Abdelouahed, K., Allaoua, B. (2017). Compressive strength of dune sand reinforced concrete. In AIP Conference Proceedings, Vol. 1814, No. 1. AIP Publishing.

Nunes, A.N. (2012) Regional variability and driving forces behind forest fires in Portugal an overview of the last three decades (1980-2009). *Applied Geography*, 34, 576-586.

Pineda Jaimes, N.B., Bosque Sendra, J., Gómez Delgado, M., Franco Plata, R. (2010) Exploring the driving forces behind deforestation in the state of Mexico (Mexico) using geographically weighted regression. *Applied Geography*, 30, 576-591.

Schmitt-Harsh, M. (2013) Landscape change in Guatemala: Driving forces of forest and coffee agroforest expansion and contraction from 1990 to 2010. *Applied Geography*, 40, 40-50.

Selim, G.M., Gamal, M. (2007) Neighborhoods and residential communities. The case of Al Ain UAE. *Housing Symposium* 3, 343-361.

Serra, P., Vera, A. & Tulla, A.F. (2014) Spatial and socioenvironmental dynamics of Catalan regional planning from a multivariate statistical analysis using 1980s and 2000s data. *European Planning Studies*, 22, 1280-1300.

Serra, P.; Pons, X., Saurí, D. (2008) Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, 28, 189-209.

Tian, L., Biquing, G., Yongfu, L. (2017). Impacts of state-led and bottom-up urbanization on land use change in the peri-urban areas of Shanghai: planned growth or uncontrolled sprawl? *Cities*, 60, 476-486.

Tourenq, C., Launay, F. (2008) Challenges facing biodiversity in the United Arab Emirates. *Management of Environmental Quality: an International Journal*, 19, 283-304.

Turner II, B.L., Skole, D.L. Sanderson, S., Fischer, G., Fresco, L.O., Leemans, R. (1995) Land-use and land-cover change – Science Research Plan. IGBP Report Nº 35; HDP Report Nº 7. Stockjolm and Geneva.

Statistics Centre Abu Dhabi (2016) Statistical Yearbook of Abu Dhabi 2016. Abu Dhabi.

Statistics Centre Abu Dhabi (2013) Statistical Yearbook of Abu Dhabi 2013. Abu Dhabi.

Van Vliet, J., Groot, H.L.F., Rietveld, P., Verburg, P.H. (2015) Manifestations and underlying drivers of agricultural land use change. Landscape and Urban Planning, 133, 24-36.

Verburg, P.H., Schot, P.P., Dijst, M.J., Veldkamp, A. (2004) Land use change modelling: current practice and research priorities. GeoJournal, 61, 309-324.

Yagoub, M.M. (2006) Application of remote sensing and geographic information systems (GIS) to population studies in the Gulf: a case of Al Ain city (UAE). *Journal of the Indian Society of Remote Sensing*, 34, 7-21.

Yagoub, M.M. (2004) Monitoring of urban growth of a desert city through remote sensing: Al-Ain, UAE, between 1976 and 2000. *International Journal of Remote Sensing*, 25, 1063-1076.

Wu, K., Zhang, H. (2012) Land use dynamics, built-up land expansion patterns, and driving forces analysis of the fast-growing Hangzhou metropolitan area, eastern China. *Applied Geography*, 34, 137-145.

7.1. Introduction

This chapter reviews the main objectives for future growth in the urban structure and environmental frameworks according to “Plan Al Ain 2030”. The Abu Dhabi Urban Planning Council, created by Emirati Decree number 23 of 2007, is responsible for the preparation and approval of the Urban Structure Framework for the “Al Ain Master Plan 2030”.

The metropolitan outline for Al Ain City is designed to help the city explore and adopt measures to respond to existing, upcoming and anticipated development needs. The plan is meant to make the city sustainable, environmentally friendly, a cultural hub, and a place where social identity and lifestyles are respected. In particular, the plan is meant to meet the needs of the growing population while helping to reverse inappropriate development trends. Notably, the 20-year framework highlights theoretical solutions that can be used to shape the face of Al Ain.

7.2. Foundation of the Al Ain City Plan for 2030

The plan is founded on the belief that a better city will benefit all residents. As such, the plan intends to accomplish a number of goals. The first is to improve and conserve the natural resources and culture of the city. The framework intends to celebrate the urban farming that makes the city unique, integrating nature with humanity. Second, the framework aims to foster economic development by leveraging financial assets in a rational and thoughtful way. While the plan is likely to face numerous challenges, the developers plan to address traffic problems within the city, the lack of public amities, transportation needs and water depletion, among others. The framework plans to minimize the challenges by ensuring that the plan is sustainable and attainable without causing major consequences for the city's inhabitants and the environment. The “Master Plan 2030” is guided by next principles: economic development through better healthcare and industries, cultural and community integration, respect for life and protection of the natural environment, and expanding the role of the oasis in urban development.

7.3. Economics

Since the city's population is expected to double from 2010 to 2030, the framework includes an economic analysis to determine the best option to secure the financial resources needed to guarantee the project's success. The plan postulates an unprecedented rise in the need for residential properties, offices, retail spaces, hotels, and industries (Table 7.1). A growing urban population will also pursue education, better healthcare, and recreation facilities. The implication is that offering better amenities will translate into better economic growth within the city in the long term. In making these market estimates, the plan relies on forecasted population data and economic growth that have been compared with global data to propose the facilities and infrastructures needed to accommodate the needs of such a large population.

Growing scenarios	Year 2020	Year 2030
Emirati	167 000	290 000
Expatriate	460 000	710 000
Total residents	627 000	1 000 000
Annual tourist visits	710 000	1 071 000
Residential units for Emirati	22 584	41 428
Residential units for Expatriate	101 706	160 633
Total residential units	124 290	202 061

Table 7.1. Growth assumptions in "Plan Al Ain 2030". Source: Abu Dhabi Urban Planning Council, 2012.

7.4. Urban structure framework

The urban overview of the city explores issues such as land use, public open spaces, transportation, the local environment and the ways these aspects will be integrated into the plan. Concerning the environmental framework, the city is surrounded by the Jebel Hafeet mountain, alluvial gravel plains, and sand dunes, features that give the city a distinctive look compared to other UAE cities. New speculative development may interfere with the local environment. To avoid potential problems, the framework outlines a plan to protect the city's sensitive landscapes, traditional farming uses, and unprotected regions like the Jebel Hafeet.

Allocating land use must ensure that new developments do not interfere with the city's traffic flow, population needs and natural beauty. Therefore, mixed-use development is planned and the "Getaway Transit Corridor" will help take care of the city’s upcoming housing and commercial demands. In addition, Emirati housing and the redevelopment of brownfield sites will help the city meet the rising housing demand. What is more, industry land will be moved away from areas near mountains and oases to ensure they are protected and not damaged by industrial and household wastes.

Presently, the city’s transport structure is skewed unreasonably toward accommodating private vehicles. However, there is a need to accommodate bicycles and pedestrians. Therefore, the flyover at Zayed bin Sultan Street will be removed, the roundabouts will be improved and missing connections will be added to ensure roads are interlinked within the city. Moreover, the truck routes south of the city will be enhanced to ensure the safe passage of goods. Shuttle buses, wider sidewalks, shading and improved crossings for pedestrians are also included in the plan.

The city is commonly known as a “garden in the wilderness”, and public spaces will be used to preserve the city's status. Notably, there will be landscaped and recreational parks including Al Ain Zoo, Hili Fun Park and camel racetracks (Yagoub, 2014). Furthermore, cultural landscapes such as Hili tomb and burial sites near Jebel Hafeet will be upgraded and protected, as well as natural landscapes within the city (Figure 7.1). Farms, forests, and plant nurseries will be instituted around the city to improve its beauty and create green spaces within the city.

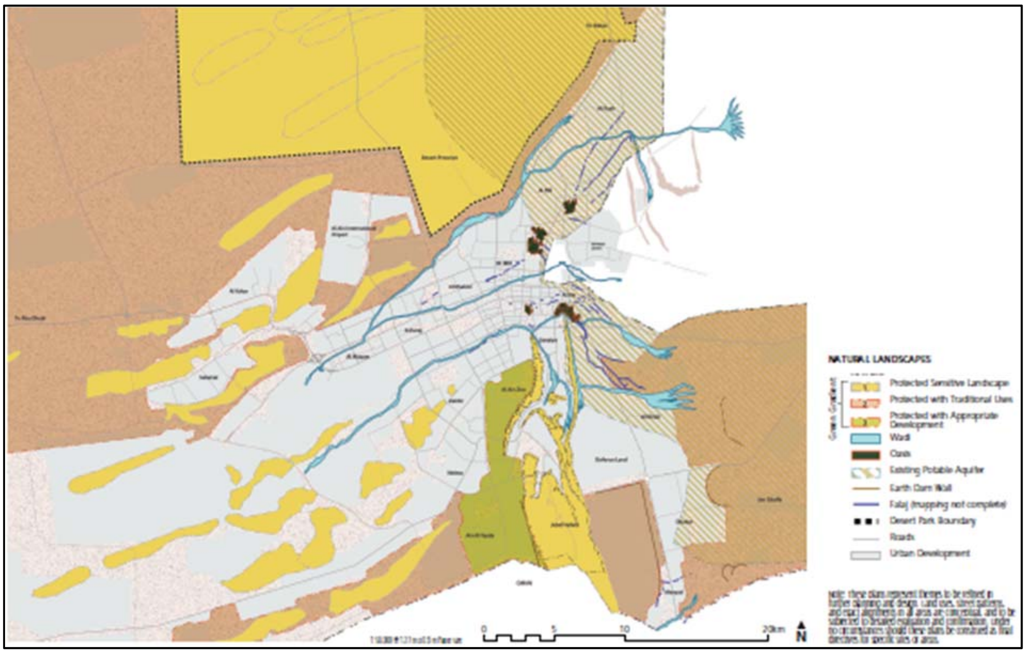


Figure 7.1. Environmental framework. Source: Abu Dhabi Urban Planning Council, 2012.

7.5. Overall patterns

The plan highlights districts that will be intensified (coded in red, orange and purple in Figure 7.2). These include Asharej, the Central District, Sanaiya, and Al Jimi. The yellow regions striped with purple lines will be added to the urban system while those outlined in red will be used to assess the total population growth in the plan (figure 7.2). As buildings are limited to four stories (G+4) per royal decree, a low-scale development compared to other cities, the scale will give the city a coherent and strong image and good ambiance. However, for low-density suburbs, G+2 standards will be used to safeguard privacy and view corridors. Taller minarets and mosque domes will be permitted to allow for a city skyline.

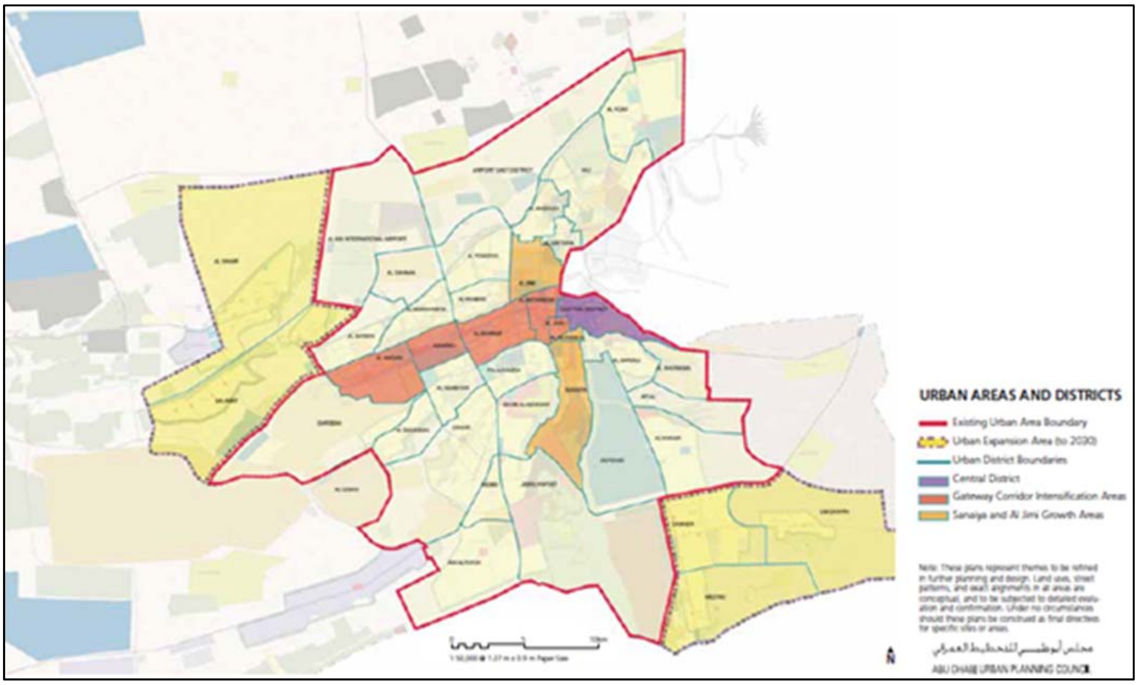


Figure 7.2. Urban growth areas and "Gateway Corridor". Source: Abu Dhabi Urban Planning Council, 2012.

Presently, the Central District is the area with the highest population density. However, this will change by 2030 as Al Maqn, Asharej and Al Muwaiji will also house a large number of the city's population according to the Master Plan. An auxiliary area comprising Hili, Al Jimi, and Sanaiya will have high densities due to the rising population. While Emirati housing is mostly common in low population areas, the plan will accommodate such houses. For office spaces, Central District and Asharej will be developed to accommodate the demand for offices. The remaining office space will be distributed along the “Gateway Corridor” to ensure people living in these areas have easy access to transport systems. Additionally, Al Jimi and Sanaiya will have office spaces to make sure that residents gain employment opportunities.

Retail density will be concentrated along the “Gateway Corridor”. The location is to ensure that workers and residents have easy access to shopping centers. Other shopping places will be located along city streets, in climate-controlled malls and local neighborhoods. Large regional malls will be reduced in size and new ones strategically located to minimize traffic congestion.

Industrial production is good for Al Ain, but heavy industries will be relocated from Sanaiya. Notably, the industries depend on efficient logistics and the most appropriate location is near good transit networks. In particular, Al Ain’s industrial areas are located at the airport (high-tech business park) and trade routes (heavy industrial district). This choice was meant to ensure that overland travel is minimized and the population is not subjected to the effects of heavy industries.

Additionally, hotel density will be concentrated in four areas to fulfill Al Ain’s future demands. The “Gateway Corridor” is a busy area, and more than 3,000 hotel rooms are found there. However, new rooms will be situated in Hili, Qattara, Jebel and Zoo to accommodate tourists visiting the city. Finally, numerous tourist and business accommodations will be set in the Central District to meet future demands.

