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Monitoring of urban growth of a desert city through remote sensing: Al-Ain, UAE, between 1976 and 2000

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Abstract. The objective of this article is to investigate the development of Al Ain city, in the United Arab Emirates (UAE), between 1976 and 2000, with particular reference to the space–time relationship. Al Ain is the fastest changing city in the Arabian Peninsula. It has gone from a *desert oasis* to a thriving modern city in just over 30 years. Maps, colour aerial photographs, satellite imagery, Global Positioning System (GPS), and Geographical Information System (GIS) were used as an aid for understanding the development of the city. Change and development in the city is evident from comparison of old maps, aerial photographs, and satellite imagery taken during 1976, 1978, 1984, 1994, 1998 and 2000. The city was found to have a tendency for major expansion in the direction of the west and south-west. Expansion in any direction was found to be governed by the availability of utilities (water, electricity), economic activities along roads (agriculture, industry), geographical constraints (valleys, sand dunes, mountains), and legal factors (boundary with Sultanate of Oman, planning and institutional rules). Many cities around the world are developed at the cost of agricultural areas, which are the main source of food. For example, in Tempe, Arizona between 1970 and 1979 and in Cairo. However, in Al Ain the research concludes that the development is based on *conservation* of agricultural areas (oases) and *reclamation* of the desert. Revenue from oil is a significant drive for this development, but even more important is the determination of the UAE government to proceed with the development.

1. Introduction

Recent publications and conferences have devoted large portions of their themes to urban remote sensing, for example *Remote Sensing and Urban Analysis*, edited by Donnay *et al.* (2001), and the *4th International Symposium on Remote Sensing Areas*, which was held in Germany on 27–29 June 2003. Remote sensing has also seen improvements in spatial resolution (from 80 m to 5 m), spectral resolution (from three to 210 hyperspectral bands), temporal resolution (shorter visiting time and image on demand), and capability for stereo-imaging (3D mapping). All these advancements are vital in detecting urban change. Change occurs continuously, but in varying increments that can be seen as gradual or abrupt. For many applications it is change that is of direct interest. The types of changes that may be observed include changes in existence (phenomena appear and disappear), shape, location, non-spatial characteristics and combinations of these. An example of a non-spatial characteristic detected with remote sensing is population (Brugioni 1983, Baudot

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2001). Furthermore, patterns of change built from multiple observations over time can lead to estimates or predictions of unobserved change. However, before we can determine whether or not change has occurred in a certain location, we must first make sure that we are comparing the same location.

The elements of change in land use can be used as a measure, indicator or predictor for increase in population, water consumption, health facilities, education, transportation and solid waste generation (e.g. the relationship between number of houses and population). The integration of historical aerial photographs, satellite imagery and GIS is of paramount importance in detecting urban change and growth, and has a high cost to benefit ratio. Numerous studies have been carried out using images from space to detect land use change, for example land cover change of metropolitan Chicago (Wang and Zhang 1999), change in Washington DC metropolitan area (Masek *et al.* 2000), and changing landscapes in eastern England (Slater and Brown 2000). However, each place has its own distinctive characteristics. Little geographic research is published on the Middle East in general and even less on the urban aspects of the region, despite the global mandate of the discipline (Stewart 2000: p.411). With this in mind, this article attempts to address urbanization and its geographical dimension in a Middle Eastern city, Al Ain, United Arab Emirates (UAE). Previous studies about the development of Al Ain had been conducted by Qanim (1986), Al Ain Town Planning Department (Al Ain Master Plan 1986), and Qanim and Al-Qaydi (2001). All of these studies were based on statistical indicators and field surveys, whereas this study is based on a combination of statistical data, remote sensing and GIS to monitor the development of the city.

2. Objectives

Monitoring of urban change is of critical importance to socio-economic development and environmental monitoring. Remote sensing as a technique has provided many advantages over traditional land cover monitoring approaches that depend on field surveys. Application of remote sensing in urban areas depends on the actual object of classification, the purpose of the classification, and the classification system used. For large-scale mapping, aerial photographs will remain the main source of data in urban applications and have a good *cost/accuracy* ratio (Thapa and Burtch 1991). However, in comparison to satellite imagery, aerial photographs have major drawbacks, such as the high cost per unit area and the fact that they are not widely available in digital format. The second generation of satellites such as Landsat TM (30 m resolution) and the third generation of high-resolution satellites such as IKONOS (1 and 4 m resolution) may gradually reduce dependency on aerial photography as a main source for urban applications. The study is intended to use a combination of aerial photographs with satellite imageries (Landsat, SPOT, IKONOS) to monitor urban change in a desert city (Al Ain, UAE). The objectives of the study can be summarized as follows:

- to detect the direction of expansion of Al Ain city and the factors affecting it; and
- to investigate the change of land use in Al Ain between 1976 and 2000.

