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Monitoring temporal changes of the surface water area of the Burullus and Manzala lagoons using automatic techniques applied to a Landsat satellite data series of the Nile Delta coast

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Abstract

This study introduces the automated shoreline techniques used to monitor the temporal change of the surface water area of the Burullus and Manzala lagoons. In this study, a series of Landsat image data are acquired at intermittent intervals between 1972 and 2006 for the Burullus lagoon and between 1972 and 2007 for the Manzala lagoon. All Landsat images were radiometrically calibrated and converted to reflectance values. The reflectance values of each date were atmospherically corrected using the 6S model. The automated shoreline technique was checked against field observations using GPS over the four seasons for each lagoon during reconnaissance for the shoreline boundary. The accuracy of the extracted shoreline boundary for each lagoon was validated by calculating the area of a large aquaculture farm in the study area from satellite imagery and the available topographic maps. The resulting accuracy of this technique was approximately 97.5%. From the spatial temporal analysis of the satellite data, the results indicate that the rate change of the aquatic surface area is $-7.3 \text{ km}^2/\text{yr}$ and $-2.7 \text{ km}^2/\text{yr}$ for the Manzala and Burullus lagoons, respectively, during the approximately 35-year study period. The changes detected in this study indicate that over this time period, the surface water area of the Manzala and Burullus lagoons has decreased by 62.6% and 61.9, respectively, compared with their original size.

Keywords: Shoreline position extraction; Coastal lagoon; Landsat; Surface area changes; Nile Delta.

Introduction

Coastal lagoons and wetlands have many benefits: they support local economies based on fisheries, agriculture and timber production: they are a source of food and energy; they offer diverse opportunities for

recreation and tourism (ALIAUME *et al.*, 2007); and they provide protection to shorelines against storms and other meteorological perturbations. During the last few decades, the northern lagoons of the Nile delta have been rapidly impacted by eutrophication from wastewater drainage and

have been altered by human activities. These activities include new transportation roads, drying processes, and urban encroachment. Population increases, together with rural and urban activities, not only directly affect the availability and quality of natural resources, but also induce secondary effects that must be evaluated from a regional viewpoint (MOUFADDAL, 2005).

Several studies have been conducted on the different aspects of the Burullus lagoon ecology (EL SABROUTI, 1984; SAAD, 1988; ABDEL MONEIM, *et al.*, 1990; FATOUH, 1990; MAIYZA, *et al.*, 1991; EL KARACHLLY, 1991; EL SHERIF, 1993; ABOUL EZZ, 1995; SHAKWEER, *et al.*, 1998). These results show that the water quality of the lagoon has changed over time. These changes are related to human intervention and eutrophication processes (BELTAGY, 1985; SAAD, 1990; KHEDR & LOVETT-DOUST, 2000; RADWAN & SHAKWEER, 2004). The bottom sediments of the lagoon are predominantly silty clay, with high organic content in some parts, and large areas of shelly to silty muddy sand (COUTLIER & STANLEY, 1987). Approximately 75 islands are scattered throughout the Burullus lagoon, with various surface areas, offering a variety of habitat types. Other studies have indicated that the size and shape of the Burullus lagoon has suffered from shrinking and, that many of the islands have increased in size (GURIGUIS *et al.*, 1996; KHEDR, 1999).

Studies on the hydro-chemical characteristics of the Manzala lagoon have been carried out by many authors (EL WAKEEL & WAHBY, 1970; WAHBY *et al.*, 1972; BISHAI & YOUSEF, 1977; DOWIDAR & ABDEL MOATI, 1983; ABDEL BAKY & EL GHOBASHY, 1990; FAHMI *et al.*, 1997). A United Nations Development Program in 1997 compiled background infor-

mation about the lagoon to be used for monitoring by remote sensing. This project reported that large amounts of particulate matter, nutrients, and bacteria are transported to Manzala lagoon via drains. BATTAGLIA & YORK, 2002 reported that dissolved oxygen differed significantly between sites, whereas conductivity, temperature, total suspended solids, ammonia and nitrate were shown to be significantly different between sampling days. In DEWIDAR *et al.*, 2008, a Chlorophyll-a model derived from remote sensing data indicated that the concentration of chlorophyll is high at the eastern and southern boundaries of the lagoon. High Chlorophyll-a concentration were associated with high concentrations of total phosphorous and high turbidity. These high concentrations may be attributed to the effect of drains and eutrophication conditions. Their study also indicated that Manzala lagoon has suffered from different levels of eutrophication resulting from human activities and poor management. RAMDANI *et al.*, 2009, stated that zooplankton communities in Manzala lagoon were generally dominated by rotifers and that the planktonic communities were comparatively highly diverse with essentially freshwater species.

