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AN INTEGRATED GEO- DATABASE FOR LAND MANAGEMENT AND GREENING ASSESSMENT OF AN ARID ISLAND AT THE FRINGES OF ABU DHABI CITY

Salem Issa
Department of Geology, College of Science, United Arab Emirates University
P O Box 17551, AL AIN, UAE

ABSTRACT

The objective of this study is to build a spatial GIS database for land management on the AL Sammalyah Island. Twenty GIS layers were created and inserted into a spatial database. GIS overlay analysis was applied to five major land cover types between 1999 and 2005 to estimate vigor of land cover change. The study drew the attention on the fact that real increase took place in most important land cover types namely mangrove, palm trees, and buildings registering more than 336%, 130%, and 300% increase respectively in six years. Hence, highlighting the success of planting salt tolerant vegetation to protect the environment and enhance the landscape in arid lands. Finally, building the GIS database was a real success; managers of the island started to use it as a source of information and generate statistics for land management, consequently reliability and flexibility of the remote sensing and GIS products were demonstrated.

Keywords: Geo-database, sustaining management, Abu Dhabi city, arid island, GIS overlay analysis.

INTRODUCTION

Arid lands are the results of various influences which prevent moisture-bearing weather systems reaching certain areas of the land surface; such influences are climatic, topographic and oceanographic (Beaumont, 1989; Cook *et al.*, 1993; Thomas, 1989a; Thomas, 1989b; Thompson, 1975). Although deserts or drylands typically do not have a large number of inhabitants, they are often the loci of economic and cultural activity. For example, the oil-producing nations of the Middle East are all found within a single arid region. Furthermore, deserts tend to be fragile ecosystems, requiring little in the way of perturbations in order to cause tremendous changes in the landscape (Okin *et al.*, 2001a; Schlesinger *et al.*, 1990; Starbuck and Tamayo, 2006). The size, remoteness, and harsh nature of many of the world's deserts make it difficult and expensive to map or monitor these landscapes or to aid planning for and management of, renewable natural resources. The situation exacerbates in developing countries where lack of accurate maps and the need for rapid and relatively accurate mapping techniques are urgent. This is becoming challenging if we know the dimension of large scale engineering projects being implemented, particularly in the wealthy Gulf States (Alhameli and Alshehhi, 2004; Essa *et al.*, 2005; Sohl, 1999). Remote sensing and GIS emerge as promising new technologies potentially considered as a time and cost effective techniques to defy these challenges. Because of the nature of the information on land use and cover change offered by these data, remote sensing has become central to many natural resource planning programmes that utilize geographical information systems (GIS) (Mulders and Girard, 1993; Ustin and Xiao, 2001). Moreover, with the use of ancillary field data and the calibration of remote sensing inputs, data integration within a GIS can enhance the extraction of information from satellite imagery and improve the accuracy of a variety of outputs (Jenssen *et al.*, 1990; Salami *et al.*, 1999). This has led to a synergistic approach in spatial data handling (Jenesen, 2000; Suga *et al.*, 1994).

Studying land resources management using spatial-related technology starts by assessing the amount of changes occurred during certain period (Deer, 1995; Mertens and Lambin, 2000; Mouat and Lancaster, 1996; Roy and Tomar, 2001; Singh, 1989). This assessment can be both qualitative (visualizing the extent) and/or quantitative (rate). Change detection is defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times. The basic principle in using remotely sensed data for change detection is that: changes in the objects of interest will result in changes in reflectance values or local textures that are separable from changes caused by other factors such as differences in atmospheric conditions, illumination and viewing angles, and soil moistures (Larsson, 2002; Luque, 2000; Sohl, 1999; Zhang *et al.*, 2002; Weng, 2002). Numerous works have been reported in these fields. For landuse change detection, imagery data from various sensors such as aerial photographs, Landsat MSS, TM, ETM, SPOT HRV, IRS and IKONOS

*Corresponding author email: salem.essa@uaeu.ac.ae

are often used, and it is common that images with various scales and from two or more sensors are used (Essa *et al.*, 2005; Lu *et al.*, 2004; Maldanado *et al.*, 2002; Miller *et al.*, 1998; Petit and Lambin, 2001; Petit *et al.*, 2001; Prakash and Gupta, 1998; Salami, 1999; Yang and Lo, 2002; Zhou *et al.*, 2004).