3. Al Ain development

Al Ain is located at approximately 24° 03′ N–24° 22′ N and 55° 28′ E–55° 53′ E (figure 1). The development of Al Ain is historically witnessed from earlier civilizations (3000 BC) in Al Hili and Jabel Hafeet (Darke 1998: p.41). The main

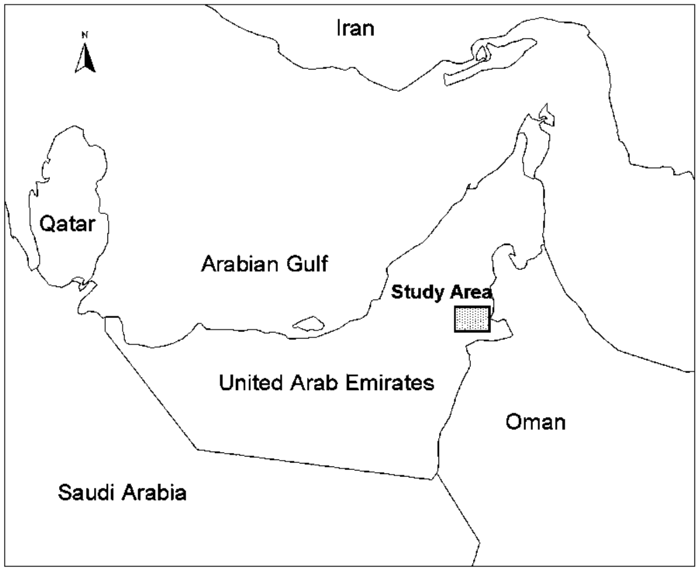

Figure 1. Location of the study area (Al Ain, UAE).

factors that may have attracted people to Al Ain include availability of ground water, oases (dates), low humidity, and the fact that the city represents a transit point between inland areas and the Arabian Gulf.

The recent-historic settlements (1960s) in Al Ain comprised some twelve-plantation villages and its modern development came about with the successful exploitation of oil in the Emirate of Abu Dhabi and the foundation of the UAE in 1971. During the 1980s and 1990s huge development projects expanded horizontally and vertically that led to the merging of the scattered villages around Al Ain to become part of the city.

An indication of Al Ain's development can be seen from the general increase in population, human requirements and infrastructure. For example, its population increased from 51 000 in 1975 to 318 525 in 1995, and it is expected that the population will reach half a million by the year 2010. Daily consumption of water increased from 1.17 to 48.7 million gallons between 1975 and 1999. Gardens, parks, and roads have also seen a continuous increase. The city has achieved two international awards on development and landscaping, the first in Spain (1996) and the second in the USA (2000).

4. Data

The data used in this study include:

- Multi-temporal aerial photographs taken in 1976, 1984 and 1998. The scales of the photographs are 1 : 5000, 1 : 3000 and 1 : 4500, respectively.
- Thematic Mapper (TM) image taken in August 1990 (Landsat 5) and October 2000 (Landsat 7).
- SPOT HRV data taken in October 1994.
- IKONOS satellite image taken in May 2000.
- Al Ain map of 1978.

Maps and aerial photographs were obtained from the Department of Town Planning at Al Ain, and satellite imageries from the Remote Sensing Laboratory at the Faculty of Science, United Arab Emirates University. The software used includes ESRI ArcGIS for vector processing, Adobe Photoshop for scanning and preliminary enhancement of aerial photos, and ERDAS Imagine 8.5 for image processing. The hardware used includes PC Pentium V, Genius Scanner, and HP DeskJet 1220C printer. The selection of data, hardware, and software used in this study (Department of Geography, UAE University) was largely governed by both availability and accessibility.