The plan is segmented into three phases that do not have specified timelines but are representative of the sequence of the development intensity. The first phase will involve important structural elements of land use strategies, consisting of restructuring of central districts and the Asharej node. The first priorities during this stage will include Emirati housing allocations, redevelopment of Hili Fun Park, the Zoo, and Jebel tourist areas. The next phase will involve the intensification of nodes along the Gateway Corridor and the tram system. Emirati houses will be built during this phase to meet demands in Salamat, Al Khabisi, and Al Khraia sub-regions. The last phase will encompass development of older regions and completion of the proposed development goals. However, it should be acknowledged that during the process, infill and redevelopment of smaller regions within the city will continue uninterrupted. Furthermore, this development will take place over an extended period, is unpredictable and future events may either slow or augment the development process. For these reasons, the plan is quite versatile, and in the case of economic and demographic fluctuations will evolve to accommodate the density over time.

7.6. Zooming in

In drafting the plan, it was believed that Al Ain would experience exponential growth over a 20-year period. However, the way the change is accommodated will be crucial during the development process and will determine whether the city retains its status as a desert garden city. Therefore, the plan aims at linking the new density with transit to provide numerous alternatives for cars. In particular, the "Great Transit Corridor" will be designed to become a transit-supportive framework for cars. The corridor is founded on the notion that five new centers will be created along the corridor from Maqam district through Downtown. All the centers will contain mixed-use nodes with retail components, and will be situated near vital cross streets to ensure they take metropolitan infill.

Other than being mixed-use areas, the regions will contain tramlines across the entire length of the corridor (Al Ghalib). Moreover, multi-family housing within the region will offer transit ridership for residents. A new node at Asharej will be strategically located near education, transport and recreation amenities, of a higher order than other regions, more similar to the Central District with regard to jobs and housing density (Figure 7.3). The centers along the corridor will be appropriately spaced for shopping and linked with Emirati neighborhoods. Additionally, an overlay will offer low-density areas with a connection to the transportation spine, as well as multiple mobility options as opposed to just cars.

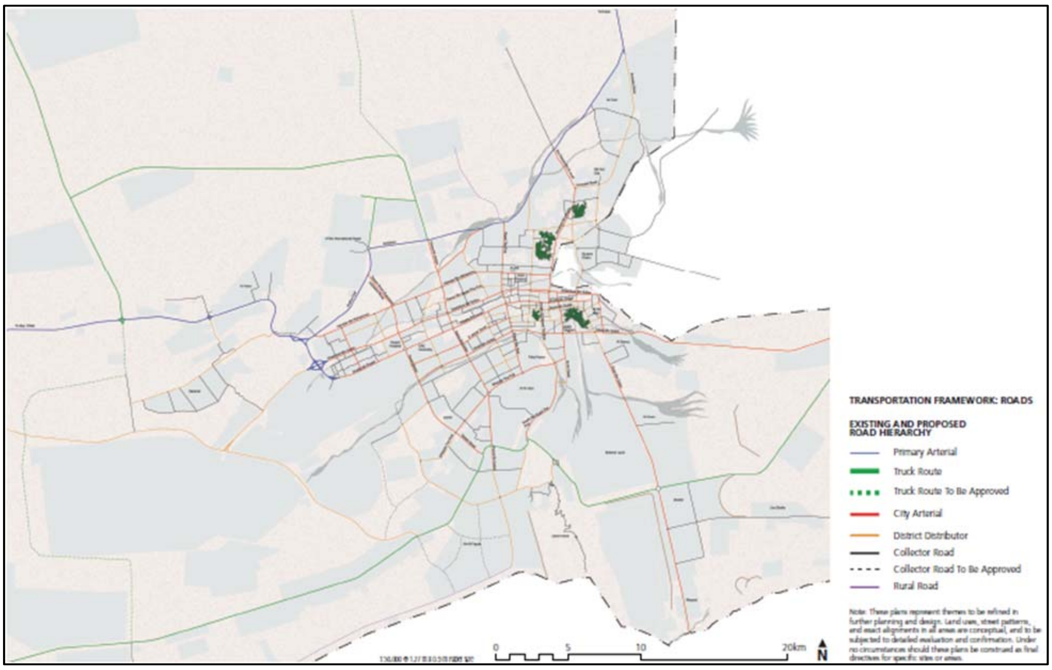


Figure 7.3. Transportation framework. Source: Abu Dhabi Urban Planning Council, 2012.

The Downtown sector has the highest population density and offers an interface to the oasis. However, it faces problems ranging from underutilization of large tracts of land to a neglect of the built environment. However, this will be improved by redeveloping underused lands, filling empty spaces with residential housing to give a new level of vitality and beauty to the area, and reorganizing the street network. In particular, the flyover that cleaves the oasis will be removed, and the space will be used to build a world-class shopping boulevard. The avenue will accommodate dual carriageways in each segment, a narrow street and wide sidewalks. On the other hand, the roundabouts that convey the city's nature will be preserved, but they will be transformed into signalized intersections to stabilize traffic and make it safer for pedestrians. Grade-separated configurations will not be supported. The Al Mudheef superblock will be overlaid with fine-grain grids to augment pedestrian access. These grids also will help to create through-roads that can take in traffic from the avenues. In addition to road networks, the oasis will be integrated into the city's environment. Notably, "green fingers" (planted pedestrian byways) will help to expand the oasis theme in the city. These fingers will link parks, public outdoor spaces and courtyards. Furthermore, shaded public spaces will create microclimates for pedestrians during the summer. To avoid structural uniformity, a retail district along the three north-south streets will be created.

7.7. Building blocks

Crucial building blocks in the attainment of the proposed developments include streetscapes, the oases and Emirati communities, as well as rail terminals and the Al Mudheef superblock. From the perspective of the plan designers, the city's oasis is not just a palm plantation; it is a cultural icon within the city. Despite being crucial to the city's culture, the palm trees are affected by urban factors such as pollution, encroachment, and loss of conventional farming practices. The plan proposes that Al Ain be recognized as a UNESCO World Heritage site founded on the belief that such acknowledgment will help conserve the oases. Other plans to support the oases are an expansion of the *falaj* system that brings water from the mountains and a public trust to help maintain groundwater around the oases. Additionally, view corridors and culturally appropriate adobe walls will be designed to improve the oases' aesthetics. All the edges of the oases ranging from the Souk to the northwestern corner will be modified to comprise botanical gardens, underground parking, adobe brickyards, and hospitality facilities to protect the oases and enhance their appeal.

The Emirati communities will be respected in redeveloping the city. Plots will be distributed to ensure that extended families have a shared courtyard, thereby giving them close proximity with one another. Narrow pathways will allow pedestrians to move easily between the courtyards. Moreover, privacy will be guaranteed using *cul-de-sac* entrances to keep out unwanted traffic. Communities will be grouped into clusters, which are then merged into neighborhoods. The neighborhoods will have a population of 8,000 to 10,000 residents, served by two education institutions (one for male students and one for female students), a mosque, recreation facilities, a women's complex and shops and other amenities crucial to the residents.

According to the developers of the plan, developing an auxiliary mixed-use node would downgrade it to a "backyard". To avoid this outcome, new mixed-use buildings and underground parking spots will be developed to ensure that Al Ain remains a vibrant city. As such, the developers propose the creation of the Al Mudheef superblock to add density and new uses to the Downtown (figure 7.4).

Figure 7.4. Design of Al Mudheef superblock. Source: Abu Dhabi Urban Planning Council, 2012.

Other than superblocks and the oases, a high-speed rail terminus will be designed to create a link between Al Ain, Dubai, and Abu Dhabi. The rail station will comprise shopping malls, hotels, offices and public meeting spaces. Its location, number of tracks, vicinity, and passenger volume will not be unveiled until the construction begins.

Finally, retail business is forecasted as likely to boom in the next 20 years. While commerce is important to the economy, the region will have streets that solely serve residential purposes. The current avenues will be transformed into shopping streets cooled by urban design devices, including shade, covered streets and retail passages suitable for pedestrians and bicycles.

7.8. Policy statements

The principles underlying the urban framework are meant to guide the development process and ensure its successful completion without any major drawbacks. However, the specific policies serve different functions in the process. Some set the standard for international best practices that can make sure the process meets global requirements and is compliant to aspects such as ISO 9001. Other policies outline the needs for further actions (supplementary studies, reporting, and the creation of regulatory frameworks and bodies) in particular spheres in case the set guidelines do not attain the required objectives. Still others outline specific actions that should be undertaken to achieve the required outcomes. Examples of policies include the following:

- Promote Al Ain as an ecologically friendly society with best practices regarding the conservation of the environment.
- Reinstate the conventional practices of intercropping in the oasis to make sure the oasis does not die.
- Undertake an inclusive development strategy for the inner city's linear entryway
- Offer an inter-city public transportation system.
- Allow the construction of golf courses in strategic places as vital elements of private development.
- Initiate a plan to build closed north-south shopping streets in the civic center.
- Accommodate Emirati neighborhoods to facilitate the co-location of extended families.
- Create an implementation method for the urban structure framework plan.

7.9. Conclusions

From an environmental perspective, one of the main objectives of the "Urban structure framework, Plan Al Ain 2030" and the section entitled "Environmental Framework Plan" (Abu Dhabi Urban Planning Council, 2012) is to protect the Al Ain macro-landscape from urban growth while protecting areas of aquifer recharge. In consequence, the highest priority is to define the urban development boundary through the creation of three national parks: Jebel Hafeet National Park, Desert Dunes National Park and a large Desert Preserve to the north of the city. As the Master Plan recognizes, the need to accommodate new urban growth is behind the proposal to create a gradient of authorized uses, applying a transition concept from complete protection to complete urbanization. The four echelons of this gradient are protected sensitive landscapes, including the three new national parks; protected areas with traditional agricultural uses, including date farming and camel ranching; protected areas with appropriate development, including urban land using sustainable, low-impact design strategies; and finally, unprotected areas with development practices that must be sustainable. The urban development boundary between the two main *wadis*, the "Gateway Corridor" in the east-west direction from Al Muwaiji to Al Maqam, will accommodate the largest portion of future residential and commercial demand. This long-term plan perspective (>20 years) includes a full coalescence procedure for infilling and redeveloping urban land.

7.10. Chapter bibliography

Abu Dhabi Urban Planning Council (2012) Plan Al Ain 2030: Urban Structure Framework Plan. Abu Dhabi.

Al Ghalib, E. (2010) Tram and train system on track for Al Ain. *The National*, extracted from: *https://www.thenational.ae/uae/tram-and-train-system-on-track-for-al-ain-1.497509*

Yagoub, M. M. (2014) Parks in Al Ain, UAE: geographical distribution, opportunities, and challenges. The Arab World Geographer, 17, 24-41.

CONCLUSIONS

The overall aim of this research was to analyse the LULC dynamics of Al Ain municipality, as an example of a medium-size town affected by urban sprawl. This city, located in the United Arab Emirates (UAE), underwent very rapid urban development from land held by the State (the Ruler) and surrounded by a desert. The study had four specific objectives: the first was to investigate the LULC changes (mainly urban, including residential and services, industrial and agricultural land) of Al Ain city at four timepoints: 1984, 1990, 2000 and 2014. The second aim was to understand the consequences from a landscape point of view of LULC changes according to the following configurations: aggregated pattern, linear pattern, leapfrogging or nodal pattern. The third objective was to incorporate spatial information at district scale from census data in order to improve the analysis of LULC changes. Finally, the fourth objective was to establish the main driving forces of LULC changes and the socioenvironmental consequences of such dynamics.

From a methodological point of view, and as explained in the introduction and in chapters 4 and 5, the applied methodology was a land-use-based modelling approach, using GIS techniques, at a macro level analysis, and a subregional and local scale at long term (1984-2014). Four different tools were applied according to the specific objectives: i) a combination of the 2014 Base Map from Al Ain Town Planning with Landsat imagery from 1984, 1990, 2000 and 2014, to map and quantify the corresponding LULC for each year and to obtain the corresponding spatial changes; ii) estimation of spatial metrics for determining urban landscape processes and patterns such as aggregation, isolation and/or sprawl; iii) statistical analysis of census data at district scale, to improve the understanding of LULC processes; and iv) a qualitative modelling based on expert knowledge to analyse the relationships between LULC changes, their driving forces and the socioenvironmental consequences. The combination of the four tools, previous to this PhD thesis applied in some Mediterranean countries, was a big challenge considering the "remoteness" of the study area.

In relation to the first tool, the 2014 Base Map provided very detailed information. The combination of this vector map with Landsat images and with a simple photointerpretation procedure, as explained in chapter 4, allowed us to extract the main

LULC changes with a high accuracy, avoiding the problems associated with remote sensing imagery: confusion of LULC when automatic classifications are used or the elevated cost of using images of high spatial resolution, among others, as described in chapter 1. The spatial scales of study were the district (a group of communities or neighbourhoods) and the sector (a group of districts).

The second tool was the quantification of some landscape metrics characteristic of Landscape Ecology, a discipline that considers the landscape as formed by a set of units distributed in space and linked by a series of flows, to understand the consequences of LULC changes. Together with the first tool, these metrics were calculated in order to verify the initial hypothesis about sprawl. Two different and complementary software applications were used: Patch Analyst, an extension to the ArcGIS® software system that facilitates the spatial analysis of landscape patches and the modeling of attributes associated with patches, and the GUIDOS Toolbox, which provides image-processing tools based on geometric concepts and can thus be applied to any kind of raster data.

The third tool, the multivariate statistical analysis from principal components, was applied at district scale, being a very uncommon scale of analysis in the UAE given the lack of tradition working with census data. Combining population, LULC and length of main roads from 2005 and 2014 (20 variables), it was possible to obtain the main dynamics of six selected principal components. Finally, the main driving forces of LULC changes and their socioenvironmental consequences (objective 4) were established using a qualitative modelling based on expert knowledge.

In this final chapter, we can conclude that the applied methodology allowed us to meet all the goals of this PhD thesis and confirm the initial hypothesis. All the chapters contributed evidence to show that the Abu Dhabi Emirate has experienced an unprecedented economic boom during the last three decades that has transformed a country inhabited by nomads into a state with the highest GDP per capita in the world. Al Ain, popular as a “garden city”, is Arabia’s greenest urban community thanks to an ambitious forestation program, despite its hyper-arid climate with a very low mean annual rainfall. It is the second largest town in the Emirate of Abu Dhabi and the fourth largest in the UAE, strategically located on the border between UAE and Oman. Furthermore, it is characterized by a vast arid desert, with intermittent dry riverbeds called *wadi*, and an area of fertile soils and oases, with large reserves of groundwater. The city's development has shown rapid growth during the last 40 years, with a population increase from 51,000 inhabitants in 1975 to 560,214 in 2010, partly thanks to the creation of a designated industrial area that houses many industries including manufacturing, and services that provide employment to many locals and foreigners. In fact, although the city has the biggest Emirati national population, most of the city's inhabitants are from other countries (31.2% of total population in 2010).

Agriculture is one of the key productive sectors in Al Ain, being additionally the main supplier of food commodities and raw materials to the Emirate food industry. According to 2013 data, more than 11,000 agricultural holdings were located there, with a mean size per farm of about four hectares. The cultivated area includes field crops, vegetables, and fruit trees, whereas livestock is an important sector with about three million head of sheep and goats, and more than 300,000 camels.