Furthermore, all large operational GIS are built on the foundation of a geographic database. After people, the database is arguably the most important part of a GIS because of the costs of collection and maintenance, and because the database forms the basis of all queries, analysis, and decision making (Ayeni and Ikwuemesi, 2002; Chen, 2002; Periera *et al.*, 2002; Suga *et al.*, 1994; Travaglia *et al.*, 2001). A database can be thought of as an integrated set of data on a particular subject. Geographic databases are simply databases containing geographic data for a particular area and subject. In recent years geographic databases have become increasingly large and complex. For example, AirPhoto USA's US National Image Mosaic is 25 terabytes (TB) in size, EarthSat's global Landsat mosaic at 15 m resolution is 6.5 TB, and Ordnance Survey of Great Britain has approximately 450 million vector features in its MasterMap database covering all of Britain (Longley *et al.*, 2005).

In the United Arab Emirates (UAE), where deserts compose more than 97 percent of its land, extensive development works have been and continue to be undertaken in the country. Thanks to investments generated from oil exports (Alhameli and Alshehhi, 2004). Transformation of islands into high value land indicates that islands in the UAE will become a focus for many investors. This development is manifested in the rapid change in landscape, settlements, and infrastructure (CER, 2000; DER, 2004), hence generating opportunities and challenges and there is a need to create spatial databases that can be used to address problems associated with the reality. During the last decade, many studies were conducted to highlight the rates and extent of change in the UAE, including change analyses studies using satellite and archived data but non of these studies were focusing on creating and managing spatial databases (Essa *et al.*, 2005; Starbuck and Tamayo, 2006; Sohl, 1999; Yagoub, 2004).

To assess development vigor, capture its footprint, and evaluate the wise exploitation of its natural resources, remote sensing and geographical information systems (GIS) are applied to a study area at the fringes of Abu Dhabi capital city with the main objective of building a spatial GIS database for optimal land resources management on AL Sammalyah Island.

MATERIALS AND METHODS

Study area

AL Sammalyah is located at approximately 24° 26′10″N - 24° 28′56″N and 54° 29′22″E - 54° 34′12″E (Fig.1). Situated in the Arabian Gulf, about 12 km north east of Abu Dhabi Island near (Um al-Nar Island) area and just opposite *Shati'-Al Raha* beach, is characterized by its rich ecosystems and marine life. The non-populated Island covers an area about 14.7 square kilometers. Its geomorphology is characterized by a flat desert surface with small artificial sandy hills and dispersed coastal S*abkhat* especially in the low lands along the shoreline. The island is characterized by its hyper arid climate; the mean annual rainfall is just below 50mm, while the mean monthly temperature exceeds 30ºC. Soil texture is dominated by sand, with high salt content reaching 31.5% Total Soluble Salts (TSS) on the surface, being mostly Chloride soluble salts giving a white color to the soils of the island**,** which produces high brightness levels on satellite imagery operating in the visible portion of the EMR, however the very narrow mangrove soils surrounding the island have dark color because of high content of organic carbon content**.** The Island is a natural reserve containing high biodiversity, particularly mangroves *(Avicenna marina)* -local name: Al qarm, which grow throughout the coastal areas of Abu Dhabi Emirate and is associated with varieties of plant communities including: Al Qasaba plant (*Arthrocnemum macrostachyum)*, Al shinnan plant (*Seidlitzia rosmarinus)*, Al Suaed plant (*Suaeda vermiculata)*, and Al Rasha plant (*Cyperus conglomerates)* (CER, 2000), (DER, 2004).

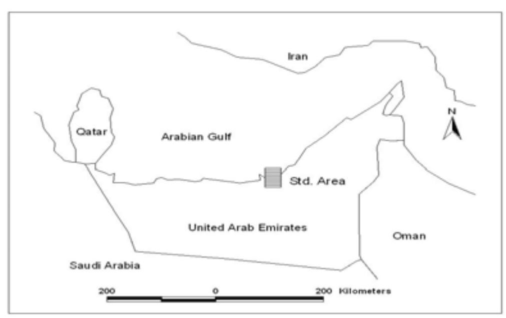


Fig. 1. Location of the study area.