5. Methodology

Aerial photographs (46 stereo-pairs) were scanned at 600 dots per inch (dpi) and snapshots of them were saved at a lower resolution (100 dpi) for quick indexing (thumbnails). Twenty points (street intersections, landmarks) have been identified on photos and imageries and their coordinates were determined by using geodetic GPS receiver. Satellite imageries and aerial photographs were geo-referenced to Universal Transverse Mercator (UTM) projection using modified-Clark 1880 spheroid and the 1967 Nahrwan datum. Aerial photographs were enhanced and mosaicked together. Aerial photographs and IKONOS imageries were used to monitor the change at local level (scale of 1 : 5000 and larger) while satellite imageries (Landsat TM, SPOT HRV, IKONOS) were used mainly to detect the direction of expansion of Al Ain city and to monitor the change at regional level (scale of 1 : 200 000 and smaller). A combination of SPOT HRV, Landsat TM, and IKONOS imageries were used to update transportation network (on-screen digitization). The technique of on-screen digitization for updating road network from satellite imageries had been adopted by various researchers (Wang *et al.* 1992) and organizations, for example, the US Bureau of the Census (Lacy 1992).

Different methods of change detection are available, for example visual analysis of multi-date images, image differencing, image rationing, spectral/temporal classification, and Principle Component Analysis (PCA). The first method, 'visual analysis of multi-date images', was adopted in the first stage of the analysis (direction of expansion). Visual interpretation of imagery by skilled interpreters in appropriate operational contexts is often the most accurate technique (Deane *et al.* 1989). A recent study by Stewart (2001) has proved the applicability of visual comparison of historic maps with satellite imagery to study landscape change. Visual interpretation indicators such as colour, size, shape, texture and shadow were extensively used in identifying features from aerial photographs and satellite imageries. In the second stage (land cover change), a computer classification method (supervised) was used to quantify the changes in terms of acreage lost or gained. Each satellite image (Landsat TM 1990 and 2000) was rectified and classified separately. Four land cover classes were inventoried on each date and the areas of classes were computed from the resulting thematic maps (classified images) and compared.

6. Analysis

An Al Ain map of 1978, a TM satellite image of 2000 (band 2, 3, and 4), and an IKONOS image of 2000 were used to detect the direction of Al Ain expansion (figure 2). Bands 2, 3 and 4 were selected because they provide a good contrast between vegetation (appearing as red) and soil with no or sparse vegetation (appearing as white to green or brown). ArcGIS software was used to delineate urban areas and transportation network from the satellite image (on screen

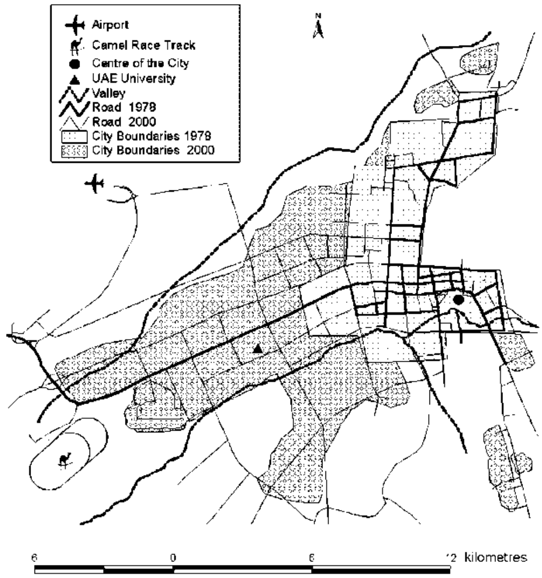

Figure 2. Al Ain expansion between 1978 and 2000. The 1978 boundaries were drawn from a historical map and the 2000 boundaries from Landsat TM data and IKONOS images.

digitization). The city was found to have a tendency for expansion in different directions at different rates (figure 2). These directions include:

- *North*: The city has seen a low rate of expansion in this direction (figure 2). The expansion is equivalent to a distance of 4 km from the 1978 boundaries. This may be due to the high sand dunes (50 m and above) and scarce services along the Al Ain–Dubai road (water and electricity). Another natural factor that influences expansion of the city to the north is Towaya valley (figure 2). The valley is a natural grazing area for nomads and there is strong support for its conservation. The policy of conservation of valleys significantly influences the direction of expansion of the city (figure 2). Since the Al Ain–Dubai road in the north has become an active commercial link in the last few years, and there is a plan to provide water and electricity along the road (from Al Fujuriah), it is anticipated that the city will expand further northward.
- *South and south-east*: Al Ain Valley, Hafeet Mountain, high sand dunes and conservation zones (defence area and a zoo) represent natural and legal constraints for expansion of the city to the south and south-east (figure 2). These areas represent vacant lands and expansion through them is equivalent to a distance of 9 km from the 1978 boundaries. The probability of expansion of the city southwards is low, due to the fact that there is no major attraction 'node' along the Al Ain–Um Alzamoul road in comparison to Abu Dhabi and Dubai roads (figure 2).
- *West and south-west*: The city has tremendously expanded to the west and south-west directions (figure 2). The expansion is equivalent to a distance of 11 km from the 1978 boundaries. This may be due to the road network connecting Al Ain to Abu Dhabi (interaction between two nodes-gravity model), and the availability of water and electricity along the pipeline and power transmission route from Abu Dhabi. In addition, many agricultural

farms (Remah) and factories (Abu Samra Vegetables Factory) are situated along Al Ain–Abu Dhabi road. In the future, Al Ain is expected to merge with modern villages extending along Al Ain-Abu Dhabi road, for example, Sleimat and Al Yahar.
- *East*: The city has not expanded eastwards due to political boundaries with the Sultanate of Oman (figure 1).

Planning powers, legal frameworks, and implementation of master plans are key responsibilities of the Town Planning Department in Al Ain (Al Ain Master Plan 1986). To a large extent the urban development plan laid down in the 1986 Master Plan has been implemented. This means planning rules are empowered and have influenced the direction of expansion. One of the planning rules that has drastically affected expansion of the city is the bylaw that limits the heights of buildings to no more than 17 m, with exceptions for landmarks such as university, hospital, and municipality buildings. This bylaw has caused the city to expand *horizontally* rather than vertically in comparison to other cities in the UAE such as Abu Dhabi and Dubai. The direction of expansion in Abu Dhabi and Dubai is largely determined by the Arabian Gulf in the north, therefore, the cities expanded largely to the south in comparison to Al Ain, which expanded to the west and south-west.

7. Urban change

Two sites have been selected to quantify the change in the land use of Al Ain from aerial photographs. Using urban land use mapping for levels II of the four-level classification adopted by the United States Geological Survey—USGS (Anderson *et al.* 1976), each site is overlaid with a polygon map delineating level II land use and land cover categories.

The first site (near the centre of the city) is predominantly commercial (figure 2). However, adjacent to it is the Al Ain oases (figure 3). The rate of change between 1984 and 1998 in a portion of the site was found to vary between 6% and 100% for some urban features (table 1). The rate of change in the number of cars (table 1) was calculated based on counting the number of cars at a particular park from the aerial

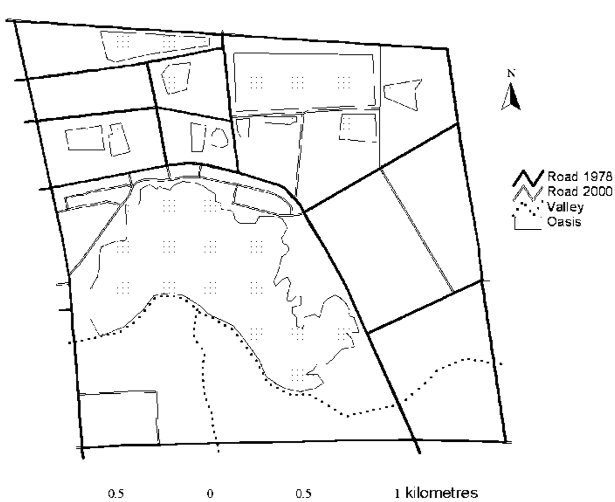

Figure 3. Resistance of the oases to urban expansion since 1978.

Table 1. Change in land use at a portion of Al Ain city centre.

	1984	1998	% change
Buildings	34	36	6
Main streets	2	4	100
Roundabout	2	4	100
Parks	5	7	40
Cars	32	97	203
Petrol stations	1	1	Rehabilitation
Historical features (forts)	2	2	Renovation

photographs of 1984 and 1998. These photographs were selected because they are coloured and are at large scale (1 : 3000 and 1 : 4500); therefore, cars appeared very clear on them in comparison to the 1976 photograph, which is black and white and at a scale of 1 : 5000. Despite the difference of month, day, and time of the day of each photograph (1984 and 1998), the change in the number of cars between the two periods shows some general correlation with the increasing number of population and the number of roads. The change in the number of cars can also be used as an indicator of change in income. This is an example of detecting non-spatial characteristics (income) from remote sensing.