However, rapid economic development, coupled with sharp population increases and the development of a large agricultural sector substantially supported by government subsidies, has led to large increases in water demands. A reduction in the groundwater has caused numerous shallow wells to go dry and the almost total cessation of natural groundwater flow within the *aflaj* systems. This has meant an increasing reliance on unconventional water resources, such as desalination and re-use of treated wastewater, and also the development of alternative conventional water supply measures, such as recharge dams, storage dams, recharge wells, interception of groundwater losses and water transfers from other Emirates.

In order to verify the working hypothesis about the type of Al Ain urban sprawl from a planning point of view (quite well planned, as explained in chapter 1), a deep analysis of the two master plans included in the period of analysis (1986-2000 and 2003-2015) was developed. The main objective of the 1986-2000 Master Plan was to maintain the city's traditional role as a center for educational, cultural and recreational activities of national importance, as the main agricultural producer of the Emirate and as an environmentally attractive garden city. Economic diversification was also included to provide stable conditions for local businesses, agricultural self-sufficiency in those products for which it was suited and the maintenance of a high level of services. Residential land comprised community facilities and other uses associated with housing such as health care centres, mosques, schools and neighbourhood centres. Additionally, new residential areas were proposed with the objective to infill vacant lots within the extant built environment and to expand in new directions. In the case of agricultural land, and despite unfavorable climate conditions and water and soil constraints, proposals were issued to increase this area, in order to settle the local population and promote commercial and traditional farms concentrating on date palms and fodder. Finally, a regional road hierarchy at national, regional and local level was proposed, the most important national roads being the Dubai Road (E66) and the Abu Dhabi Road (E22).

Derived from the Master Plan of 2003-2015, the Urban Structure Plan aimed at achieving six goals: social and economic prosperity, natural resources conservation, efficient and convenient transport systems, enhancement and preservation of the environment, conservation of the historic and landscape value, and effective engineering utility systems (Al Ain Municipality Town Planning, 2007). The combination of these six aims constitutes the “primary” goal used to locate and to forecast future needs for employment, housing, related road traffic, and community facilities. This would help to minimize traffic and environmental congestion by building elevated grade-segregated junctions and new road networks, reinforce existing and new communities, enhance and conserve natural resources for sustainability purposes, and increase the attraction of Al Ain for investments in tourism and other sectors. In the case of agricultural land, the vision was to limit the allocation of farms and reduce subsidies in order to save water resources and reduce groundwater pollution.

In general, the main objectives of these plans were achieved: an expanded road network, extensive provision of public services, a noticeable increase in housing construction, and greater interest in environmental preservation. Our conclusion is that Al Ain shows a clear example of urban sprawl that was quite well planned, in contrast to other urban growth areas such as Dubai.

Chapter 4 described the main LULC changes and their landscape dynamics. From an urban viewpoint, a particularity of Al Ain –compared with Dubai or Abu Dhabi cities– is that urban growth has been horizontal rather than vertical. In consequence, this city offers a specific example of urban sprawl, clearly differing from the Dubai urban brand or from other urban development forms. According to the analysis of LULC changes, urban growth of Al Ain City was not uniform either in space or in time. Excepting the large palace construction in Al Rawdha in 1984-1990, the biggest increase in residential land occurred in 1990-2000, averaging 330 hectares per year, whereas in services the greatest growth occurred in 1984-1990, with 641.3 hectares per year. In 1984-1990, the Western sector showed its highest increase in residential land and services, and the Centre sector its highest increase in services. In 1990-2000, the greatest increase in residential land was in the Eastern, Centre and Downtown sectors, whereas the greatest increase in residential land and services occurred in the Northern sector. The greatest increase in services occurred in 2000-2014 in the Southern sector. In summary, urban development has been widespread following the directions of the Al Ain Town Planning Department (and the Urban Planning Council since 2007), as explained in chapter 3. They also included housing and services management and zoning, and other directives such as urban plot size or building height, restricted to a maximum of four floors.

Another conclusion from this research is that an intensive process of agricultural sprawl was also observed, mainly between 1990 and 2000 with an average increase of 3,265.6 hectares per year, as a particularity of Al Ain compared with other countries or regions. In most of the world, urban growth proceeds at the expense of agricultural land. Therefore, Al Ain constitutes an exception to the general trend of agricultural land as the main loser in the face of urbanization because there has been a massive conversion of barren land to agricultural land. The main reason for this increase was the objective to reach agricultural self-sufficiency in those products for which the location was suited according to the 1986 Master Plan. At the same time, the clear reduction of its increase in 2000-2014 can be attributed to the 2003 Master Plan. According to our results, the increase in agricultural land also was not uniform either in space or in time. The Western sector had the largest growth in agricultural land between 1990 and 2000, and between 1984 and 1990. The second main sector was the Northern between 1990 and 2000, and the third the Southern between 1990 and 2000. In the Centre sector, the largest growth was between 1984 and 1990; the main increase in the Eastern sector occurred between 2000 and 2014.

In the case of industry, increments were very restricted and localized. The Centre sector had the largest increase, which took place mainly between 2000 and 2014. Sanaiya district had the highest activity level, ranging from motor manufacturing companies to art centres. Other sectors experiencing industrial increase were the Western between 1990 and 2000, the Southern in the same period, and the Eastern sector. Factories involved in processing and manufacturing have attracted significant numbers of foreign workers, mainly men, as reported by our statistical analysis in chapter 5.

From the landscape analysis, diverse urban patterns were extracted according to the sectors and the years of development. The main landscape transformations were urban compaction (filling in vacant land) in the Centre sector, whereas the most clearly sprawl development occurred in the Western sector, mainly between 1984 and 1990, and with less intensity in the Eastern sector. In the Northern and Southern sectors, the urban sprawl was very limited, being more prone to a leapfrogging urban pattern and a linear pattern associated with the main roads. Therefore, one of the main aims of the two master plans, the integration of the extant fragmented urban areas, was achieved in the city centre and in some zones of the new residential areas. In the case of agricultural land, the main landscape changes showed important spatial differences: its growth was isolated in the Eastern sector, associated with linear patterns in the Northern and Southern sectors, restricted to vacant land to the north and south in the Centre sector and, finally, sprawled throughout the Western sector.

Adding the results obtained from the multivariate statistical analysis, we can conclude that the urban development, considering private and public houses, was more associated with housing the local population (both men and women), foreign women and religious facilities, whereas the increment in services was more related to foreign workers (both men and women) and private homes. Therefore, part of the rapid sprawled urban development can be attributed to the migration of local residents from the Downtown to the Central District and to the West, fulfilling the household and service needs. These dynamics allowed stakeholders to gain more space and comfort, and also augmented the appeal of the developing service sectors located in the West such as Maqam Palace, UAE University or Tawam hospital, among others. Besides the local Emiratis, the service sector development, mainly in the Downtown sector where the palm land oasis is located, together with some districts of the Central region and of the western part of the Eastern, attracted a huge number of foreign workers from India, Pakistan, and Egypt. Finally, agricultural activity from 2005 to 2010 led to sprawl to the West and South, with no increase in the North region.

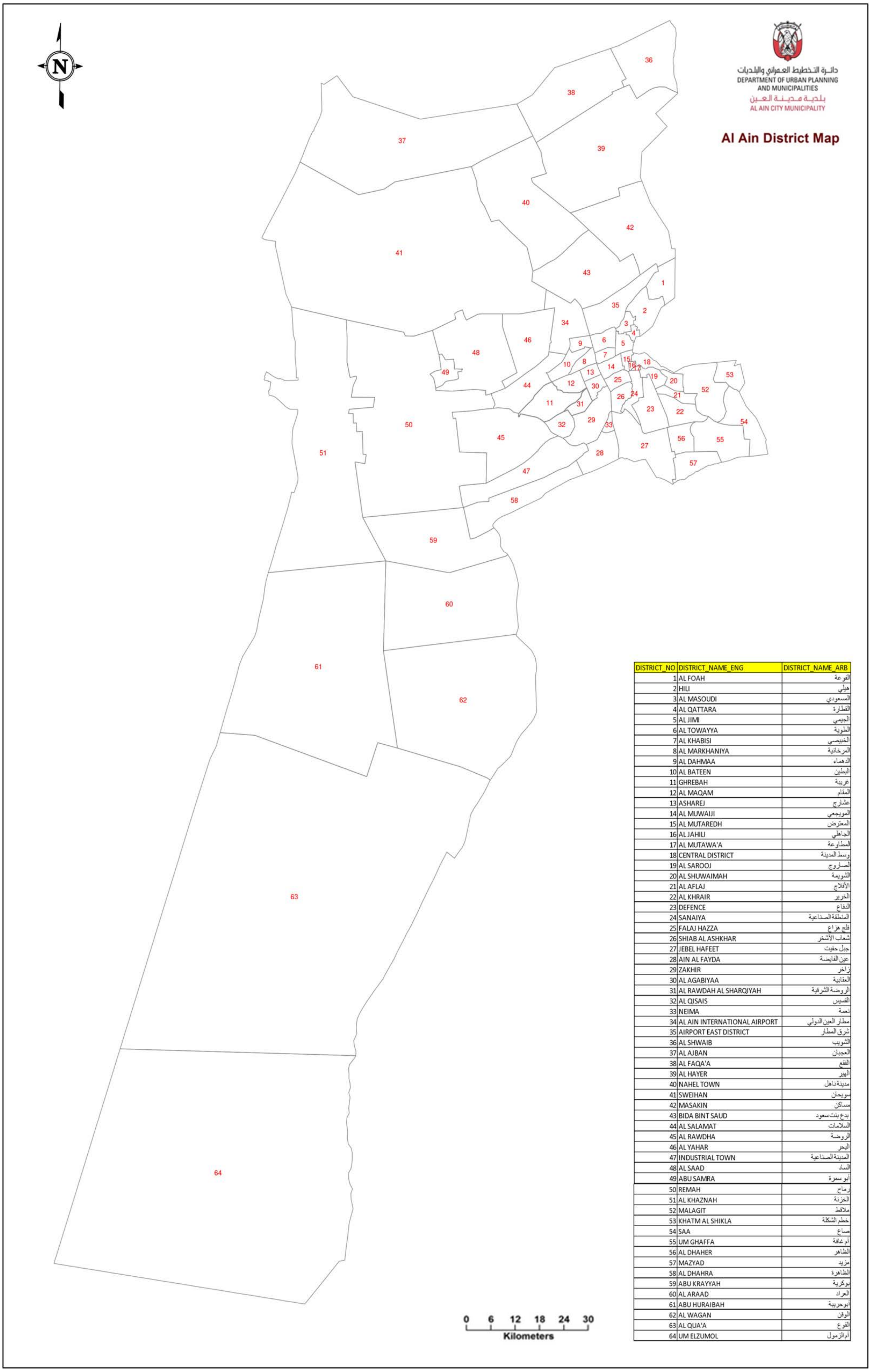
Therefore, according to the results obtained in this PhD thesis, Al Ain is an excellent example of a medium-sized city experiencing rapid urban growth, mainly since the mid-1980s, with hundreds of thousands of hectares of new residential and services land, guided by two master plans (1986–2000 and 2003–2014) and by the Al Ain Town Planning Department (and since 2007, the Urban Planning Council). In general, the main objectives of these plans were achieved: an expanded road network, an extensive provision of public services, and a noticeable increase in housing construction. Therefore, our conclusion is that Al Ain shows a clear example of horizontal urban sprawl, quite well planned, very differentiated from other urban growth areas such as Dubai, but with diverse landscape patterns according to the urban sectors and years of development. Simultaneously, the massive conversion of barren land to agricultural land has allowed Al Ain to be quite self-sufficient in some products, especially vegetables, according to the 1986-2000 master plan.

From chapter 6, it can be concluded that the growth and development of the city of Al Ain can be attributed mainly to oil revenues and to its physical location and geography, but also to the government initiative through two master plans with investment in services and in a favourable business environment. All these driving forces have produced a significant population increase and the specialization in some services and tourism.

Al Ain shares some socio-environmental issues with other sprawling world cities, but with some particularities given its specific driving forces. The common issues related to unregulated population growth, shortage of affordable housing or insufficiently funded public services were clearly not found in Al Ain, whereas others were present, such as reduction and fragmentation of habitat available for wildlife, overgrazing, invasion of non-native species, increasing water demand, soil salinization or issues associated to sand dunes, among others. From a social point of view, the negative effects comprise longer commuting times and higher spatial segregation of social classes, health effects due to air pollution from traffic congestion and altered perception of the landscape scenery and its character.

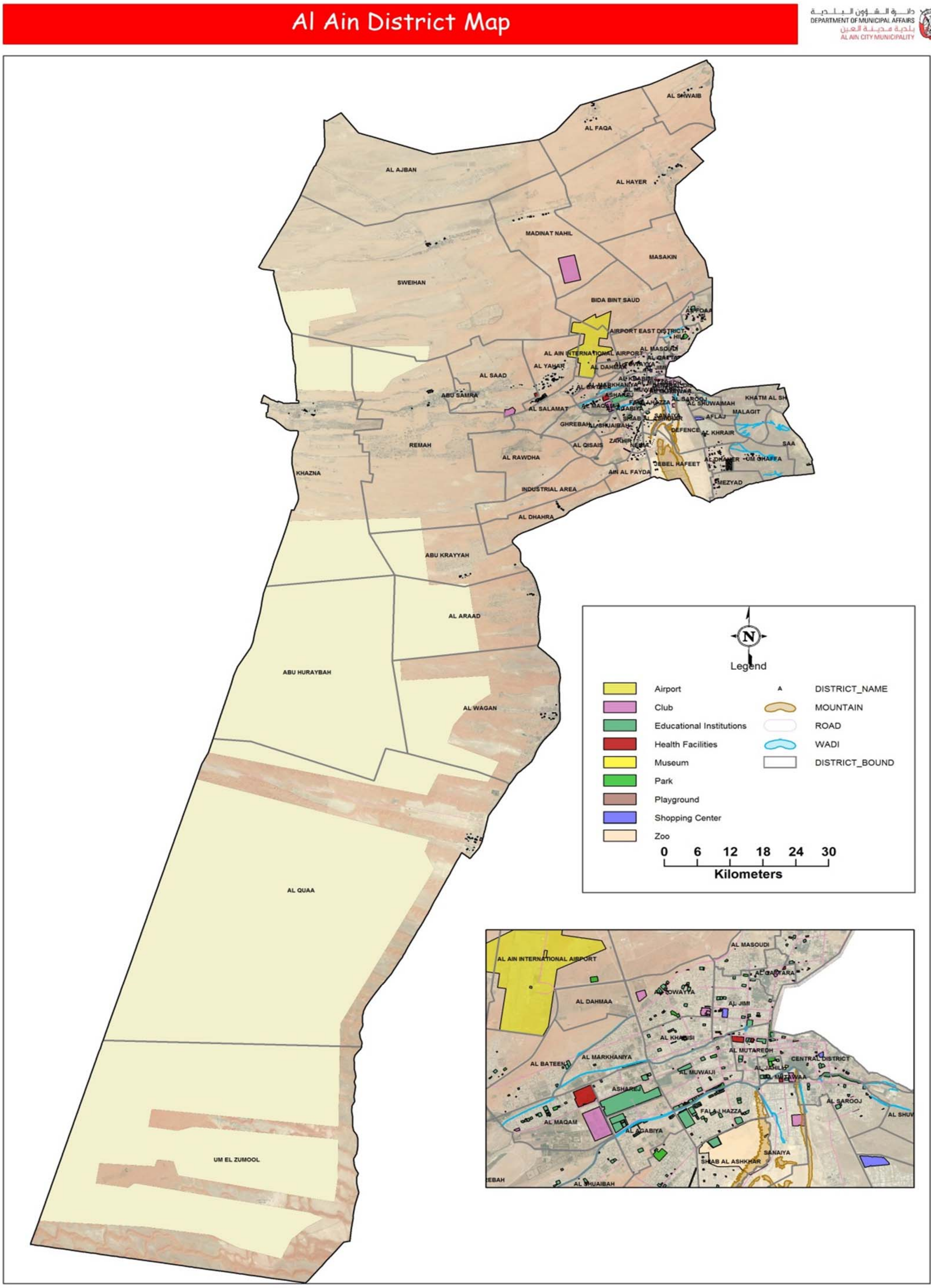
Finally, the main objectives of the current master plan, "Al Ain 2030", are to protect the city's macro landscape from urban growth and ensure the sustainability of areas of aquifer recharge. Consequently, the highest priority is defining the urban development boundary through the creation of national parks. The need to accommodate new urban growth is behind the proposal to create a gradient characterized by protected sensitive landscapes, protected areas with traditional agricultural uses, protected areas with appropriate development, and unprotected areas with development practices that must be sustainable. The plan proposed a process of urban coalescence in the "Gateway Transit Corridor", between the two main *wadis*, in the east-west direction from Al Muwaiji to Al Maqam, with the objective to densify the housing and commercial activities and services, and more clearly mark the boundaries of the city. Growing crops may be hampered by the high costs of fertilizers and the limited water availability. In fact, according to some authors, the future of Al Ain is in higher education, quality health care, finance, trade and tourism.