MATERIALS

A multi-temporal dataset of remote sensing data was acquired for the study area. It was composed of aerial photographs from 1985, 1999, 2005, and 2006 (Table 1). Most aerial photographs were procured at the Military Survey Department (MSD), and Abu-Dhabi Municipality (AD). The software used includes ESRI ArcGIS v9.1 software for vector processing, and ERDAS Imagine 8.4 for image processing. The hardware used includes PC

Table 1. Imagery dataset produced for the GIS database.

Type	Date	Resolution	Projection
B/W Aerial photograph	1985	2meters	UTM, zone40N
Color Aerial photograph	1999	2 meters	UTM, zone40N
Color Aerial photograph	2005	2 meters	UTM, zone40N
Color Aerial photograph	2006	2 meters	UTM, zone40N

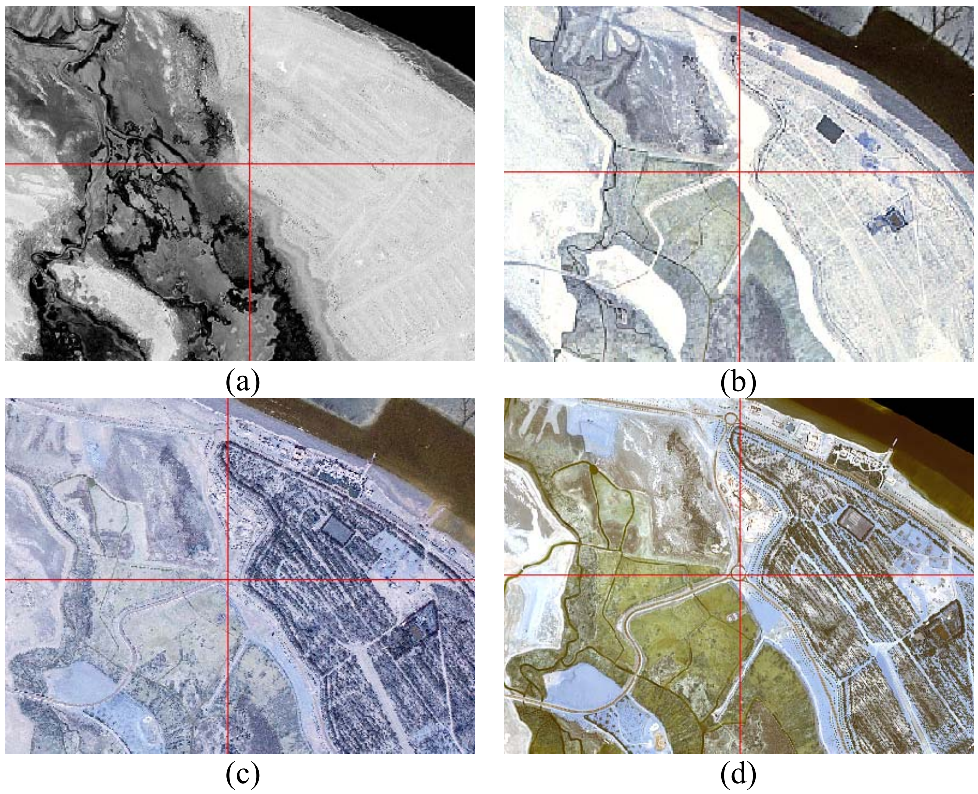


Fig. 2. Snap shots for a specific area on the Island: (a) 1985; (b) 1999; (c) 2005; and (d) 2006. Simple visual inspection of the different dates shows evidences of human footprints and engineering developments occurring on the Island.

Pentium IV 3.2 GH speed, and HP color LaserJet printers. The selection of data used in this study was largely governed by availability and accessibility of archived data especially at the MSD archives; the selection of hardware, and software was governed by the UAEU geology department's facilities. In addition to the raster datasets, an elevation layer was available from the AD municipality.