Generally speaking, there is no major change in the number of commercial buildings (only 6%) in the site. The reason for the low rate of change is attributed to the adoption of a decentralization policy, where more commercial areas have been dispersed around the city (district centres). On the other hand, the owners of agricultural lands in the city centre (oases; see figure 3) may be reluctant to sell their land for reasons related to social status or economical benefits. The oases had played a significant role in the history of Al Ain, as they had been used in the past as a main source of water, food, and shelter. Therefore, they represent special heritage to the land owners. Some owners of the oases believe that having a farm at the heart of the city will reflect their historical roots. The economical benefits of the oases are realized from cash incentives, which are granted to everybody who grows a palm tree, rather than revenue generated from agricultural products (dates).

In comparing the oases from aerial photographs of 1976, 1984 and 1998, the historical map of 1978, Landsat data of 1990 and 2000, SPOT data of 1994, and the IKONOS image of 2000, it was found that there was no loss in the total area covered by palm trees (1 761 896 m^2; figure 3). The area is equivalent to 3.1% of the total area of the city in 1978 and 1.2% of the total area of the city in 2000 (figure 2). As part of a strong move to promote tourism in the city, the oases had been decorated as tourist resorts (Al Salmani 2001). An important added attraction for tourists is the location of Al Ain Museum and Sheikh Zayed Old Palace Museum at the perimeter of the oases. Conservation of the oases also means conservation of the valleys (figures 2 and 3) upon which palms survived for hundreds of years. An added advantage of conservation of the oases is their role in reducing air pollution at the city centre (acting as 'lungs of the city'). Conservation of the oases at the city centre is similar to conservation of parks in some other international cities, for example, Hyde Park in London and Titiwangsa in Kuala Lumpur.

This study revealed an important fact about the association of the people to the oases throughout the period prior to 1976. This is evident from the clustering of human settlements near the north-eastern part of the oases, i.e. people at that time depended on agriculture (palms). It was also noticed that during this period a large

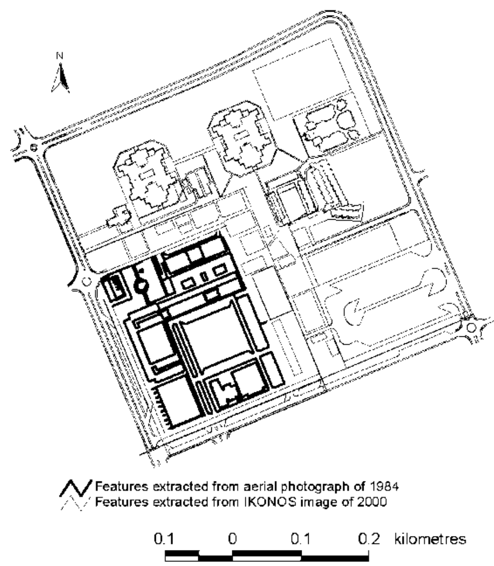

Figure 4. The UAE University (Al Maqam Campus) between 1984 and 2000. Using the USGS land cover classification level II, the main change in the area was found from sandy areas to services, residential (hostels), and transportation. All new buildings and roads were built on the desert (desert reclamation).

proportion of residential neighbourhoods were built using clay and palm tree branches as appropriate materials for the hot climate. However, tracing the same area in the 1998 photograph and the 2000 IKONOS image, settlements have disappeared and been replaced with a market, i.e. shifting from an agricultural to a commercial society. This socio-economic development is attributed to the high revenues generated from oil.

The second site is one of the four campuses of the United Arab Emirates University (Almaqam) and it is predominantly an educational facility, established during the 1980s (figure 4). The campus has seen an increase in the number of students, staff, workers, classrooms, laboratories, residential quarters and recreational areas. The number of students admitted to the campus has been increasing annually from 205 in 1977 to 3500 in 2000. The site was not covered by the photographic missions of 1976 and 1998, therefore, other available data were used (an aerial photograph of 1984 and an IKONOS image of 2000). The change in the land use of the site is quite clear when comparing the 1984 photographs with the 2000 IKONOS image (table 2, figure 4). The rate of change in terms of built-up areas was 189%, which is approximately three times the number of buildings in 1984 (table 2). New buildings include academic buildings for the faculties of

Table 2. Change in land use at the United Arab Emirates University (Almaqam).