Previous remote sensing studies have been carried out to extract shoreline position. . MCFEETERS (1996) used a Normalised Difference Water Index (NDWI) for the detection of water bodies. FRIHY *et al.*, 1998, used a screen manual digitising method to detect the water body of the Manzala lagoon. The waterline can also be mapped through image classification including density slice analysis (RYAN *et al.* 1991; GORMAN *et al.* 1998; BRAUD & FENG 1998; MOORE, 2000; FRAZIER & PAGE 2000; PAJAK & LEATHERMAN 2002; STOCKDON *et al.*, 2002; HORRITT *et al.*, 2003). Time series remotely sensed

images with a medium spatial resolution are ideal data sources for mapping coastal land uses and monitoring their changes over a large area (SHI *et al.*, 2001). BOSWORTH *et al.*, 2003 used a segmentation technique for multispectral Landsat TM imagery achieved using multi-resolution combined with watershed pyramids with variational region growth. DI *et al.*, 2003, investigated a novel approach to the automatic extraction of shorelines from high-resolution IKONOS satellite imagery using a mean shift segmentation algorithm as a first step, followed by a local refinement process. Monitoring changes in the coastline is an important task in some applications, such as cartography and the environmental management of the entire coastal zone (DELLEPIANE 2004; ALESHEIKH *et al.* 2004). FOODY *et al.* (2005) proposed a technique called a super-resolution mapping approach applied to soft classification. LIRA (2006) proposed a new methodology to segment open water bodies based on a variant of principal component analysis. Furthermore, the use of satellite remote sensing data was found to be a cost effective approach to quantifying changes over large geographic regions (SESLI *et al.* 2008). DEWIDAR & FRIHY (2008) used an automated waterline technique for detecting pre and post beach response to engineering hard structures at the northwestern part of the Nile delta from Landsat satellite data. AHMED *et al.*, 2009, used ISODATA unsupervised techniques to classify Manzala lagoon into three main classes of open water, emergent vegetation and dry land. They indicated that Manzala lagoon has declined in area by approximately 50%.

The aim of the present work is to quantify the loss of the water body areas of the Manzala and Burullus lagoons over a period of 35 years (1972-2007) using automatic

techniques applied to Landsat time series data. The automatic technique developed in this study can be used to update north Egyptian coastal lagoon maps. The results of this research are also important for decision makers to manage the north coastal lagoons of Egypt for future generations and conserve it as a natural defence against expected climate changes.

Study areas

The coastal lagoons and the Nile River of Egypt are the largest wetlands in the north of Africa, representing approximately 25% of the total wetlands of the Mediterranean Sea (SAAD, 2003). These lagoons contribute no less than 50% of the total wild fish catch produced in Egypt (SAAD, 2003). Moreover, they are important sites for the passage and breeding of migratory birds. In the following two sections, the study areas are described in detail.

Manzala lagoon

Manzala lagoon is the most economically important fishing ground among the northern Delta lagoons in Egypt. This lagoon supplies the Egyptian people with approximately 50% of the total Egyptian fish catch (BISHAI & YOSEF, 1977). Manzala lagoon is situated at the eastern margin of the Damietta branch between 31° 45' - 32° 20' E longitude and 31° 00' - 31° 30' N latitude (Fig. 1). The area was reduced from 1647 km² to approximately 862 km² during the early 1990s to approximately 777 km² in 1993 (ABDEL BAKY & EL GHOBASHY, 1990) as a result of extensive agricultural reclamation activities, especially on the southern and south western sides of the lagoon. Within the lagoon are hundreds of islands which vary in size and shape. Some islands in the north, which often have a long axis