METHODOLOGY

1. Aerial photographs are scanned at a resolution of 1200dpi. The nearest neighbour method of grey-level interpolation is applied. An image-to-image registration is used to register other datasets using the corrected 2000-aerial photograph as a master image.
2. Five land cover types representing the years 1999 and 2005 are created namely: Roads; Water constructions; Vegetation; Buildings; and Barren land, using heads up on-screen digitizing. The years 1999 and 2005 were chosen because changes were visible on available aerial photographs only from the 1990s; no major activities were noticed from the mid-1980s aerial photographs. On the other hand, there was a delay in acquiring the 2006 aerial photograph which led to the adoption of the 2005 as a second date.
3. Evaluation and visualization of the change between past and present to assess the vigour of human footprint manifested by construction and rehabilitation activities on the island is achieved

using traditional change detection techniques and GIS overlay analysis.

4. TIN is generated using Geoprocessing tools available in ArcGIS 9.1. Data used to generate the TIN are spot heights with vertical accuracy of 2 meters.

5. Designing, building and populating the GIS database with respect to the following general steps:

   i. Data sources selected for entities and attributes are user requirements identified through field visits, discussions and scientific reports.

   ii. ArcGIS version 9.1 geodatabase structure is adopted for the design and building of the database

   iii. Shapefiles created by digitizing using ArcGIS 9.1 under Edit session, and then converted to the database using geoprocessing tools available in ArcGIS.

   iv. Metadata is created using ArcGIS metadata standards.

   v. All data are projected to UTM, zone 40N, Nahrawan Datum.

   vi. Integration of different data types including: aerial photographs, vector and ancillary data, and TIN.

RESULTS

Imageries dataset

A total of four large scale aerial photographs spanning the period from the mid-1980s to include the most recent aerial photos of 2005 and 2006 (Table 1, Fig. 2) were processed and integrated into the database. The dataset was registered to Nahrwan_1967 coordinate system, Universal Transverse Mercator projection, zone 40. A minimum of 10 ground control points (GCPs) were collected for each photograph and a second degree polynomial transformation was used to project them. The total RMS was less than 0.4 pixels. The resulting aerial photographs were resampled using ERDAS Imagine Map Interpreter Function and a unique pixel resolution of 2 meters was achieved for the whole dataset. The 1999 and 2005 aerial photographs were used to create GIS layers for main land cover types. The layers were then used to evaluate the change during this active period; furthermore they were used to populate the spatial database produced for the island (Fig. 2).

GIS layers

Ten GIS vector layers (feature classes in the database) representing five land cover types for each of 1999 and 2005 were created (Table 2). These feature classes were chosen as they reflect most of the engineering and rehabilitation and greening works carried out on the island. Thus analyzing those parameters is a key factor to evaluate the level of development and to assess the vigour of human footprint on the study area during the research period. Field evidences confirmed the level of development and demonstrated the presence of human footprint on the study area (Essa *et al.*, 2005).

Table 2. Vector GIS layers considered for representing and studying land cover classes for 1999 and 2005.

Land cover classes (visual Interpretation of large scale aerial photographs) of 1999 and 2005	
1.	Transportation: Roads / Footpaths/ tracks and Roundabouts
2.	Water constructions: bodies / Water channels
3.	Vegetation: Shrubs & grass / Palm trees / Mangroves
4.	Buildings
5.	Barren land

A Triangulated Irregular Network (TIN) was generated from available spot heights with vertical accuracy of 2 meters (Fig. 3). The TIN was created to be used for 3D modeling and visualization as will as to estimate the volume of soils brought into the island during the study period.

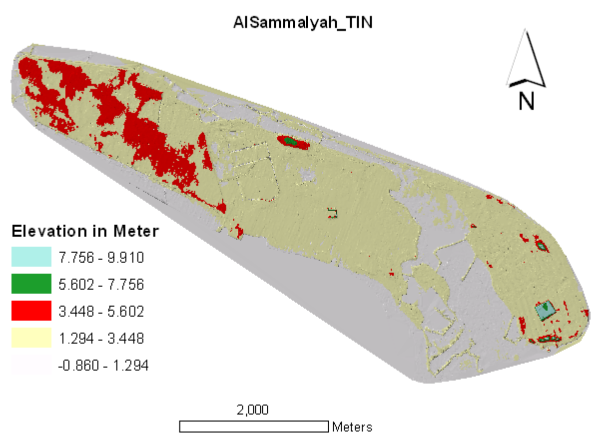


Fig. 3. AL Sammalyah Triangulated Irregular Network (TIN).