ANNEXS



DISTRICT_NO	DISTRICT_NAME_ENG	DISTRICT_NAME_ARB
1	AL FOAH	الفوعة
2	HILI	هيلي
3	AL MASOUDI	المسعودي
4	AL QATTARA	القطارة
5	AL JIMI	الجيمي
6	AL TOWAYYA	الطوية
7	AL KHABISI	الخبيصي
8	AL MARKHANIYA	المرخانية
9	AL DAHMAA	الدهماء
10	AL BATEEN	البطين
11	GHREBAH	غريبة
12	AL MAQAM	المقام
13	ASHAREJ	عشارج
14	AL MUWAIJI	المويجعي
15	AL MUTAREDH	المعترض
16	AL JAHILI	الجاهلي
17	AL MUTAWA'A	المطاوعة
18	CENTRAL DISTRICT	وسط المدينة
19	AL SAROOJ	الصـاروج
20	AL SHUWAIMAH	الشويمة
21	AL AFLAJ	الأفلاج
22	AL KHRAIR	الخرير
23	DEFENCE	الدفاع
24	SANAIYA	المنطقة الصناعية
25	FALAJ HAZZA	فلج هزاع
26	SHIAB AL ASHKHAR	شعاب الأشخر
27	JEBEL HAFEET	جبل حفيت
28	AIN AL FAYDA	عين الفايضة
29	ZAKHIR	زاخر
30	AL AGABIYAA	العقابية
31	AL RAWDAH AL SHARQIYAH	الروضة الشرقية
32	AL QISAIS	القسيس
33	NEIMA	نعمة
34	AL AIN INTERNATIONAL AIRPORT	مطار العين الدولي
35	AIRPORT EAST DISTRICT	شرق المطار
36	AL SHWAIB	الشويب
37	AL AJBAN	العجبان
38	AL FAQA'A	الفقع
39	AL HAYER	الهير
40	NAHEL TOWN	مدينة ناهل
41	SWEIHAN	سويحان
42	MASAKIN	مساكن
43	BIDA BINT SAUD	بدع بنت سعود
44	AL SALAMAT	السلامات
45	AL RAWDHA	الروضة
46	AL YAHAR	اليحر
47	INDUSTRIAL TOWN	المدينة الصناعية
48	AL SAAD	الساد
49	ABU SAMRA	أبو سمرة
50	REMAH	رماح
51	AL KHAZNAH	الخزنة
52	MALAGIT	ملاقط
53	KHATM AL SHIKLA	خطم الشكلة
54	SAA	صاع
55	UM GHAFFA	أم غافة
56	AL DHAHER	الظاهر
57	MAZYAD	مزيد
58	AL DHAHRA	الظاهرة
59	ABU KRAYYAH	بوكرية
60	AL ARAAD	العراد
61	ABU HURAIBAH	أبوحريبة
62	AL WAGAN	الوقن
63	AL QUA'A	القوع
64	UM ELZUMOL	أم الزمول

Annex 2.1. Map of Al Ain districts. Blue lines indicate the valleys and the brown colour the main mountains. Source: Al Ain Municipality, 2014.



Annex 2.2. Map of districts and services. Source: Al Ain Municipality, 2016.

Applied Geography 95 (2018) 88–100

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

A district and sector land-use and landscape analysis of urban sprawl in Al Ain municipality (United Arab Emirates): Just a quick conversion from sand to a built-up environment?

Sayed Adnan Sharaf[a], Pere Serra[b,*], David Saurí[b]

[a] Department of Municipal Affairs, Al Ain City Municipality, United Arab Emirates
[b] Department of Geography, Universitat Autònoma de Barcelona, Spain

ABSTRACT

Al Ain, located in the United Arab Emirates, is an example of medium-sized desert city with rapid urban growth guided by two master plans from the 1980s. The present study is an empirical contribution to analyse the spatial-temporal land-use and land-cover (LULC) dynamics from 1984 to 2014 applying three different tools: i) a Base Map of Al Ain Town Planning from 2014 combined with four Landsat images to extract the main LULC changes; ii) a landscape analysis using spatial metrics to determine processes of sprawl; iii) statistical analysis of census data at district scale to obtain a better understanding of changes. Results show an intensive urban sprawl mainly, between 1984 and 1990, with an increase in residential land and in services, very clear in the Western sector as proposed by the 1980s Master Plan. Urban compaction was observed in the Centre and Downtown sectors whereas in the Northern and Southern sectors the urban pattern was leapfrogging and associated to the main roads. Simultaneously, and as a particularity of Al Ain, an intensive process of agricultural sprawl occurred, mainly from 1990 to 2000. The increase was very isolated in the Eastern sector, quite associated to linear patterns in the Northern and Southern sectors, restricted to the north and south in the Centre sector, where vacant land was available, and sprawled throughout the Western. Finally, according to the statistical analysis, the residential increase was more associated to Emiratis, public and private houses, foreign women and religious facilities, whereas the increment of commercial services was more linked to foreign workers, privates houses and religious facilities.

1. Introduction

Monitoring of land-use and land-cover (LULC) changes is critical to effective strategies of spatial management and environmental protection. LULC changes can include negative outcomes such as soil degradation, deforestation or biodiversity loss (Abd El-Kawy, Rad, Ismail, & Suliman, 2011; Biro, Pradhan, Buchroithner, & Makeschin, 2013; Serra, Pons, & Saurí, 2008). As urban growth is a world-wide phenomenon and the most irreversible land alteration, urban transformations have been one of the most analysed changes (Aguilera, Valenzuela, & Botequilha-Leitão, 2011). Nevertheless, the specific trajectories and forms of urban growth remain relatively unknown (Bhatta, Saraswati, & Bandyopadhyay, 2010). According to some authors, urban growth in most of the world appears to have taken the form of disperse or sprawled low density spatial patterns beyond the edge of a city boundary (EEA, 2016; Gargiulo Morelli & Salvati, 2010). However, although urban sprawl is a process equally shared by developed and developing countries, causes and characteristics may differ considerably (Shahraki et al., 2011).

Due to their geostrategic situation, between the developed Western nations and the rising Asian economies, and near world centers of oil production, cities in the Arabian Peninsula have rapidly gained significance in the global economy. Given the fast development of some Arab cities in recent decades, the term ‘instant city’ has been proposed to describe the way they seem to have suddenly appeared out of nowhere. Another trend is the increasing role of branding the urban spaces to endow them with a global image (Helmy, 2008). Some examples of large-scale urban megaprojects are the iconic design of palm-shaped islands in Dubai (Nassar, Blackburn, & Whyatt, 2014) or ‘The Pearl’ in Qatar (Elsheshtawy, 2008). Besides these urban branding projects, as examples of vertical growth, other processes are mostly manifested as urban sprawl. In general, studies on urban sprawl have mainly focused on large cities and metropolitan areas (Moreira, Fontes, Dias, Batista e Silva, & Loupa-Ramos, 2016; Paulsen, 2014), although

* Corresponding author.
E-mail address: pere.serra@uab.cat (P. Serra).

https://doi.org/10.1016/j.apgeog.2018.04.008
Received 24 October 2017; Received in revised form 24 April 2018; Accepted 25 April 2018
0143-6228/

mid-sized urban areas may be experiencing the highest rates of urban growth as in Coimbra (Portugal) (Tavares, Pato, & Magalhães, 2012).

Extensive research has been done to analyse LULC and urban growth, applying various tools and techniques, such as field work, aerial photographs and/or satellite imagery (Chakraborty, Sachdeva, & Joshi, 2016; Patino & Duque, 2013; Yagoub, 2004). After significant advances in sensor technologies during the last 30 years, two issues for using very-high spatial resolution can be the high financial costs and the insufficient number of archived imagery years. Therefore, from a longer temporal perspective, the best option to detect urban growth using remote sensing imagery is Landsat data, as in the case of Issa and Shuwaihi (2012). Nevertheless, as the authors recognized, accurately mapping urban areas is not an easy task at 30-m pixel resolution because the heterogeneous nature of urban environment produces confusions from mixed pixels.

Given the need to improve the knowledge about urban trajectories and forms, this paper has three objectives. The first was to investigate LULC changes from 1984 to 2014 in the city of Al Ain, located in the United Arab Emirates (UAE), combining GIS and remote sensing data. This medium-sized town has very rapidly developed from land held by the State and surrounded by desert, with a horizontal urban growth. In consequence, this city offers a specific example of urban sprawl, clearly differing from other urban development forms.

The second aim was to understand the consequences of LULC changes from a landscape point of view, based on the calculation of some landscape metrics to verify the initial hypothesis about the specificity of Al Ain urban sprawl. They were applied to distinguish which spatial characteristics reflected LUC changes (mainly urban, including residential and services, agricultural and industrial land) according to the configurations of four urban patterns: aggregated, linear, leapfrogging or nodal pattern (Aguilera et al., 2011). The spatial scales of study were the district, defined as a group of communities or neighbourhoods, and the sector, a group of districts. The final objective was to apply a statistical analysis using the most recent census data (2010), at the district scale, to improve the understanding of LULC processes, mainly those related to population, sex and origin.

2. Study area

Al Ain, known as the “garden city” due to its greenery, is the second largest town in the Emirate of Abu Dhabi and the fourth largest in the UAE. The Emirate is divided into three main municipalities: Abu Dhabi, the Western region and Islands, and Al Ain (Fig. 1).

Al Ain has a strategic location on the border between UAE and Oman. It is characterized by a vast arid desert, dominated by sand and gravel, with intermittent dry riverbeds known as *wadis*, a rugged mountainous region (Jabel Hafeet) and an area of fertile soils and oases, with large reserves of groundwater. The climate is hyperarid (Böer, 1997) with a mean annual rainfall of 96.4 mm. The city's development shows rapid growth during the last 40 years, with a population increase from 51,000 inhabitants in 1975 to 560,214 in 2010. In that year, 31.2 percent of the population was local and the rest foreigners.

Agriculture is one of the key productive sectors, being additionally the main supplier of food commodities and raw materials to the Emirate food industry. According to the Statistical Year Book of 2013, 11,985 agricultural holdings were located in Al Ain, with a mean size per farm of about four hectares. The cultivated area includes field crops, vegetables and fruit trees. The total number of sheep and goats in the Emirate totalizes 2.9 million head, with the majority (62%) located in Al Ain area, whereas the total number of camels was 330,220 head, mostly in Al Ain (56%). The Emirate derives its water from three major sources: groundwater (about 70% of water withdrawals), reused treated wastewater (6%) and desalinated water from the Arabian Gulf (24%) (Columbia University, 2010).

The Emirate of Abu Dhabi is one of the world's major producers of oil, which was first discovered in 1958. Al Ain, in particular, created a designated industrial area that houses many industries including manufacturing, and services that provide employment to many locals and foreigners. The Municipality of Al Ain was established by a royal decree in 1967, after which it began providing public services in the city and neighbouring districts. After another royal decree in 1974, the municipal government began to take a more active role in regulating the city's affairs. As shown in Fig. 2, Al Ain was divided into six sectors, with a total area of 8370 km^2, and 63 administrative districts (two of which were not included in this study due to their south remote location: Al Qua'a and Um El Zumol).

During the study period (1984–2014), two master plans for urban planning were developed, covering 1986–2000 and 2003–2014, respectively, and coordinated by the Al Ain Municipality and the Town Planning Department. The main objectives of the 1986–2000 Master Plan were the maintenance of the traditional role of the city as a centre for educational, cultural and recreational activities of national

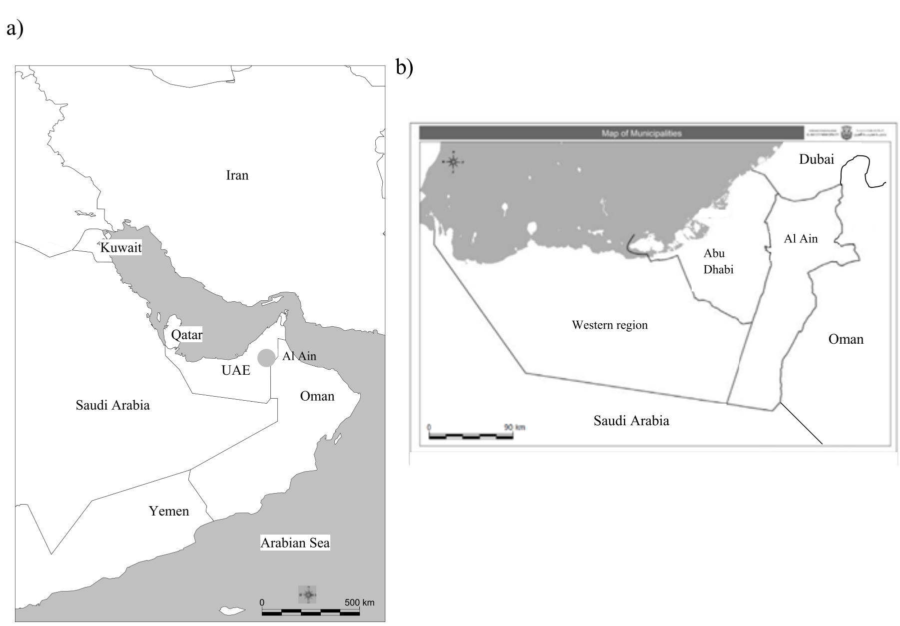


Fig. 1. Location of the United Arab Emirates (UAE) (a) and division of Abu Dhabi Emirate in three municipalities (b). Source: Al Ain City Municipality.