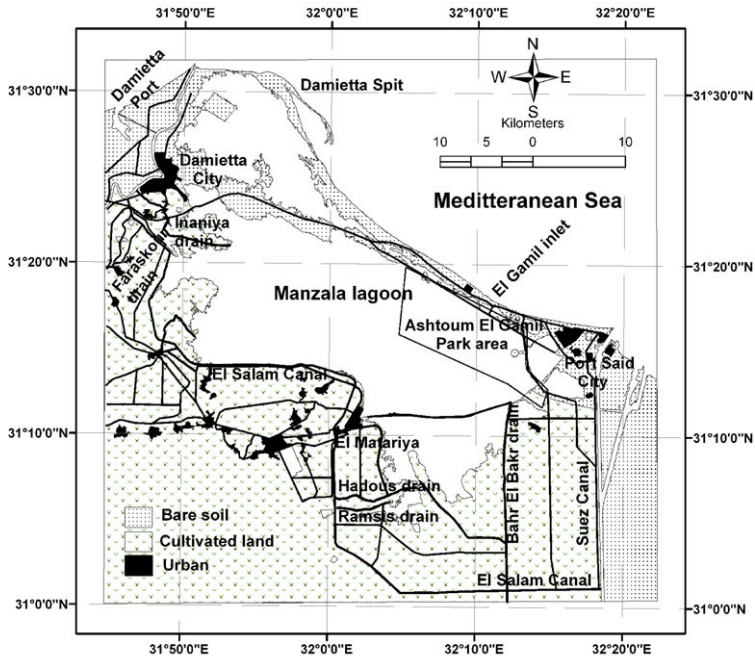


Fig. 1: The main geomorphological features derived from Landsat-7 ETM+ image data dated 2007 for Manzala lagoon.

parallel with the coast, have been attributed to former coastal sand ridges, whereas islands further south, which are less elongated in a north-south direction, may reflect deposition along former branches of the Nile (ARBOUILLE & STANELY 1991; AYACHE, *et al.*, 2009). The lagoon lies within the borders of five of Egypt's governorates (Dakahlia, Damietta, Port Said, Ismailia and Sharkiya) and is connected to the Mediterranean via an artificial opening, the El-Gamil inlet (100 meters wide), approximately 10 km west of Port Said city. The northwestern side of the lagoon is connected with the Damietta estuary by the El Suffara and El Ratama canals north of Damietta City. The exchange of water and biota between the lagoon and the adjoining Mediterranean Sea is possible through these outlets. The north-

ern part of the lagoon is affected by marine water invasion through the El Gamil inlet, while the southern and southwestern parts annually receive approximately $6695 \times 10^3 \text{ m}^3$ of sewage effluents and agricultural and industrial drainage waters without treatment from several drains and canals, namely Bahr El Bakar, Ramsis, Hadous, El Matariya, El Serw, Faraskour, Inaniya, and Port Said city. The major part of the drainage water (78%) is discharged by the Bahr El-Bakar, Ramsis and Hadous drains. The latter drains are heavily contaminated by sewage and industrial wastes. The construction of the international coastal road and the fast growing new human settlements on either side of the high way are also among the serious threats to biodiversity in the lagoon (Fig. 3A).

The lagoon's average depth is approx-

imately 1.25 m (DEWIDAR, *et al.*, 2008), and it is traversed by several sandy and clayey islets that divide the lagoon into several more or less isolated small basins known locally as “Bahour”. To the north of the lagoon is a recently protected area called Ashtoum El Gamil. This area was established by the Egyptian Prime Ministers Decision No.459/1988 & Modify Deicer No.2780/1988. The area is approximately 175 km² and is completely located inside the lagoon (Fig. 1). The main purpose for creating this protected area was the protection of many resident and migratory species of birds, saline and fresh water fish, natural plants and historical sites scattered throughout the lagoon. However, there is a proposal to increase the size of this protected area to encompass larger, more important parts of Manzala lagoon.