Geo-database

As a result, the Al Sammalyah database integrates 20 GIS vector and raster layers encompassing various types of features on the surface of the Island (Table 3). The building of the actual GIS database is essential for sustainable development and management of the island in the long term.

Table 3. AL Sammalyah GIS Database layers

No.	GIS Layer
The image dataset	
1.	B/W Aerial photograph, 1985
2.	Color Aerial photograph, 1999
3.	Color Aerial photograph, 2005
4.	Color Aerial photograph, 2006
The 1999 change analysis input layers	
5.	Roads Network –first date
6.	Water constructions –first date
7.	Vegetation –first date
8.	Buildings –first date
9.	Barren Land –first date
The 2005 change analysis input layers	
10.	Roads Network –second date
11.	Water constructions –second date
12.	Vegetation –second date
13.	Buildings –second date
14.	Barren Land –second date
The Overlay output layers	
15.	Roads change analysis
16.	Water change analysis
17.	Vegetation analysis
18.	Buildings change analysis
19.	Barren land change analysis
The TIN layer	
20.	Al Sammalyah TIN layer

DISCUSSION

The main activity of the research was the assembling of a complete set of multi temporal remotely sensed dataset for the Al Sammalyah Island. GIS overlay analysis method for detecting and visualizing changes between the two dates was applied. Roads buffers; Water constructions; Vegetation; Buildings; and Barren land layers were mapped, also areas and lengths were measured hence producing a qualitative (Fig. 4) and a quantitative (Table 4) estimation of the change.

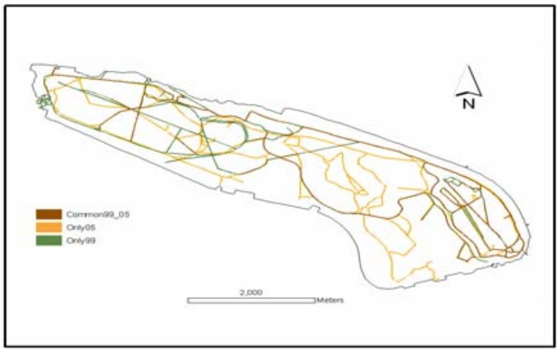
Evaluation and visualization of the change

Change maps shown in Figure 4 together with statistical analysis presented in Table 4 and Table 5 confirm the following:

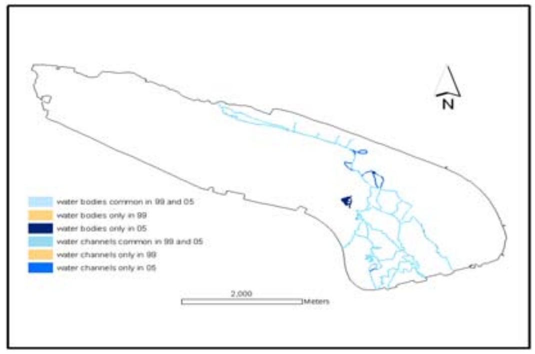
- An increase in the buildings surface of more than 300% in six years, totaling an area of about 10 hectares in 2005, representing 0.7% of the total island area.
- Results of the change analysis indicate good progress in the level of greening of the island, especially in the increase of the salt-tolerant mangrove plantation during the study period:
  - Mangrove testifies the most significant land cover type area increase. An increase of more than 336% in six years, totaling an area of about 165 hectares in 2005, representing 11.2% of the total island area. This indicates the amplitude of greening and reclamation efforts occurring on the island particularly when we know that this very adapted salt-tolerant plant is irrigated using sea water during high tide-water time.
  - Palm trees show an increase of more than 130% in six years, totaling an area of about 21 hectares in 2005, representing 1.4% of the total island area.
  - Grass is a new land cover type introduced at a later stage. An estimated area of about 2.4 hectares in 2005, representing 0.2% of the total island area. Indicating that the island has reached an advanced stage in its urbanization and development.
- In 1999 barren land alone occupied about 71% of the total area of the island. This percentage has only slightly changed in six years period approaching around 69% of the island area in 2005. This low decrease of barren land percentage shown on aerial photographs in the second period is attributed to the removal of natural vegetation cover during reclamation works.