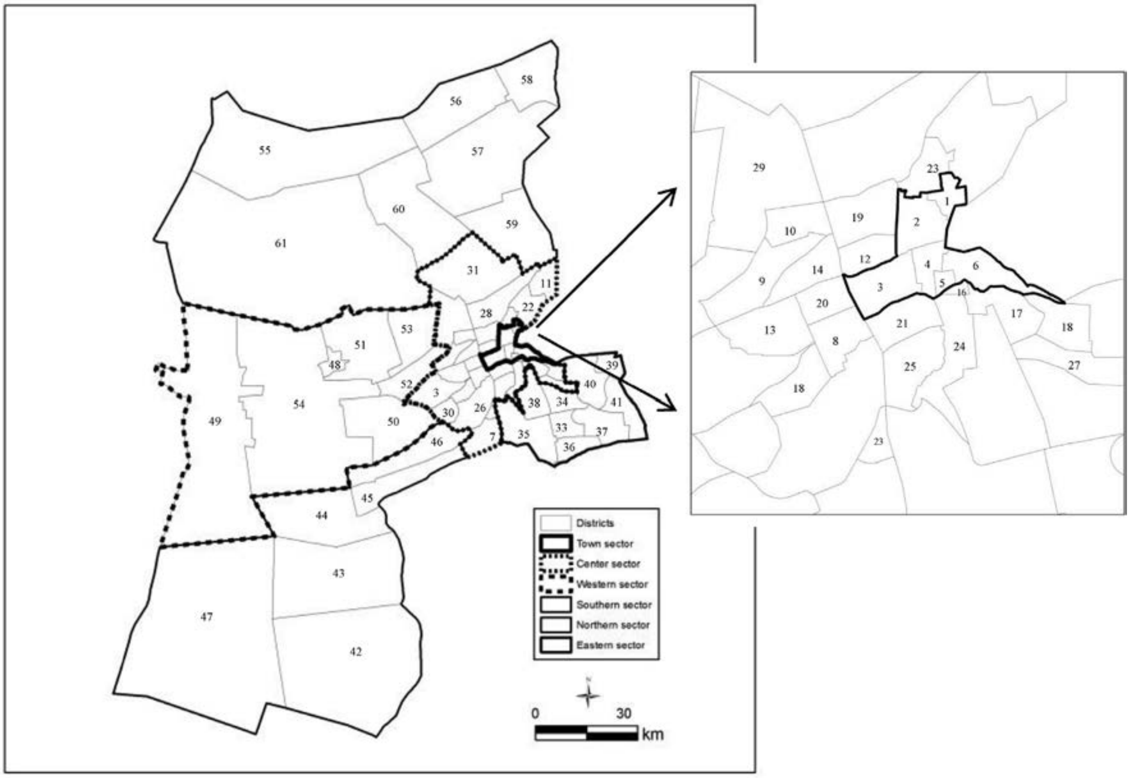


Fig. 2. Districts and sectors of Al Ain municipality. *Downtown sector*: 1. Al Qattara, 2. Al Jimi, 3. Al Muwaiji, 4. Al Mutaredh, 5. Al Jahili, and 6. Central District; *Centre sector*: 7. Ain Al Fayda, 8. Al Agabiyaa, 9. Al Bateen, 10. Al Dahmaa, 11. Al Foah, 12. Al Khabisi, 13. Al Maqam, 14. Al Markhaniya, 15. Al Masoudi, 16. Al Mutawa'a, 17. Al Sarooj, 18. Al Shuawaimah, 19. Al Towayya, 20. Asharej, 21. Falaj Hazza, 22. Hili, 23. Neima, 24. Sanaiya, 25. Shiab Al Ashkhar, 26. Zakhir, 27. Al Aflaj, 28. Airport East District, 29. Al Ain International Airport, 30. Qisais, 31. Bida Bint Saud, and 32. Grebah; *Eastern sector*: 33. Al Dhaher, 34. Al Khrair, 35. Jebel Haffet, 36. Mezyad, 37. Um Ghaffa, 38. Defence, 39. Khatm Al Shikla, 40. Malagit, 41. Saa; *Southern sector*: 42. Al Wagan, 43. Al Araad, 44. Abu Krayyah, 45. Al Dhahra, 46. Industrial Town, 47. Abu Huraibah; *Western sector*: 48. Abu Samra, 49. Al Khaznah, 50. Al Rawdha, 51. Al Saad, 52. Al Salamat, 53. Al Yahar, 54. Remah; *Northern sector*: 55. Al Ajban, 56. Al Faqa'a, 57. Al Hayer, 58. Al Shwaib, 59. Masakin, 60. Nahel Town, 61. Sweihan. Source: Al Ain City Municipality.

importance, as the main agricultural producer of the Emirate and as an environmentally attractive garden city (TPDAA, 1986). The integration of the existing fragmented urban areas and the continuity and cohesion of the town's urban structure at different stages of future growth were additional objectives. In the case of agricultural land, proposals were issued to increase the area, with the objective to settle local population. Finally, a regional road hierarchy at national, regional and local level was proposed, improving the capacity of the existing and constructing news as the E-14.

The Master Plan of 2003–2015 aimed to achieve social and economic prosperity, natural resources conservation, efficient transport systems, conservation of the historic and landscape value and the attraction for investments in tourism and other sectors (Al Ain Municipality Town Planning, 2007). The two main regions established for major development were the Eastern sector, with housing construction to double the population together with extensive commercial areas and other services, and the Western sector, mainly with new housing for citizens (nationals) together with commercial services.

3. Materials and methods

3.1. Change detection combining GIS and remote sensing

The method used to analyse LULC changes was designed to avoid the problems described in the Introduction section, mainly the lack of long temporal perspective and of enough spatial resolution of remote sensing images in urban areas. The data provided by the Al Ain Town Planning Department, at 1:1000 scale for 2014, was a base map obtained from *in situ* surveys and aerial photographs, and available in GIS vector model. Each polygon included all the LULC features very detailed, such as agricultural plots, houses (private or public), type of services (schools, archaeological sites, cemeteries, etc.), or industrial buildings, among others.

To identify the temporal scale of LULC changes, four Landsat images of days with the clearest atmosphere, without clouds or haze, were selected: 15th May 1984 (Landsat-5), 25th August 1990 (Landsat-5), 27th November 2000 (Landsat-7) and 26th November 2014 (Landsat-8). They were selected as close as possible to the dates of the Al Ain Master Plans (1986–2000; 2003–2014) with the exception of 1990 used as an intermediate date. The vector base map from 2014 was then opened on the first satellite image (1984) to retain the oldest polygons with human activity using a visualization of false-colour images. LULC characteristics were visually overlaid with the raster data, which allowed the removal of polygons without human activity in 1984 (Fig. 3). When the 1984 image data covered equal or above 50 percent of the 2014 vector data, the polygon was maintained for analysis. The remaining features reflected the LULC in 1984 with high reliability. This was repeated successively for the remaining years (1990, 2000 and 2014). When this process was completed, a map was drawn to represent all the LULC changes that occurred between and after those years (Sharaf & Serra, 2016).

3.2. Landscape analysis

According to Aguilera et al. (2011), spatial metrics can be a useful tool for planners to better understand and characterize urban processes and their consequences. Their work identified three spatial urban processes: aggregation, compaction and isolation, and simultaneously, four

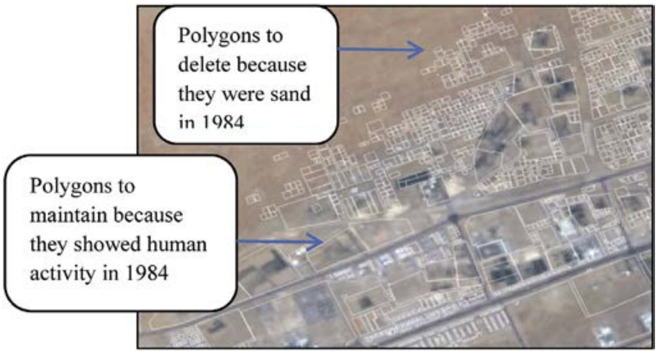


Fig. 3. A visual overlay of the base vectorial map 2014 (in white) and the RS image from 1984; some polygons were maintained because they showed human activity and others deleted because they were sand. The final vectorial outcome corresponded to the 1984 base map. Source: own elaboration from base map of Al Ain Town Planning and Landsat image.

urban patterns: aggregated pattern, linear pattern, leapfrogging, and finally, a nodal pattern. The Graphical User Interface for the Description of image Objects and their Shapes, GUIDOS Toolbox software (Vogt, 2017), provides image-processing tools based on geometric concepts and can be applied to any kind of raster data. From binary maps (presence and non-presence of a specific LULC class), this package measures the shape, size and connectivity of the spatial patterns using a distance threshold. Six parameters were quantified: core, islet, bridge, edge, the Euclidean distance between features and the overall network connectivity.

Two LULC categories, urban and agriculture were individually considered in landscape analysis. After converting the polygons to raster (with a pixel size of 10 m), core pixels were extracted, taking into account that the inner part of a polygon of the 2014 base map occupied at least one pixel edge width (Soille & Vogt, 2009). Continuous areas with less than 1000 pixels were considered small cores, from 1000 to 4600 medium cores, and above, large cores. Islet pixels were those features without any core. Another metric was the measurement of edge pixels, corresponding to the outer boundaries of core pixels. To analyse landscape connectivity, bridges (connector pixels emanating from two or more connected cores), average distance and maximum distance were included. The last two calculated indicators were the Equivalent Connected Area Relative (ECAR) and entropy. The overall network connectivity (expressed as ECAR) assumes that a network is composed of cores and bridges whereas entropy was used as a descriptor of spatial fragmentation. According to Bhatta et al. (2010), entropy is perhaps the most widely used technique to measure the extent of urban sprawl, indicating higher values its presence.

3.3. Statistical analysis

To analyse the territorial dynamics of Al-Ain city at a district scale, the methodology from Serra, Vera, and Tulla (2014) was applied. The procedure applies principal component analysis (PCA) with data extracted from the 2010 census and from spatial analysis using GIS techniques. LULC data were extracted from the 2014 base map, considering the administrative boundaries of the 61 districts that conform the municipality of Al Ain (see Fig. 2). Available variables included in the statistical analysis are shown in Table 1.

Factor analysis (FA), in general, and PCA in particular, are among the most common statistical methods applied in planning and socio-economic studies (O Salvati & Carlucci, 2016; among others). The objective of FA is to obtain comprehensive new factors that express the essential information contained in a set of variables (Afifi & Clark, 1996). To assess the requirement of FA that the original variables must be correlated in order to share common factors, the Kaiser-Meyer-Olkin (KMO) test was calculated. The next step was the extraction of PCs according to an eigenvalue (the variance explained by each PC) greater than one. The third step was to obtain the factor matrix showing the factor loadings of each retained PC in relation to each original variable. After rotating this matrix, to facilitate its interpretation, the last step was to calculate the values for each PC and district using the factor score coefficients.

Table 1
Variables included in the statistical analysis. Source: Statistics Center of Abu Dhabi.

Variables	Source	Measurement units
Population by sex and origin		
Local males	Statistical censuses	Absolute number
Local females	Statistical censuses	Absolute number
Non-local (foreign workers) males	Statistical censuses	Absolute number
Non-local (foreign workers) females	Statistical censuses	Absolute number
Land-use at plot level and at district scale		
Government employment houses	Base maps	Hectares
Shoping centers	Base maps	Hectares
Retail shops	Base maps	Hectares
Commerce buildings	Base maps	Hectares
Religious facilities	Base maps	Hectares
Recreation facilities	Base maps	Hectares
General industry	Base maps	Hectares
Light industry	Base maps	Hectares
Heavy industry	Base maps	Hectares
Company camps	Base maps	Hectares
Farm land	Base maps	Hectares
Poultry	Base maps	Hectares
Palm land	Base maps	Hectares
Private houses	Base maps	Hectares
Public houses	Base maps	Hectares
Extracted from GIS techniques		
Distance from main roads	Own elaboration	Kilometers

4. Results

4.1. Land use changes

The LULC change analysis from 1984 to 2014 showed that agricultural land occupied the largest area, followed by services, residential, and industrial land (Fig. 4). The results also showed that the most important increase between 1984 and 1990 was in residential land and in services; between 1990 and 2000, the principal increase was in agricultural land. Finally, changes between 2000 and 2014 were small, showing a clear reduction in LULC expansion. In general terms, and according to Fig. 5, the main expansions follow the Abu Dhabi roads to the west (E-22 and E-30), the road to the south (E-95) and the two northern roads (E-66 and E-16).

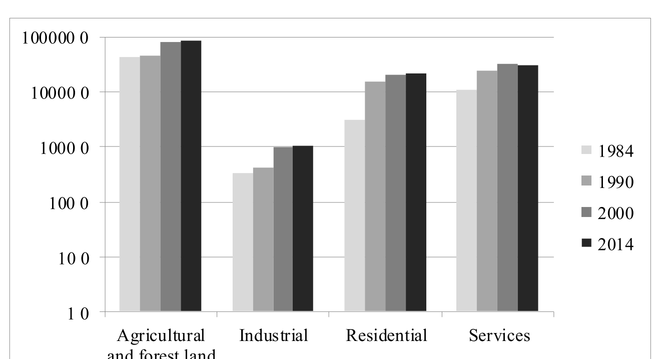


Fig. 4. Land use changes 1984–2014, in hectares. Source: own elaboration from Al Ain Town Planning Base Map and Landsat data.