Burullus lagoon

Burullus lagoon lies on the eastern side of the Rosetta branch of the Nile River, oc-

cupying a central position along the Mediterranean Nile delta coast of Egypt. The lagoon extends between longitude 30° 30' and 31° 10' E and latitudes 31° 21' and 31° 35' N (Fig. 2). Burullus is the second largest of the Nile delta coastal lagoons at approximately 53 km long and 13 km wide, and it has water depths ranging from 0.5 to 2.5 m (FRIHY & DEWIDAR, 1993). GUIRGUIS *et al.*, (1996) stated that the area of the Burullus lagoon has been reduced to 452 km². TORAB and AZAB (2007) mention that the area of the Burullus lagoon has been reduced during the last century from 8688.5 km² (1925) to 553.4 km² (1984) to 489.4 km² (2001) as a result of human activities and land reclamation projects, especially after the construction of the High Aswan Dam. MOUFADDAL *et al.* (2008) stated that the Burullus lagoon surface area has decreased to 460 km² as a result of extensive agricultural reclamation activities, especially on the southern and southeast-

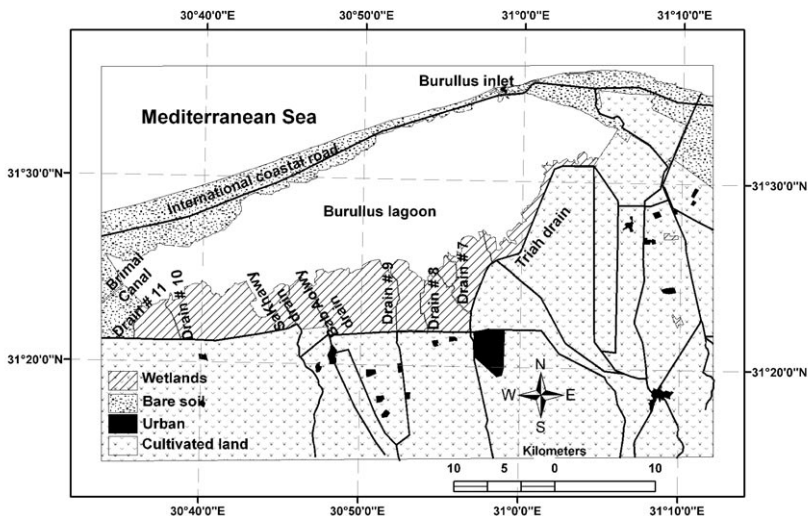


Fig. 2: The main geomorphological features derived from Landsat-7 ETM+ image data dated 2006 for Burullus lagoon.

ern sides of the lagoon. Burullus lagoon is connected to the Mediterranean Sea at its northeastern edge through the Burullus inlet (Fig. 3B), which is approximately 250 m wide and 5 m deep. The northern border is separated from the Mediterranean Sea by a strip of land covered with sand bars and dunes. Seven drains and fresh water canals are connected to its eastern, southern and western shores. The lagoon barriers are sandy and range from 0.4 to 5.5 km in width. These barriers are generally < 1.5 m above mean sea level, with beach face slopes ranging between 5° and 13°. Low relief backshores and foredunes characterise the western barrier. The eastern barrier is narrow and backed by barchans coastal dunes. These dunes encroach landward onto a cultivated coastal flat. Water is discharged into the lagoon through a series of seven land drains. The estuarine water of the Rosetta mouth of the Nile River is also mixed with the lagoon water through the Brimbal Canal. These water sources and others (rainfall and seepage of underground water) cause

a rise in the lagoon level inducing a lagoon sea current (SAAD, 1990). Burullus lagoon is designated as a wetland nature reserve under the International Ramsar Convention of 1988 and is one of the significant wetlands along the Mediterranean coast. The lagoon has been a major area for human activities, including urban and rural development, agriculture reclamation projects, and recreation, navigation and industrial activities.

Material and Methods

In this study, a series of image data were acquired at periodic intervals between 1972 and 2006 for Burullus lagoon and between 1972 and 2007 for Manzala lagoon, i.e., covering a time span of approximately 35 years (Table 1). The images were acquired at unequal intervals at a good quality level, with no effective clouds or sensor defects such as striping. The study area is visible in the TM and ETM+ scenes (Path / Row 176/38 and 177/39) and in MSS (Path / Row 190/38,

Table 1
Acquired dates, sensor type and spatial resolution of remote sensing data used in this study.