A close examination of the above items points out many remarks, e.g., the low percentage decrease in barren land during the study period, despite good advancements in land reclamation and greening. This is attributed to the huge engineering works undertaken on the island in order to replace original high salt content soils by a new layer of soil brought from the main land. This has destroyed almost all existing natural vegetation cover mainly bushes, from 151.6 to 23.1 ha and mixed forest, from 153.9 to 144.4 ha in 1999; resulting in a more vegetation-void land appearing on the aerial photographs of the second date. However, if we look at the thematic distribution of land cover types on the island, significant achievements were acquired demonstrated in terms of land reclamation, urbanization and engineering works (Table 5).

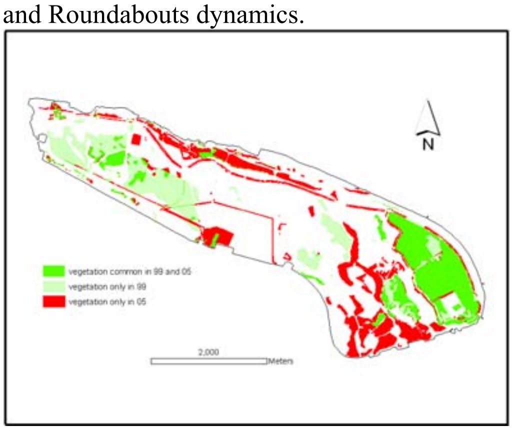
Engineering works and urbanization were demonstrated by the increase in built up areas and roads network infrastructure. Whereas, rehabilitation and human fingerprints were demonstrated by the increase in water



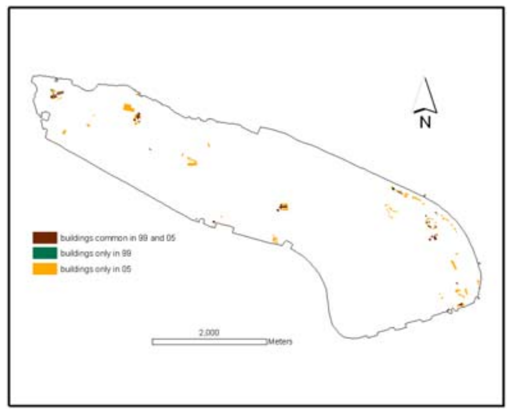
(a) Roads Network: Main roads / Footpaths/ Tracks and Roundabouts dynamics.



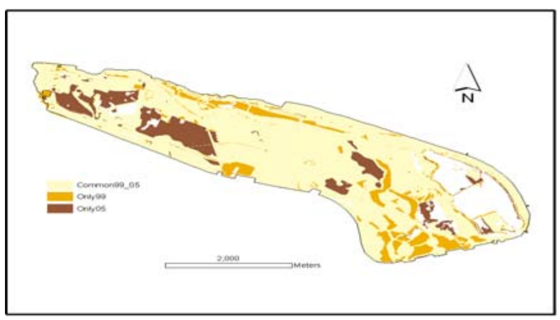
(b) Water construction dynamics



(c) Vegetation: Shrubs & grass / Palm trees / Mangroves dynamics



(d) Buildings construction dynamics



(e) Barren land dynamics

Fig. 4. Overlay analysis mapping results of the change analysis between 1999 and 2005 for five major land cover classes: (a) Roads buffers dynamics; (b) Water construction dynamics; (c) Vegetation dynamics; (d) Buildings construction dynamics and; (e) Barren lands dynamics. The vigor of human footprints and development magnitude (rehabilitation and engineering works) on the ground was demonstrated.

constructions, manifested by either artificial water bodies for hosting migrant birds or by the construction of water channels for land reclamation and irrigation. This is confirmed by the high expansion rate of Mangrove vegetated areas which increased from near 2% in 1999 to reach more than 11% of the total area of the island in 2005.