	1984	2000	% change
Buildings	10	17	70
Parks	3	7	133
Main streets	1	4	300
Total built-up area (m^2)	183 175	529 401	189

Engineering, Humanities, and Agriculture, and new student hostels. The main change in the land use of this site is the displacement of desert to residential and academic facilities. Such a change, i.e. reclamation of desert, is considered a globally unusual phenomenon.

7.1. *Satellite image classification*

The Thematic Mapper (TM) images taken in 1990 (Landsat 5) and 2000 (Landsat 7) were used to detect the urban change at the city level. Using a supervised classification method under ERDAS Imagine 8.5, a total of 250 training sites (signatures) were selected to represent land cover types such as high land, desert, buildings and green areas in each image. Change in high land is rare, but as a land cover type it must be included in classification of satellite images if the area includes it. Change in desert is also rare, but in the UAE, large desert areas had been reclaimed. Change detection using Write Function Memory Insertion (Jensen 1996) was used to detect the change *visually* in land cover between 1990 and 2000. Band 1 of the 1990 image was placed in the green image plane, band 1 of the 2000 image in the red image plane and no image in the blue image plane. All areas that did not change between the two dates are depicted in shades of yellow. The use of ERDAS Imagine 8.5 functions such as blend, fade and flicker were found useful in studying urban change between the two epochs (animated-like displays). Both the Write Function Memory Insertion method and the flicker and blend functions in ERDAS were found suitable for visual inspection only (no quantitative values for the change).

Accuracy assessment to evaluate the classified images (1990 and 2000) was done by selecting 350 ground truth sites (reference values). The overall classification accuracy was found to be 87.71% with an overall kappa statistic of 0.8349 (table 3). The majority of matching between ground truth and classified sites were green areas, high land, and desert. This is due to the high reflectance of palm trees and sand in most of the bands, especially palm in the near infrared region. However, the

Table 3. Error matrix for the classification map derived from TM data of Al Ain, 1990.

Classification	Built-up	Green area	Desert	High land	Row total
Built-up	95	19	0	2	116
Green area	1	56	0	0	57
Desert	2	1	81	8	92
High land	3	0	7	75	85
Column total	101	76	88	85	350

Class name	Reference total	Classified total	Number correct	Producer accuracy	User accuracy
Built-up	101	116	95	94.06%	81.90%
Green area	76	57	56	73.68%	98.25%
Desert	88	92	81	92.05%	88.04%
High land	85	85	75	88.24%	88.24%
Total	350	350	307		

Overall classification accuracy = 87.71%.
Overall kappa statistic = 0.8349.
Conditional kappa values for each category are: 0.7455 for built-up, 0.9776 for green area, 0.8403 for desert, and 0.8446 for high land.

Table 4. Change in land cover at Al Ain between 1990 and 2000.

Land cover	1990 (ha)	2000 (ha)	% change
Agriculture	18 400	32 700	77.7
Buildings	14 870	20 222	36.0
Desert	66 105	43 405	−34.3
Mixed	4 500	7 548	67.7
Total	103 875	103 875	

majority of misclassification was in urban areas (table 3) and this is due to the intermingling of buildings, roads, parks and trees.

Table 4 shows the change in land cover in the city between 1990 and 2000. The biggest change was in agricultural areas (77.7% increase)—this was a direct consequence of the UAE policy towards encouraging agriculture. The philosophy behind increasing agriculture is to reduce dependency on oil and to expose farmers to new farming techniques (dripping irrigation, salt-tolerant vegetation, etc.). Due to this policy, vast desert areas had been converted to agricultural farms. The total area covered by buildings had also seen an increase of 36% between 1990 and 2000 (table 4). The increase is attributed to the increase in population, income, and establishment of new services buildings (schools, hospitals, etc.). The main decrease in the land cover of Al Ain was in the desert area (table 4); this is due to intrusion of agriculture and buildings on the desert.