| Serial # | Burullus lagoon | | | Manzala lagoon | | |
|----------|-----------------|-------------|-----------------------------|----------------|-------------|-----------------------------|
| | Acquired date | Sensor type | Spatial Resolution (meters) | Acquired date | Sensor type | Spatial Resolution (meters) |
| 1 | 31/08/1972 | MSS | 57.00 | 31/08/1972 | MSS | 57.00 |
| 2 | 11/09/1984 | TM | 28.50 | 03/01/1973 | MSS | 57.00 |
| 3 | 10/08/1990 | TM | 28.50 | 20/09/1984 | TM | 28.50 |
| 4 | 17/06/1993 | TM | 28.50 | 11/04/1995 | TM | 28.50 |
| 5 | 18/04/1997 | TM | 28.50 | 07/06/1998 | TM | 28.50 |
| 6 | 12/02/2000 | TM | 28.50 | 11/11/2000 | ETM+ | 14.25 |
| 7 | 22/02/2001 | ETM+ | 14.25 | 24/08/2003 | ETM+ | 14.25 |
| 8 | 17/06/2002 | ETM+ | 14.25 | 18/06/2005 | ETM+ | 14.25 |
| 9 | 09/08/2004 | ETM+ | 14.25 | 04/03/2007 | ETM+ | 14.25 |
| 10 | 12/06/2006 | ETM+ | 14.25 | | | |

190/39, 191/38 and 191/39). All image scenes were subjected to image processing using ERDAS Imagine software version 9.1 (ERDAS, 2006). In this study, automated shoreline positions were formed for each date with image data. The satellite image data were processed according to the following steps.

Geometric corrections

The study data were geometrically corrected to the Universal Transverse Mercator (UTM) map projection system zone number 35 and number 36 north. A layer stack was formed for all 8 bands of the ETM+ sensor for each date (ERDAS, 2006). Recent Landsat-7 ETM+ image data were rectified to a topographic map scale of 1:50000 with more than 35 ground control points evenly distributed within 2006 for Burullus lagoon and 2007 for Manzala lagoon. A second-degree polynomial and nearest neighbour interpolation were used for resampling the image to the UTM reference system. The image rectification accuracy was < 0.5 pixel for each date. Other dates of satellite images scenes were registered to the rectified image of 2006 for Burullus lagoon and 2007 for Manzala lagoon. The image registration accuracy is < 0.4 pixels between each date and the 2006 and 2007 imagery.

Atmospheric corrections

In this study, all Landsat images were radiometrically calibrated and converted to reflectance values. Radiometric calibration can greatly improve our ability to compare landcover change at one location and is required for studies involving multiple temporal uses of Landsat images in two or more geographically district locations. ERDAS Imagine Model Maker was used to convert the DN of the image values to apparent at sensor reflectance values. The re-

flectance values of each date were atmospherically corrected using the 6S model (VERMOTE *et al.*, 1997). The input parameters of the 6S model describe the atmospheric conditions, aerosol model and concentration; target and sensor altitude, band definitions; definitions of the target and environment reflectance and latitude and longitude of the target; and azimuth and zenith angles of the Sun and sensor. Continental type aerosol was assumed and a locally measured visibility value for each date was taken from the stations of the Egyptian Meteorological Authority. The atmospheric corrected data were checked with the standard spectral reflectance curves of four materials: sand, mud, vegetation and water (LILLESAND, *et al.*, 2008). The method of checking the atmospheric data included the creation of reflectance profiles for each material type (sand, mud, vegetation and water) from the corrected image using the spectral profile module of the ERDAS Imagine software. Using this module, the behaviour of each spectral band curve was graphically checked against the standard.

Shoreline position extraction

To extract the shoreline position an image threshold was determined using band 4 (0.8-1.1 μm) for MSS and band 7 (2.0-2.35 μm) for TM/ETM+ (shortwave infrared) to create a binary image or image mask (zero value for water and one value for land) for each date. The selections of these bands depend on the strong capability of water to absorb the incident energy at particular wavelengths. Thus, the water appears black in colour in these bands and with a sharp edge detected between water and land. To ensure the waterline mapping accuracy in the case of the MSS image data 3 x 3 edge enhancement filters were used to sharpen the boundary between the water and land

classes. Binary images (masked images) are used as input layers in the unsupervised classification ISODATA algorithm to form a complete separation between the land class and the water class and to remove the effect of submerged vegetation (macrophytes) and scattered islands inside the lagoon. Horizontal and vertical Sobel filters (ERDAS, 2006) were used on each unsupervised classified image of each date to enhance edge detection. Some editing to remove small objects and fill holes was carried out for each filtered image on each date. The filtered images for each date were converted to vector layers using the Raster to Vector module (ERDAS, 2006).