One last interesting observation is the chronological development of the island. The researcher found that first, roads were constructed, then water channels, then vegetation, then water bodies, then buildings were constructed the last, reflecting ideal chronological sequence of human settlement in a relatively very short time (six years). This proves the rate and level of urbanization at which the island in particular and the UAE in general are being transformed from a once deserted area, into one of the most urbanized countries on Earth at an unprecedented scale in human history.

Table 4. Land cover change analysis statistics in the study area (1999 - 2005).

N o	Class name	1999	2005	Change	% Net Change
1.	Roads Network				
	- Main Roads (km)	17.43	19.92	2.49	+14.27
	- Footpath/ tracks (km)	36.06	43.90	7.84	+21.8
	Total Lengths (km)	**53.49**	**63.82**	**10.33**	**+19.31**
	- Roundabout (number)	2	8	6	+300
2.	Water bodies (ha)	0.09	1.94	1.85	+2000
	Water Channels (km)	21.1	23.2	2.1	+10
3.	Vegetation				
	- Bushes (ha)	151.6	23.1	128.5	-84.8
	- Mixed Forest (ha)	153.9	144.4	9.5	-6.2
	- Mangrove (ha)	37.7	164.5	126.8	+336.3
	- Palm trees (ha)	9.1	21.3	12.2	+134.1
	- Grass (ha)	-	2.4	2.4	new
	Total Areas (ha)	**352.3**	**355.7**	**3.4**	**+1%**
4.	Buildings (ha)	2.31	9.66	7.35	+318
5.	Barren land (ha)	1045	1025	20	-1.4

Note: * Decrease carries negative sign while increase carries positive sign.
* Total island area = 14.75 km^2 = 1475 ha

Table 5. Land cover types percentage distribution in 1999 and 2005.

Land cover types	% of Island area (1999)	% of Island area (2005)
Buildings	0.2	0.7
Mangrove	2.6	11.2
Palm trees	0.6	1.4
Grass	0	0.2

TIN building and 3D Visualization

Derived contour lines layer and a Triangulated Irregular Network (TIN) were created from spot heights; the later is used in the database for visualization purposes. A 3D surface model of the island was produced permitting the creation of a fly-through traversing the island following a predefined path. Likewise, the idea of producing and comparing two TIN models for the island from 1999 and 2005 was innovative. This is true in the sense that it would have allowed for the estimation of the volume of soils brought into the island during the study period, therefore, demonstrating the capability of remote sensing and GIS to assist even in large scale engineering construction works. Unfortunately, the researcher was unable to achieve this challenging idea, as huge amounts of new soils continued to be added to the island during the study period hence hindering the possibility of producing the second 3D model!

GIS layers creation and Database building

The building of the actual Al Sammalyah database is essential for sustainable development and management of the island in the long term. The GIS database integrates raster, vector and TIN data. Large scale aerial photographs were scanned, corrected, processed, interpreted and converted to ArcGIS geodatabase format. An integrated geodatabase of 20 GIS vector and raster layers encompassing various types of features on the surface of the Island (Table 3), and spanning four different dates is now in the hands of decision makers of the island for the best management of its land resources. The history of each unit of the total 1475 hectares of the island can be studied and analyzed back to the mid eighties. The database helps in planning the land of the Island for any future development. Information can be extracted about the dimensions or extent of any of the main land cover types e.g. extent of mangrove, or building of new site seeing constructions for tourists and visitors, engineering works, etc. Another important point to learn about the database of the island is its open structure nature, in the sense that it is possible to add new data or GIS layers for any feature class of the island at any time (e.g. soil layer, water table layer, salt distribution layer, land suitability layer, etc.). Land suitability maps are of particular importance, as they will help in assisting and directing managers in their greening and construction efforts for sustainable development of the island in the long run.