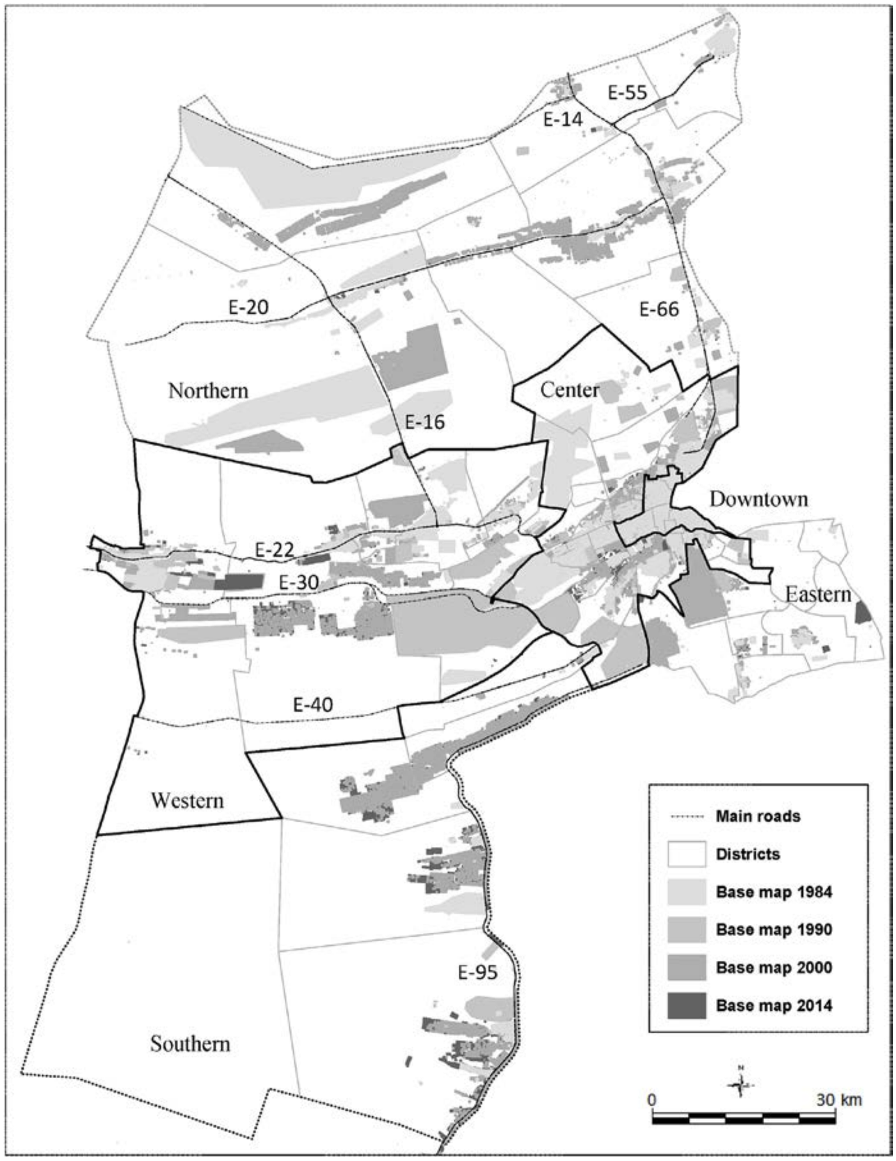


Fig. 5. Map of land-use changes by polygons, districts and sectors. The main road network is included. Source: own elaboration from Al Ain Town Planning Base Map and Landsat data.

4.1.1. Urban and agricultural growth

In the Eastern sector, the biggest residential land increases were in Jebel Hafeet from 1990 to 2000 (Fig. 6a). In the case of services, the biggest increases from 1990 to 2000 occurred in Jebel Hafeet and in Al Daher, from 2000 to 2014 in Um Ghaffa, and in Mezyad and Al Khrair the most growth occurred in 1984–1990. The urban growth in the Southern was less intensive than in the Eastern being the districts with more residential growth Al Wagan and Al Dhahra, from 1990 to 2000, whereas the main increase in services occurred in Al Wagan and in Abu Krayyah, between 2000 and 2014 (Fig. 6b). In the Northern sector, all districts experienced some urban growth, mainly from 1990 to 2000 (Fig. 6c).

According to Fig. 6d, in the Centre sector the residential urban growth took place from 1984 to 1900 in Al Khabisi and in Al Sarooj, whereas in services Al Maqam, Al Bateen and Ain Al Fayda were the most important. Urban growth in the Downtown districts was small, and occurred mostly between 1990 and 2000. For the period 1984–1990, one showed both residential and services growth (Al Jimi) and another (Al Muwaiji) had only residential growth (Fig. 6e). The urban growth in the Western sector happened between 1984 and 1990 due to construction of a palace in Al Rawdha. From 1990 to 2000, Al Yahar showed urban increase whereas from 2000 to 2014, the increase was mainly in Remah due to services (Fig. 6f).

In the Eastern sector, from 1990 to 2000 largest agricultural growth occurred in Um Ghaffa, whereas from 2000 to 2014 it was in Saa and in Jebel Hafeet, whereas (Fig. 7a). Industrial growth, generally small in area, was significant in Al Khrair and in Malagit from 1984 to 1990 and in Al Khrair and in Al Daher from 1990 to 2000. In the Southern sector, some districts observed important increases in agricultural land from 1990 to 2000, while Abu Huraibah and Industrial Town had no increment (Fig. 7b). Industrial expansion was only located in the Industrial Town, and only in the 1990–2000 period. In the Northern sector, all districts had large increases in agricultural land between 1990 and 2000. In the case of Nahel Town, the growth mainly followed the road E-20 (Fig. 7c), while industrial expansion was practically non-existent.

In the Centre sector, only some districts showed a significant increase in agricultural land (Fig. 7d). Between 1990 and 2000, there were small increments and from 2000 to 2014 the main increase was in Bida Bint Saud. The single district with a substantial increase in industrial land was Sanaiya, from 2000 to 2014. In the case of the

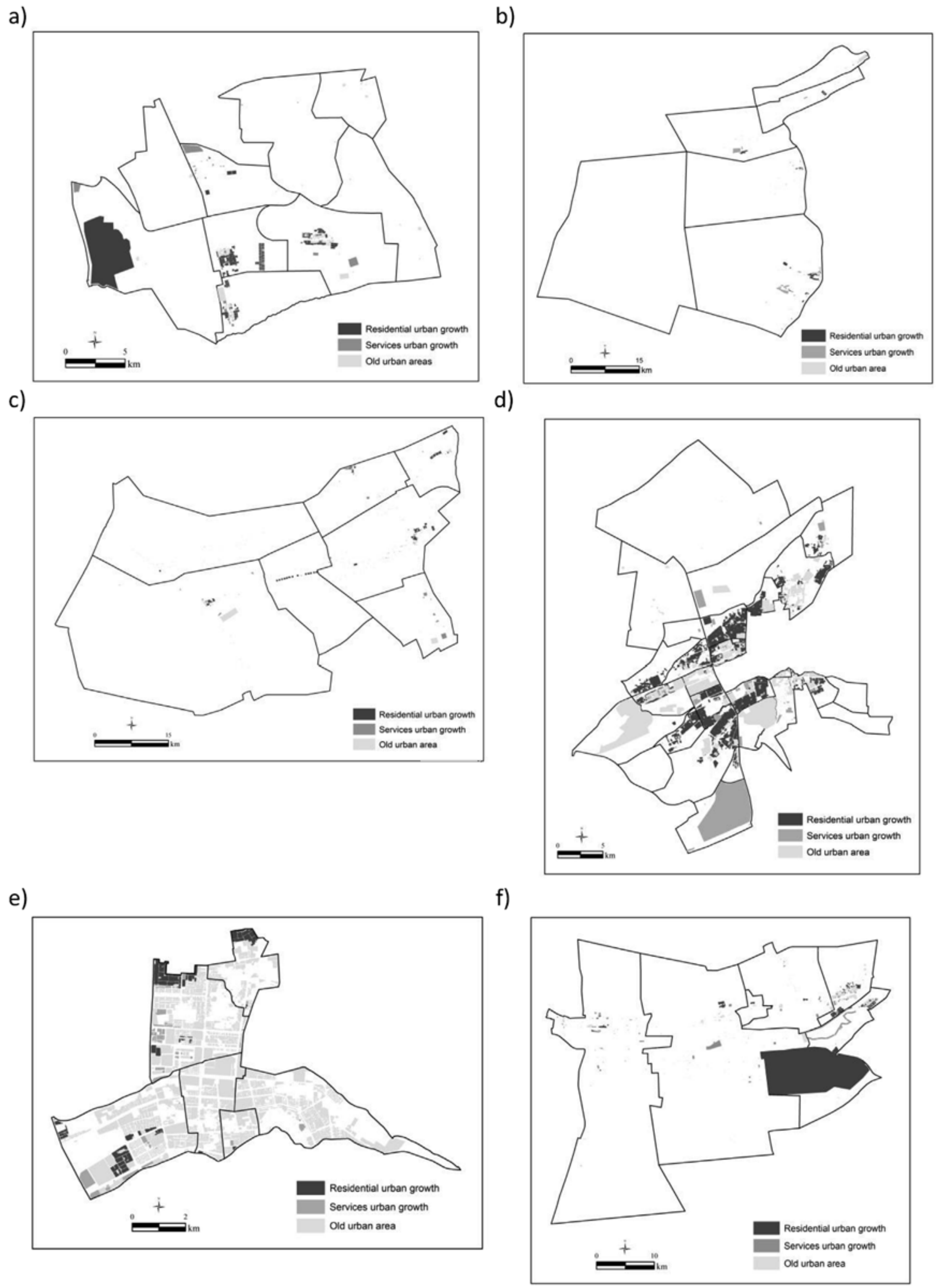


Fig. 6. Urban growth of Eastern (a), Southern (b), Northern (c), Centre (d), Downtown (e), and Western (f) sectors. Source: own elaboration from Al Ain Town Planning and Landsat data.

Downtown sector, no significant change in agricultural and industrial land was identified and, finally, all districts in the Western, with the exception of Al Rawdha and Al Yahar, experienced an increase in agricultural land, mainly from 1990 to 2000 (Fig. 7e). Finally, the districts with industrial increases were Al Saad and Remah, from 1990 to 2000.

4.2. Landscape results

4.2.1. Urban landscape

According to landscape results, the Eastern region experienced a great increase in large core areas whereas there was a decrease of islets, edges and bridges (Fig. 8a). The average distance and the maximum distance, measured in pixels, were slower in 1984 compared to 2014:

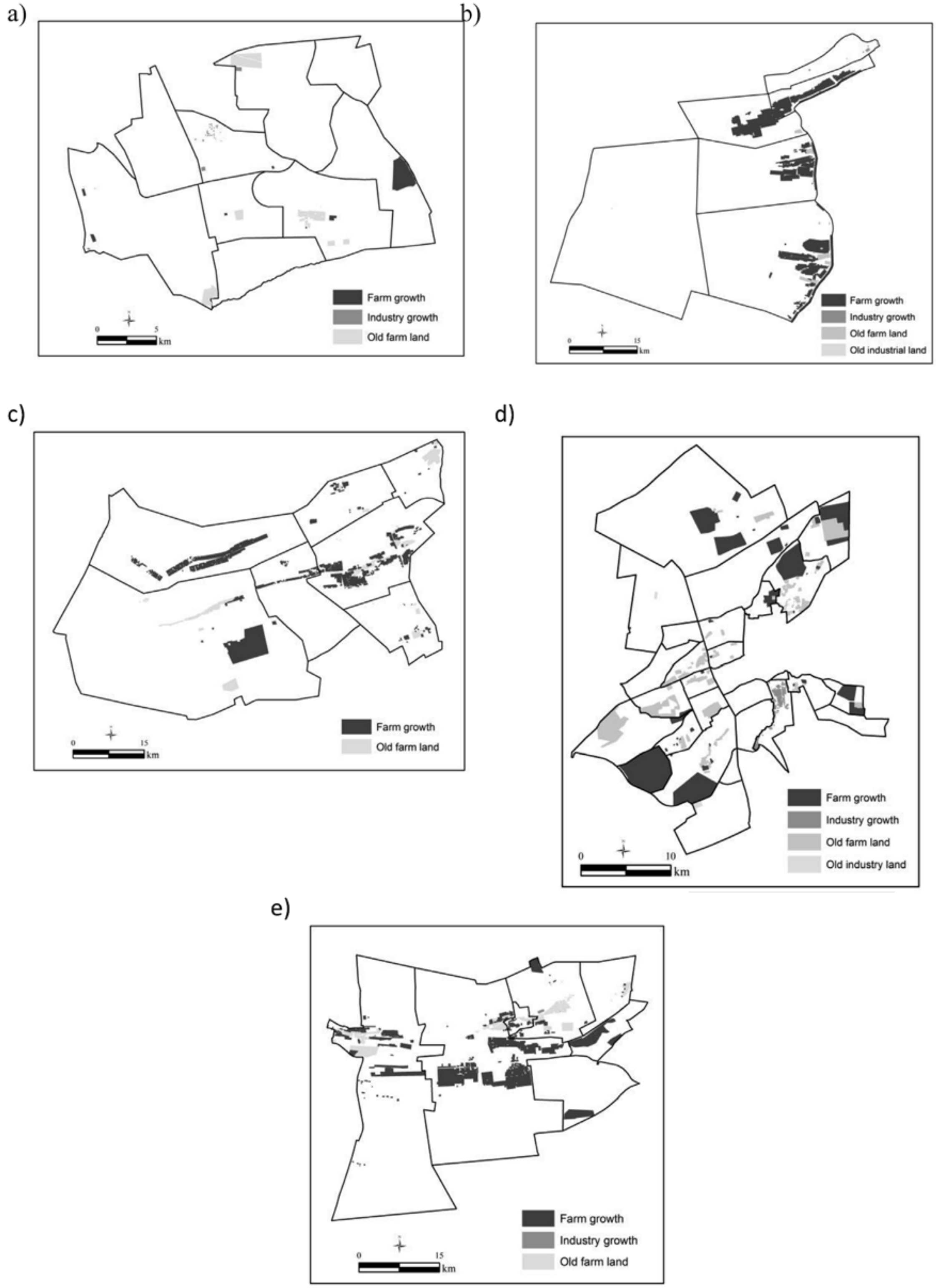


Fig. 7. Agricultural and industrial land growth of Eastern (a), Southern, (b), Northern (c), Centre (d), and Western (e) sectors. Source: own elaboration from Al Ain Town Planning and Landsat data.

from 5.9 to 30.6; and from 27.2 to 155.8, respectively. Finally, the core network connectivity (ECAR) was higher in 2014 compared with 1984 (Fig. 9), whereas the entropy value in 2014 (2.08) was also higher than in 1984 (0.73).