In comparing land use change, especially buildings with socio-economic indicators (table 5), it was found that there was an average difference of 18.9% between the rate of change in population, water, electricity, solid waste and the total area covered by buildings (table 5). The empirical allometric model suggested by Batty and Longley (1994) was used to estimate population from the remote sensing results (table 4). The model relates population size (N_{k}) to occupied area (A_{k}) as follows:

$$N_{\mathrm{k}} = \gamma A_{\mathrm{k}} \tag{1}$$

where γ is a constant of proportion. Substituting the values of the total area of buildings from table 4 and total population from table 5 for 1990, the constant of proportion was found to be equal to 16.14. Assuming a population of 2000 unknown and substituting in equation (1) using the constant of proportion

Table 5. Change in socio-economic indicators of Al Ain between 1990 and 2000 (adapted from Al Ain Annual Statistical Report 2000: p.88, Al Ain Master Plan 1986: p.23 and Qanim and Al-Qaydi 2001: pp.55, 73, 85, 110, 111, 116).

Indicator	1990	2000	% change
Population	240 000	360 000	50.0
Water†	31.7	50.4	59.0
Electricity‡	2 662 054	4 724 104	77.5
Solid waste§	248.5	331	33.2
Average rate of change			54.9
Rate of change in buildings			36.0
Difference			18.9

†Daily consumption of water in millions of gallons.
‡Electricity in $\mathrm{MW\,h^{-1}}$.
§Solid waste in $\mathrm{t\,day^{-1}}$.

calculated from 1990, the population of 2000 was found to be 326 383. Comparing this value with the known population of 2000 (360 000), an under-estimation error of 33 617 was found. The error is considered moderate and equivalent to 9% of the total known population of 2000. In the absence of accurate socio-economic data, the rate of change in built-up area derived from remote sensing can be used to give an approximate estimation to the rate of change in population, water and electricity consumption and solid waste generation (table 5).

7.2. *Driving forces for the expansion and development of Al Ain*

The driving forces for the growth of Al Ain can be summarized as follows:

- *Government*: Al Ain is the homeland for many leaders in the UAE, therefore it has special favour. Large amounts of money have been allocated to various development projects such as roads, houses, landscaping, health, and educational services.
- *Demography*: The population in Al Ain has increased from 51 000 in 1975 to 360 000 in 2000. This means more houses, schools, hospitals, etc. are needed. Therefore, more desert land has to be reclaimed.
- *Structure*: Higher buildings can accommodate more people than lower buildings; however, one of the bylaws adopted by the planning authority in Al Ain is a limitation of building height to 17 m. Therefore, the city expands horizontally rather than vertically.
- *Income*: People with high income demand more space for their activities. The income in Al Ain has seen a sharp increase as a result of revenues from oil. The average annual income of citizens in Al Ain is between $36 000 and $60 000. Comparing houses from old aerial photos (1976) with recent photos (1998), an increase in the size of houses is noticed. This is particularly evident in new residential districts adjacent to Towaya Valley (figure 2).
- *Geography*: Geographical factors such sand dunes, mountains, valleys, and utilities had an impact on the direction of expansion of the city (see §6).

8. Significance of the study

The significance of this study can be summarized as follows:

- Millions of dollars have been spent in photographic missions covering Al Ain city between 1976 and 1998. However, utilization of photographic resources is very limited and sometimes is hidden from the public. One of the results of this study is the production of a historical remote sensing Atlas, making use of historical photographs. The Atlas depicted the development of the city through time series photographs and satellite imageries (between 1976 and 2000) and accompanied by comments. Copies of the Atlas have been distributed free of charge to Al Ain Municipality, Al Ain Museum, and part of the Atlas is available online for the public (http://faculty.uaeu.ac.ae/~myagoub/main_Alain.htm). Through the Atlas, people unfamiliar with remote sensing (even illiterate) have realized the importance of remote sensing in understanding historical development of the city, and this is considered an advantage and benefit of remote sensing to local community.
- The Department of Town Planning in the city have acknowledged the contribution of the study for its planning mission (on how to use remote sensing to check land use change and hence master plan implementation).

Figure 5. The architectural design of Al Ain Hospital reflecting its symbol (H). Note the 'H' shapes on the aerial photograph of 1984. The figure shows how non-spatial characteristics (design intention) can be deduced from remote sensing.