The importance of building GIS spatial databases gains its importance in the region especially with growing attention given to islands that resulted in building artificial islands such as Palm and World islands built in Dubai. Definitely, the associated high cost of these artificial islands greatly justifies the implementation of GIS spatial databases to manage and sustain the development on these islands.

Flexibility and reliability of Remote Sensing and GIS

Demonstrating the flexibility and accuracy of remote sensing and GIS technologies in providing essential and updated information for resources mapping and management is one of the objectives of this study. This is of paramount importance undertaken to convince high ranking administrators of the importance of using RS/GIS technologies in management and decision making process. Since most developing countries' governments have a preference towards rapid solutions with low maintenance cost in the long run. These governments are welling to provide a one-time don with the expectation to see quick and concrete results. Investing this one-time money don to build a digital, accurate and comprehensive geo-database to manage land resources is a well thought-out and a great achievement. This geo-database has the potentiality for archiving, retrieval, querying and processing, visualization and disseminating of results amongst decision makers and the public.

Furthermore, building the GIS database was a real success. Managers of the island started to use it to do measurements and generate statistics about main land cover types like mangrove and palm trees plantation. Visualization is another product being used to print maps and generate reports for important meetings to justify funding and persuade superiors. The open structure nature of the GIS database makes it possible to expand and add more layers deemed necessary to the database in the future. The reliability and flexibility of the remote sensing and GIS products are demonstrated by assisting and directing managers in their efforts for the sustainable development of the island in the long run.

Significance of the study

This is probably the first time that an integrated spatial GIS database for land management of a specific protected island is built in the UAE. The uniqueness of such database resides in the following elements:

i. First of its kind in the UAE. Other examples can follow for other islands especially, those artificially constructed to manage tourism and sustainable development of these high costly islands.
ii. Inclusion of historical large scale aerial photographs spanning more than 20 years period.
iii. Inclusion of the change detection analysis results integrated with the rest of the basic GIS database layers.
iv. Provides evidence of environmental conservation and urban development being carried out on the island. Indicators include increase in vegetation cover extent, especially salt-tolerant plants, and increase in buildings, roads and water constructions.
v. Opportunities to undertake future GIS-based research to conduct environmental impact studies of oil or marine pollution on the ecosystems of the island.
vi. Creation of 3D simulation for the island to assess the important engineering works undertaken and visualize the artificial landscape created on the island.

The building and maintenance of a geodatabase for the AL Sammalyah Island is another step in the construction and publication of a Spatial Decision Support System (SDSS). Such a system is considered as a priority for the actual research project forthcoming period. Once built, published and maintained the SDSS will serve three types of customers: i) Decision makers who will use the system to make the decision making process quicker and more efficient; ii) Tourists and eco-tourists who will be able to search the database and get answers to their queries, and iii) Students and researchers who can retrieve data and extract information about the island.

Correlation between the amount of money invested and the level of engineering works achieved is now possible and open for planners. Future work should invite developers and GIS researchers to use RS and GIS technologies to calculate and model the relation between the amount of "money spent" and volume of "engineering work" undertaken.

CONCLUSION

The present study is the first conducted primarily to, first; quantify rates of change and levels of development using GIS and remote sensing; second build a spatial geodatabase to integrate and store all spatial data available. The geodatabase shows the evolution of the island landscape in time, in addition to the actual status of the island as of 2005, 2006. The geodatabase provides opportunities for quick and timeless maintenance, and provide a basis for the construction and publication of the Island SDSS. On the island, large-scale reclamation started in the early 1990s and has increased very rapidly since then. Urbanization and the spread of water bodies was testimony to the development of the island for enhancing scientific research and developing the ecosystem. Further, results provided convincing evidences of modernism, but also conservation, greening, and desert watering which were successfully achieved. The successful engineering and reclamation works conducted proved that dedication and wise decisions can make differences in enhancing local environmental conditions. The production of an integrated geospatial database for land management was the first in the UAE. It is believed that other institutes will follow as past experiences proved that such study example was usually followed by other public institutes in the country as well as in other Gulf States. The spread of artificially built islands in the UAE as well as in the region such as Palm and World islands in Dubai justifies the implementation of such GIS spatial databases to help in the management of tourism and economic development on these islands.

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