In the case of the Southern sector, the main difference between 1984 and 2014 was the strong increase in medium cores as a result of the development of new residential land and services (Fig. 8b). Therefore, a weaker process of aggregation was detected, confirmed by the similar values in islets, edges and bridges and by the weak decrease in average distance (from 10.5 to 8.4 pixels). The maximum distance also increased very little (34.9–43.8 pixels), while the ECAR showed fewer connections (Fig. 9). Finally, the entropy value in 2014 was just slightly

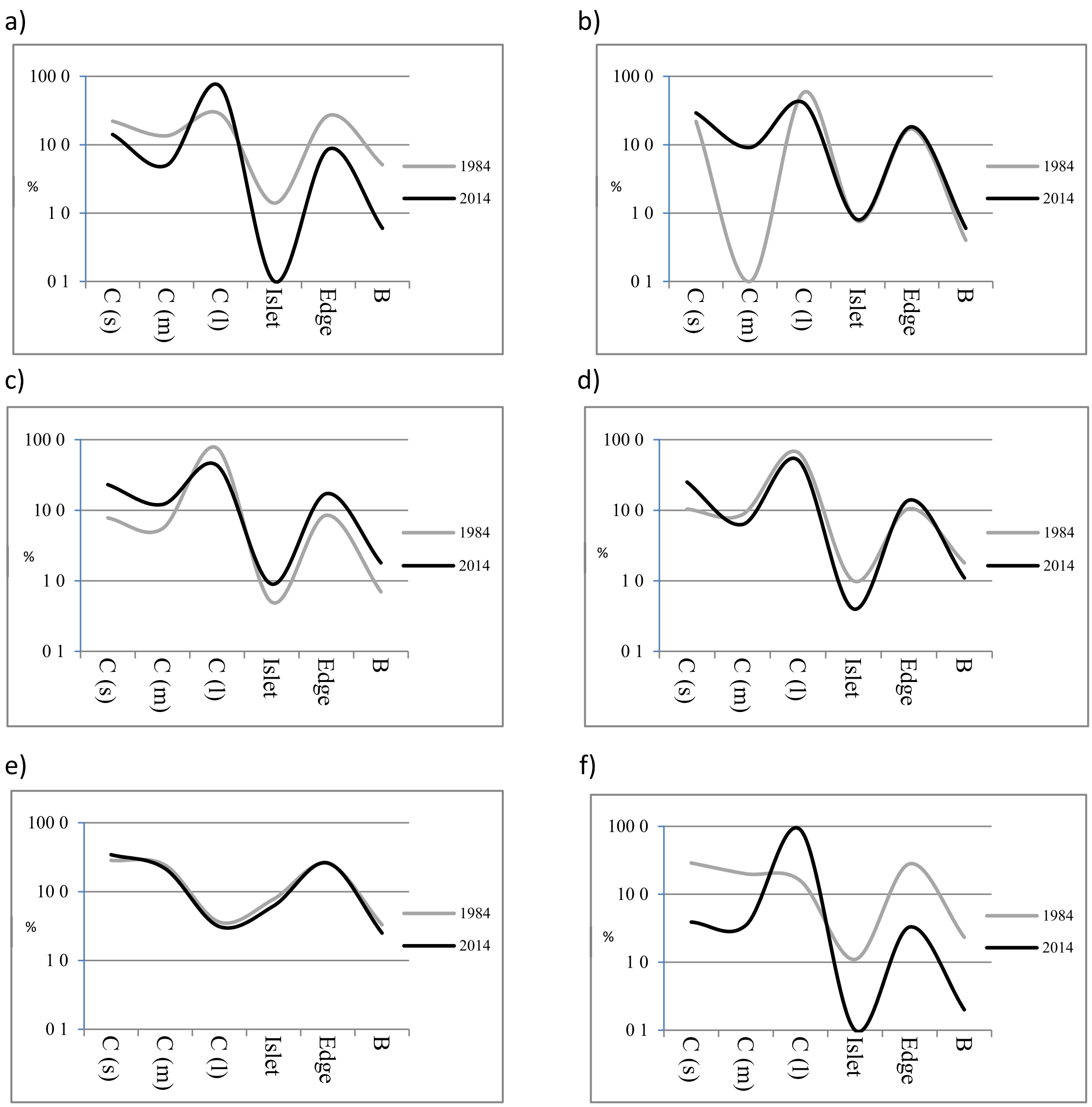


Fig. 8. Urban landscape parameters (in percentage) of Eastern (a), Southern (b), Northern (c), Centre (d), Downtown (e), and Western (f) sectors. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

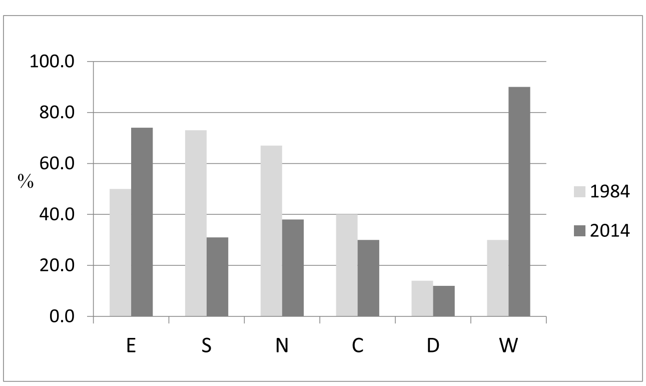


Fig. 9. Urban Equivalent Connected Area Relative (ECAR) (in percentage)) of Eastern (E), Southern (S), Northern (N), Centre (C), Downtown (D), and Western (W) sectors. Source: own elaboration.

higher (0.5) than in 1984 (0.2).

In the Northern sector, the main landscape dynamic from 1984 to 2014 was an increase of small and medium cores (Fig. 8c) whereas a weak increase in islets, edges and bridges was detected. The average distance and the maximum distance showed a decrease and no change, respectively whereas the ECAR indicated a decrease in connectivity (Fig. 9). Finally, in 2014 entropy was slightly higher (0.37) compared with 1984 (0.11).

In the Centre sector, there was an increase in small cores in a landscape dominated by large cores but with less intensity than in 1984 (Fig. 8d). The islets and bridges decreased but the edge increased a little; average distances also decreased a little, although the maximum distance increased. The ECAR value showed a decrease from 1984 to 2014 (Fig. 9), whereas the entropy indicated a clear increase in urban sprawl from 1984 to 2014 (2.79 and 4.93, respectively). The Downtown sector had fewer landscape changes, as a result of the feeble urban growth (Fig. 8e). Finally, in the Western sector, there was a decrease in the small and medium cores, while large cores increased, and also a decrease in islets, edges and bridges (Fig. 8f). A clear increase in average distance and maximum distance was detected (from 5.9 to 134.1 and from 32.8 to 394.2, respectively), with more landscape connectivity according to the ECAR increase (Fig. 9), and a clear process of urban sprawl according to the entropy values (0.57 in 1984 and 1.21 in 2014).

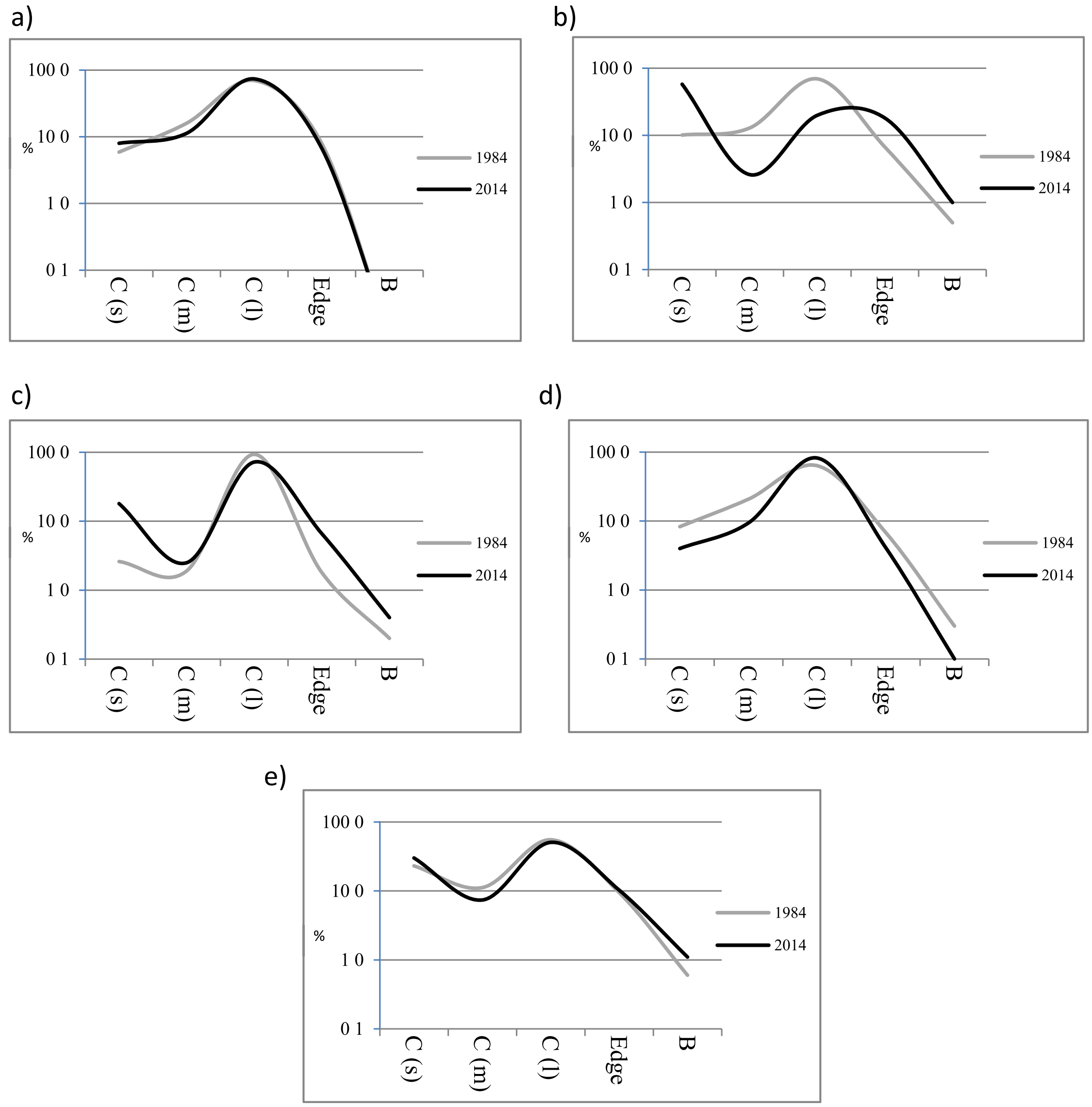


Fig. 10. Agricultural landscape parameters (in percentage) of Eastern (a), Southern (b), Northern (c), Centre (d), and Western (e) sectors. C (s): Core (small); C (m): Core (medium); C (l): Core (large); B: Bridge. Source: own elaboration.

4.2.2. Farm landscape

After not considering the islets pixels because all the values were very small, in the Eastern sector a small decrease in medium cores and a slight increase of small and large cores were detected (Fig. 10a). The average distance and the maximum distance increased whereas the ECAR showed an increase from 1984 to 2014 (Fig. 11), and the entropy value remained very similar (from 0.70 to 0.71, respectively). The farm growth of the Southern sector was characterized by a large increase in small cores compared with the decrease in medium and large cores with an increase of edges and bridges (Fig. 10b). As a consequence, average distance decreased but maximum distance increased. Finally, the ECAR showed a decrease from 1984 to 2014 (Fig. 11), and the entropy showed a very clear process of sprawl (from 0.53 in 1984 to 4.06 in 2014).

In the Northern sector, there was an increase in small and medium cores and a small decrease in large cores (Fig. 10c). We detected also a weak increase in bridges, with less average distance and equal maximum distance. The ECAR indicator showed a decrease from 1984 to 2014 (Fig. 11), whereas the entropy was higher in 2014 (2.9 versus 0.8) as a result of sprawl increase. In the Centre sector, there was a decrease in small and medium cores and a small increase in large cores with a

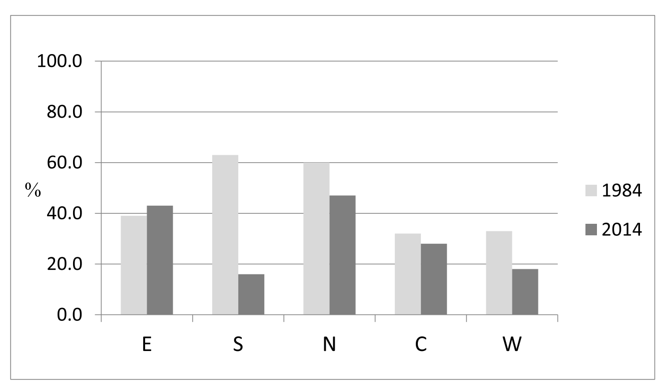


Fig. 11. Agricultural Equivalent Connected Area Relative (ECAR) (in percentage)) of Eastern (E), Southern (S), Northern (N), Centre (C), Downtown (D), and Western (W) sectors. Source: own elaboration.

decrease in edges and bridges and an increase in average distance and maximum distance (Fig. 10d). The ECAR showed a small decrease from 1984 to 2014 (Fig. 11), as in the case of the entropy increase (1.63

Table 2
Final scores from loading matrix. In bold, the values > 0.6 and in italics, the values ≥ 0.25 and 0.6 < . Source: own elaboration.

Variables	Principal component					
	1	2	3	4	5	6
Local males	0.03	**0.97**	−0.08	−0.09	−0.05	0.08
Local females	0.03	**0.97**	−0.08	−0.09	−0.05	0.08
Non-local (foreign workers) males	**0.64**	0.10	*0.51*	0.15	*0.38*	0.06
Non-local (foreign workers) females	**0.81**	*0.50*	−0.02	−0.03	−0.02	0.06
Government employment houses	−0.01	−0.06	−0.03	0.17	**0.94**	−0.01
Shoping centers	**0.87**	0.04	−0.03	−0.02	−0.03	0.00
Retail shops	**0.87**	0.20	−0.05	0.14	0.02	0.04
Commerce buildings	**0.70**	−0.08	−0.04	−0.09	−0.06	−0.03
Religious facilities	*0.26*	*0.43*	−0.01	0.05	−0.02	**0.83**
Recreation facilities	−0.07	−0.03	−0.01	−0.07	−0.03	**0.97**
General industry	0.00	−0.04	**0.92**	0.05	−0.05	0.06
Light industry	−0.07	−0.12	**0.89**	0.07	−0.03	−0.05
Heavy industry	−0.06	−0.12	**0.08**	−0.03	*0.25*	−0.04
Company camps	−0.03	−0.06	0.17	−0.07	**0.93**	−0.05
Farm land	−0.07	−0.10	−0.19	**0.88**	0.12	0.01
Poultry	−0.07	−0.04	0.19	**0.72**	−0.08	−0.05
Palm land	**0.88**	0.03	−0.02	0.08	0.00	0.08
Private houses	*0.52*	**0.61**	−0.09	−0.12	−0.07	0.07
Public houses	0.12	**0.88**	−0.07	0.08	0.00	0.05
Distance from main roads	0.22	0.00	0.09	**0.87**	0.10	0.01
Total variance (%)	21.30	17.80	13.50	11.00	10.10	8.40

versus 2.05).

In the Downtown sector, the parameters showed no significant landscape changes whereas in the Western sector there were an increase in small cores and a decrease in medium and large cores, with very similar edges and bridges. In parallel, there was an increase of both the average and the maximum distance (Fig. 10e). The ECAR showed a decrease from 1984 to 2014 (Fig. 11) and the entropy an important increase, from 1.84 in 1984 to 5.35 in 2014, as a result of intensive sprawl.

4.3. Statistical analysis

Factor analysis results showed that the KMO value was 0.65. According to 2014 data, six PCs were retained, covering 82.1% of total variance (21.3, 17.8, 13.5, 11.0, 10.1 and 8.4, respectively). After the Varimax rotation, the six PCs were labelled, according to the relationship with original variables, as follows (Table 2): PC 1 as "foreign workers associated to commercial services"; PC2 as "local people associated to private and public housing"; PC3 as "industry"; PC4 as "rural activity"; PC5 as "houses of big public and private companies"; finally, PC6 was labelled as "religious and recreational facilities".

The districts with the highest values for "foreign workers associated to commercial services" were located inside the Downtown sector together with some districts of the Centre sector and in the western part of the Eastern district (Fig. 12a). This emplacement indicated the importance of commercial services and foreign population around the city centre, where oasis palm land is mainly placed. Fig. 12b shows the situation of "local people associated to private and public housing", being the districts with the highest values located around the city centre and in some close districts of the Western and Eastern sectors. The districts with the highest values for "industry" were located outside the city centre and along the E-22 and E-30 roads (Al Saad, Industrial Town and Sanaiya) (Fig. 12c). The highest values for "rural activity" were located outside the city centre and inside the Southern, Western and Northern sectors (Fig. 12d). The districts with the highest values for "houses of big public and private companies" were mainly located outside the city centre, with the exception of Al Khrair (Fig. 12e). Finally, Fig. 12f shows the situation of "religious and recreational facilities", being the districts with the highest values mainly located outside and around the city centre.