Architects in the department had discovered for the first time the pattern of building design in the city. This is very clear from the design of Al Ain hospital in the form of an 'H' when viewed from the 1984 aerial photograph (figure 5). No building in the city other than the hospital was found to have the form 'H' in its design. This led to the understanding that the design of the hospital was intentionally made to reflect the facility's symbol (H), and this is an example of using remote sensing to understand non-spatial characteristics (intention of design). Colour-coded maps showing the age of buildings were produced from aerial photographs of 1976, 1984 and 1998, and the IKONOS image of 2000 (figure 4). The maps revealed the transformation in the design and material of buildings that is linked to social and economical changes.

- Historians, geographers, and social scientists that have carried out studies related to Al Ain city have enriched their materials by photographs from the Atlas. Generally, aerial photographs and satellite imageries are better than maps for documentation of facts (Black 2001) and the richness of their contents. Because maps are abstract to reality and sometimes might be generalized (e.g. by omission of features), it is necessary for many applications to use a combination of photographs and maps (also because maps include annotations which do not exist in photographs).
- The city of Al Ain is famous throughout UAE for its oases, and this study has shown through remote sensing the association of people to the oases (by detection of human settlements around the oases from 1976 aerial photographs). Tracing the oases from 1976 to 2000 showed minor changes in the green area covered by palm trees (figure 3). This fact reflected conservation of the environment, which is an important issue for environmental campaigners and people who work in the tourism industry.
- Updating of maps using conventional techniques, such as surveying, is a time-consuming and costly process. In developing countries, where there is a scarcity of expertise and budget, the cost of updating maps is sometimes prohibitive. This study has shown that remote sensing can be used to update transportation network (figure 2) and land cover maps (figure 3) in a short time and with minimal cost. Information on road networks can be used for urban transport planning and land cover maps can be used for different planning purposes (e.g. location of new facilities and master plans).

9. Conclusion

The direction of Al Ain expansion is governed by natural, legal, and political constraints that have compelled the physical form of the city to be stretched over a wide distance in the western and south-western directions along the Al Ain–Abu Dhabi road. There are noticeable *spatial relationships* between the transportation network, utilities and urban expansion. New settlements are found to follow roads originating from Al Ain to different destinations, for example, to Abu Dhabi, Dubai, and Um Alzamoul. The study shows that remote sensing can be used to check the general direction of expansion of the city and the degree of implementation of master plans. The areas of change in land use were compared with the change in socio-economic indicators (population, water consumption, electricity and solid waste). It was found that there was an average difference of 18.9% between the rate of change in buildings and the socio-economic indicators. In the absence of accurate socio-economic data, the rate of change derived from remote sensing can be used to give an approximate estimation. The policy adopted by His Highness Sheikh Zayed Bin Sultan, leader of UAE, to encourage farming and conservation of environment is evident from remote sensing (77% rate of change in agriculture between 1990 and 2000). Development in the city may be attributed to the revenues from oil, the establishment of the first and the largest UAE University, the dedication of the city as an agricultural and tourist city (intensive farming and landscaping), and above all its status as the homeland of the UAE leaders.

This study has shown that a combination of aerial photographs with IKONOS imagery can be used to monitor urban change at large scale. This combination is useful in making use of the advantages of both sources, with advantages including the high resolution of aerial photographs, and the low-cost and frequent coverage of satellite imageries. For urban change at small scale (regional growth), low resolution satellite imageries such as TM data (30 m) and SPOT data (20 m) are found to be useful. The advantage of such imagery is in providing wide area coverage and spectral characteristics (colour bands).

Despite the lesser role of the oases after exploitation of oil in 1970s and 1980s, they are still surviving. Tracing the oases from 1976 to 2000 through aerial photographs and satellite imageries (Landsat, SPOT and IKONOS), it was found that there was no loss in the total area covered by the oases at the city centre. The reasons for the conservation of the oases are historical, social, and recently environmental and eco-tourism-related. Aerial photographs of 1976 showed that people were associated with the oases, indicating that the main activity of the people was in the field of agriculture. Commercial, administrative, and service jobs became the main activity of the people after the 1980s, when Al Ain took the form of a city.

Currently, planning operations in Al Ain are dependent on field survey and aerial photographs. It is recommended that multi-spectral and high-resolution satellite imageries to be used also as a planning tool (for studying urban expansion, checking implementation of master plans, updating of the transportation network). At costs ranging from approximately \$150–\$250 per square mile, planners can now acquire high-resolution space imagery at a fraction of the cost of other imagery sources.

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