5. Discussion

In the period 1984–1990, the Western sector showed the maximum increase in residential land and services, and the Centre sector had the maximum increase in services. In the period of 1990–2000, the maximum increase in residential land was in the Eastern, Centre and Downtown sectors, whereas the maximum increase in residential land and services occurred in the Northern sector. The maximum increase in 2000–2014 happened in services in the Southern sector.

The spatial metrics showed a much clearer process of urban sprawl in the Western than in the Eastern sector, whereas the Southern and Northern sectors showed similar dynamics, with very limited sprawl, probably similar to a leapfrogging urban pattern. In the Downtown sector, changes were small given the lack of available new land while in the Centre sector there was a clear process of urban land compaction from vacant land. Therefore, the integration of the extant fragmented urban areas was achieved in the city centre and in some districts of the new residential areas, as planned in 1986–2000 Master Plan. Therefore, the planning target based on the idea of urban growth phases, diffusion and coalescence, with multiple waves over different time periods (Dietzel, Herold, Hemphill, & Clarke, 2005; Nassar et al., 2014), appears to have been achieved in those sectors. This rapid sprawled urban development since the 1980s can be attributed, at least, to the migration of local residents from the city centre, associated to private and public houses, to foreign women workers, and to religious facilities, as reported by our statistical analysis, to gain more comfort and space and to the attraction of the increasing service sector, located in the west as the Maqam Palace, the UAE University or the Tawam hospital (Selim & Gamal, 2007; Yagoub, 2006). Besides local Emiratis, the service sector increment, mainly in the Downtown sector where palm land in oasis is placed, attracted a high number of foreign workers from India, Pakistan, and Egypt, among other countries (Elessawy & Zaidan, 2014), both women and men associated to private houses and religious facilities, as pointed out by our statistical analysis.

In consequence, from our results it can be extracted that the urban sprawl of Al Ain city has been quite planned from the two mentioned master plans, seeming clear in the case of the urban growth of Western and Eastern sectors with an expansion of residential and services land. This situation is the opposite from the unplanned urban sprawl of some developed or developing countries, due to the influence of multiple factors as the land tenure or housing prices in the case of Athens (Colantoni, Grigoriadis, Sateriano, Venanzoni, & Salvati, 2016), as the ambition of local governments to attract investment through land leasing in Shanghai (Tian, Ge, & Li, 2017) or the numerous populations concentrated in peripheral areas with illegal allotments in Brazil (de Espindola, Carneiro, & Façanha, 2017), among others reasons (Acheampong, Yu, Enomah, Anchang, & Eduful, 2018; Pawe & Saikia, 2018).

On the other hand, in most of the world, urban growth proceeds at the expense of agricultural land (Tian et al., 2017). This LULC conversion has been very clear in Mediterranean countries such as Spain (Gallardo & Martínez-Vega, 2016) or Greece (Salvati, Sateriano, & Bajocco, 2013). The main reasons for agricultural abandonment are the globalization of agricultural markets, the increase in land price, and/or the farmers' age (Serra, Saurí, & Salvati, 2017). Nevertheless, in Al Ain municipality an enormous increase in agricultural land from sand land was identified, located outside the city centre and in some cases far from the main roads as reported by our statistical analysis, constituting an exception to the general trend. The mains reasons have been the investment of money earned from oil in building dams and desalination plants, together with the land given by the government to Emiratis to create their own farms, and with some other subsidies (UAE Ministry of

Fig. 12. Results of Principal Component Analysis (PCA) for the six PC retained. PC 1: "foreign workers associated to commercial services" (a); PC2: "local people associated to private and public housing" (b); PC3: "industry" (c); PC4: "rural activity" (d); PC5: "houses of big public and private companies" (e); PC6: "religious and recreational facilities" (f). Source: own elaboration.

Information and Culture, 2006).

In the case of industry, increments were very restricted and localized. The Centre sector had the largest industrial increase, which took place mainly between 2000 and 2014. Sanaiya district had the highest activity level, ranging from motor manufacturing companies to art centers and attracting foreign workers, mainly men, as reported by our statistical analysis.

From a future environmental point of view, one of the main objectives of the recent "Urban structure framework plan, Plan Al Ain 2030" (Abu Dhabi Urban Planning Council, 2012) is to protect the Al Ain macro-landscape and areas of aquifer recharge from urban growth. The highest priority was to define the urban development boundary, applying a transition concept from complete protection (establishing three national parks) to complete urbanization. The urban development boundary between the two main *wadis*, the Gateway Transit Corridor in the east-west direction from Al Muwaiji to Al Maqam (Fig. 2), will accommodate the largest portion of future residential and commercial demand.

6. Conclusions

The main objective of this research was to analyse the LULC dynamics of Al Ain municipality, as an example of a medium-size town affected by urban sprawl. Three different tools were applied: i) a combination of the 2014 base map from Al Ain Town Planning with Landsat imagery; ii) landscape metrics; iii) statistical analysis of census data at district scale.

The outputs showed that Al Ain is a city experiencing rapid urban growth, mainly since the mid-1980s, with hundreds of thousands of hectares of new residential and services land, guided by two master plans (1986–2000 and 2003–2014). In general, the main objectives of these plans were achieved: an expanded road network, an extensive provision of public services, and a noticeable increase in housing construction. Therefore, our conclusion is that Al Ain shows a clear example of urban sprawl quite planned, very differentiated from other urban grows as Dubai, but with diverse landscape urban patterns according to the sectors and the years of development. The main transformations were the urban compaction, in the Central sector, whereas the clearest sprawl dynamic was located in the Western sector, between 1984 and 1990. In the Northern and Southern sectors, the urban pattern was "leapfrogging" and a linear pattern associated with the main roads. In general, the increase in residential land was more related to local population, foreign women and religious facilities, whereas the increase in services to foreign workers and private houses, as demonstrated by our statistical analysis.

An intensive process of agricultural sprawl was also observed, mainly between 1990 and 2000, as a particularity of Al Ain compared with other countries, being an unexpected result from our initial research. The main reason of such increase was the objective to reach agricultural self-sufficiency in those products for which it was suited according to the 1986 Master Plan. Nevertheless the increase showed important spatial differences: it was isolated in the Eastern sector, associated with linear patterns in the Northern and Southern sectors, restricted to vacant land to the north and south in the Centre sector and, finally, sprawled throughout the Western.

Finally, according to Plan Al Ain (2030), urban coalescence will be emphasized along the proposed Gateway Transit Corridor, densifying housing and commercial activities and services, and more clearly marking the boundaries of the city. Probably, growing crops will be hampered by the high costs of fertilization and the limited water availability. In fact, according to some authors, the future of Al Ain is in higher education, quality health care, finance, trade and tourism (Ben Hamouche, 1999; Selim & Gamal, 2007).

Acknowledgements

The authors would like to thank the anonymous reviewers for many helpful comments and the Al Ain City Municipality and the Abu Dhabi Statistics Centre for their support and for providing essential data for this research.

References

Abd El-Kawy, O. R., Rad, J. K., Ismail, H. A., & Suliman, A. S. (2011). Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Applied Geography, 31*, 483–494.

Acheampong, M., Yu, Q., Enomah, L. D., Anchang, J., & Eduful, M. (2018). Land use/cover change in Ghana's oil city: Assessing the impact of neoliberal economic policies and implications for sustainable development goal number one – a remote sensing and GIS approach. *Land Use Policy, 71*, 373–384.

Afifi, A. A., & Clark, V. (1996). *Computer-aided multivariate analysis.* London: Chapman & Hall.

Aguilera, F., Valenzuela, L. M., & Botequilha-Leitão, A. (2011). Landscape metrics in the analysis of urban land use patterns: A case study in a Spanish metropolitan area. *Landscape and Urban Planning, 99*, 226–238.

Al Ain Municipality Town Planning (2007). *The master plan, traffic and transportation study for Al Ain and its region to the year 2015.* UAE: Manusell Consultancy Services Ltd.

Ben Hamouche, M. (1999). Opting for growth: A strategy for Al Ain. *Habitat International, 23*, 303–317.

Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography, 30*, 731–740.

Biro, K., Pradhan, B., Buchroithner, M., & Makeschin, F. (2013). Land use/land cover change analysis and its impact on soil properties in the Northern part of Gadarif region, Sudan. *Land Degradation & Development, 24*, 90–102.

Böer, B. (1997). An introduction to the climate of the United Arab Emirates. *Journal of Arid Environments, 35*, 3–16.

Chakraborty, A., Sachdeva, K., & Joshi, P. K. (2016). Mapping long-term land use and land cover change in the central Himalayan region using a tree-based ensemble classification approach. *Applied Geography, 74*, 136–150.

Colantoni, A., Grigoriadis, E., Sateriano, A., Venanzoni, G., & Salvati, L. (2016). Cities as selective land predators? A lesson on urban growth deregulated planning and sprawl containment. *The Science of the Total Environment, 545–546*, 329–339.

Columbia University (2010). *Sustainable water management. Assessment and recommendations for the Emirate of Abu Dhabi.* New York: School of International and Public Affairs 128 pages.

Dietzel, C., Herold, M., Hemphill, J. J., & Clarke, K. C. (2005). Spatio-temporal dynamics in California's central valley: Empirical links to urban theory. *International Journal of Geographical Information Science, 19*, 175–195.

Elessawy, F., & Zaidan, E. (2014). Living in the move: Impact of guest workers on population characteristics of the United Arab Emirates (UAE). *The Arab World Geographer, 17*, 2–23.

Elsheshtawy, Y. (2008). *The evolving Arab city. Tradition, modernity and urban development.* London: Routledge.

de Espindola, G. M., Carneiro, E. L. N. C., & Façanha, A. C. (2017). Four decade of urban sprawl and population growth in Teresina, Brazil. *Applied Geography, 79*, 73–83.

European Environmental Agency (EEA) (2016). *Urban sprawl in Europe. EEA report 11*Copenhagen: European Environment Agency.

Gallardo, M., & Martínez-Vega, J. (2016). Three decades of land-use changes in the region of Madrid and how they relate to territorial planning. *European Planning Studies, 24*, 1016–1033.

Gargiulo Morelli, V., & Salvati, L. (2010). *Ad hoc urban sprawl in the Mediterranean city. Dispersing a compact tradition?* Roma: Edizioni Nuova Cultura.

Helmy, M. (2008). *Urban branding strategies and the Emerging Arab Cityscape.* Stuttgart, Germany: Universität Stuttgart.

Issa, S., & Shuwaihi, A. L. (2012). Characterization of Al Ain city urban growth using multi-temporal remote sensing data and GIS. *International Geoinformatics Research and Development Journal, 3*, 1–17.

Moreira, F., Fontes, I., Dias, S., Batista e Silva, J., & Loupa-Ramos, I. (2016). Contrasting static versus dynamic-based typologies of land cover patterns in the Lisbon metropolitan area: Towards a better understanding of peri-urban areas. *Applied Geography, 75*, 49–59.

Nassar, A. K., Blackburn, G. A., & Whyatt, J. D. (2014). Developing the desert: The pace and process of urban growth in Dubai. *Computers, Environment and Urban Systems, 45*, 50–62.

O Salvati, L., & Carlucci, M. (2016). Patterns of sprawl: The socioeconomic and territorial profile of dispersed urban areas in Italy. *Regional Studies, 50*, 1346–1359.

Patino, J. E., & Duque, J. C. (2013). A review of regional science applications of satellite remote sensing in urban settings. *Computers, Environment and Urban Systems, 37*, 1–17.

Paulsen, K. (2014). Geography, policy or market? New evidence on the measurement and causes of sprawl (and infill) in US metropolitan regions. *Urban Studies, 5*, 2629–2645.

Pawe, C. K., & Saikia, A. (2018). Unplanned urban growth: Land use/land cover change in the Guwahati metropolitan area, India. *Geografisk Tidsskrift-Danish Journal of Geography, 118*, 88–100.

Salvati, L., Sateriano, A., & Bajocco, S. (2013). To grow or to sprawl? Land cover relationship in a Mediterranean city region and implications for land use management. *Cities, 30*, 113–121.

Selim, G. M., & Gamal, M. (2007). Neighborhoods and residential communities. The case of Al Ain UAE. *Housing symposium: Vol. 3*, (pp. 343–361).

Serra, P., Pons, X., & Saurí, D. (2008). Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography, 28*, 189–209.

Serra, P., Saurí, D., & Salvati, L. (2017). Peri-urban agriculture in Barcelona: Outlining landscape dynamics vis à vis socio-environmental functions. *Landscape Research*. (in press). Available at: https://doi.org/10.1080/01426397.2017.1336758.

Serra, P., Vera, A., & Tulla, A. F. (2014). Spatial and socioenvironmental dynamics of Catalan regional planning from a multivariate statistical analysis using 1980s and 2000s data. *European Planning Studies, 22*, 1280–1300.

Shahraki, S. Z., Saurí, D., Serra, P., Modugno, S., Seifolddini, F., & Pourahmad, A. (2011). Urban sprawl pattern in land-use change detection in Yazd, Iran. *Habitat International, 35*, 521–528.

Sharaf, S. A., & Serra, P. (2016). Land-use dynamics in Al-Ain city (United Arab Emirates): A spatial statistical analysis at district scale. *2nd annual international conference on geography, 6-9 June 2016, Athens, Greece*. Athens Institute for Education and Research.

Soille, P., & Vogt, P. (2009). Morphological segmentation by binary patterns. *Pattern Recognition Letters, 30*, 456–459.

Statistics Centre Abu Dhabi (2013). *Statistical yearbook of Abu Dhabi 2013.* Abu Dhabi.

Tavares, A. O., Pato, R. L., & Magalhães, M. C. (2012). Spatial and temporal land use change and occupation over the last half century in a peri-urban area. *Applied Geography, 34*, 432–444.

Tian, L., Ge, B., & Li, Y. (2017). Impacts of state-led and bottom-up urbanization on land use change in the peri-urban areas of Shanghai: Planned growth or uncontrolled sprawl? *Cities, 60*, 476–486.

Town Planning Department of Al Ain (TPDAA) (1986). *Master plan for the region of Al Ain. Final report*, *Vol. 1*. Al Ain, UAE: Regional Strategy and Urban Development Plan. Town Planning Department.

UAE Ministry of Information and Culture (2006). *UAE yearbook 2006.* London: Trident Press Ltd.

Vogt, P. (2017). *Guidos Toolbox (Graphical User Interface for the description of image objects and their shapes): Digital image analysis software collection.* Available at: http://forest.jrc.ec.europa.eu/download/software/guidos.

Yagoub, M. M. (2004). Monitoring of urban growth of a dessert city through remote sensing: Al Ain, UAE, between 1976 and 2000. *International Journal of Remote Sensing, 25*, 1063–1076.

Yagoub, M. M. (2006). Application of remote sensing and geographic information system (GIS) to population studies in the Gulf: A case of Al Ain city (UAE). *Journal of the Indian Society of Remote Sensing, 34*, 7–21.