Validation of shoreline extraction

To validate the resultant water body vectors, each vector dataset was superimposed over the false colour composite 543 RGB for TM/ETM+ for each date. This false colour composite enhanced the sharp edges between vegetation, wetland and surface water bodies. During this check, some net lines were removed from the boundary vectors due to the ridges between basins (Fig. 3C). The fieldwork took place during the four sea-

sons to carry out reconnaissance for the water boundary of each lagoon using the Garmin Etrex Summit GPS. To detect the accuracy of shoreline extraction in this study, a large aquaculture farm of El Matariya was selected. The farm area measured from a topographic map (1:50,000) was 4.0 km². Vectors extracted from this map were then superimposed over the extracted vectors from satellite data. Additionally, the resultant calculated area value was checked through personal communication with the Ministry of Water Resources and Irrigation. The area value calculated by this approach was approximately 3.9 km² yielding an accuracy of ~ 97.5%.

Image differencing

Image differencing is a technique whereby changes in brightness values or other datasets are determined by the cell-by-cell subtraction of co-registered image datasets (SINGH 1989, GREEN *et al.* 1994). To quantify the changes between the resultant water body areas, the image differencing technique was used between each vector dataset (Table 2 & 3). The change of water body surface area between each two dates may be

Table 2
Some numerical indicators of Manzala lagoon surface area loss.

| Year | Boundary area (km²) | Islands (km²) | Time interval (year) | Changed (km²) | Unchanged (km²) |
|-------------|---------------------------------------|---------------------------------|-----------------------------|---------------------------------|-----------------------------------|
| 1972 | 1079.4514 | 137.8 | 1972-1973 | 22.7188 | 1056.8354 |
| 1973 | 1072.5638 | 137.8 | 1973-1984 | 109.1993 | 970.3549 |
| 1984 | 992.8424 | 135.4 | 1984-1995 | 205.0346 | 874.5196 |
| 1995 | 923.401 | 126.4 | 1995-1998 | 196.5536 | 883.0006 |
| 1998 | 929.9031 | 132.4 | 1998-2000 | 232.8163 | 846.7379 |
| 2000 | 861.6439 | 129.1 | 2000-2003 | 235.6176 | 843.9366 |
| 2003 | 860.693 | 133.9 | 2003-2005 | 259.5957 | 819.9842 |
| 2005 | 844.0394 | 114.6 | 2005-2006 | 290.5385 | 789.0157 |
| 2007 | 800.9148 | 125.1 | | | |

Table 3
Some numerical indicators of Burullus lagoon surface area loss.

| Year | Boundary area (km ²) | Islands (km ²) | Time interval (year) | Changed (km ²) | Unchanged (km ²) |
|------|----------------------------------|----------------------------|----------------------|----------------------------|------------------------------|
| 1972 | 682.6 | 30.1 | 1972-1984 | 70.2638 | 612.3796 |
| 1984 | 626.7 | 32.6 | 1984-1990 | 213.6698 | 468.9736 |
| 1990 | 474.5 | 30.7 | 1990-1993 | 218.0388 | 464.6046 |
| 1993 | 476.3 | 34.2 | 1993-1997 | 218.7327 | 463.9107 |
| 1997 | 470.9 | 32.8 | 1997-2000 | 229.8094 | 452.834 |
| 2000 | 464.6 | 30.6 | 2000-2001 | 228.5244 | 454.1447 |
| 2001 | 461.2 | 33.0 | 2001-2002 | 227.3936 | 455.2498 |
| 2002 | 462.3 | 33.6 | 2002-2004 | 228.5244 | 454.1447 |
| 2004 | 459.4 | 33.8 | 2004-2006 | 229.9893 | 452.6541 |
| 2006 | 457.0 | 34.7 | | | |

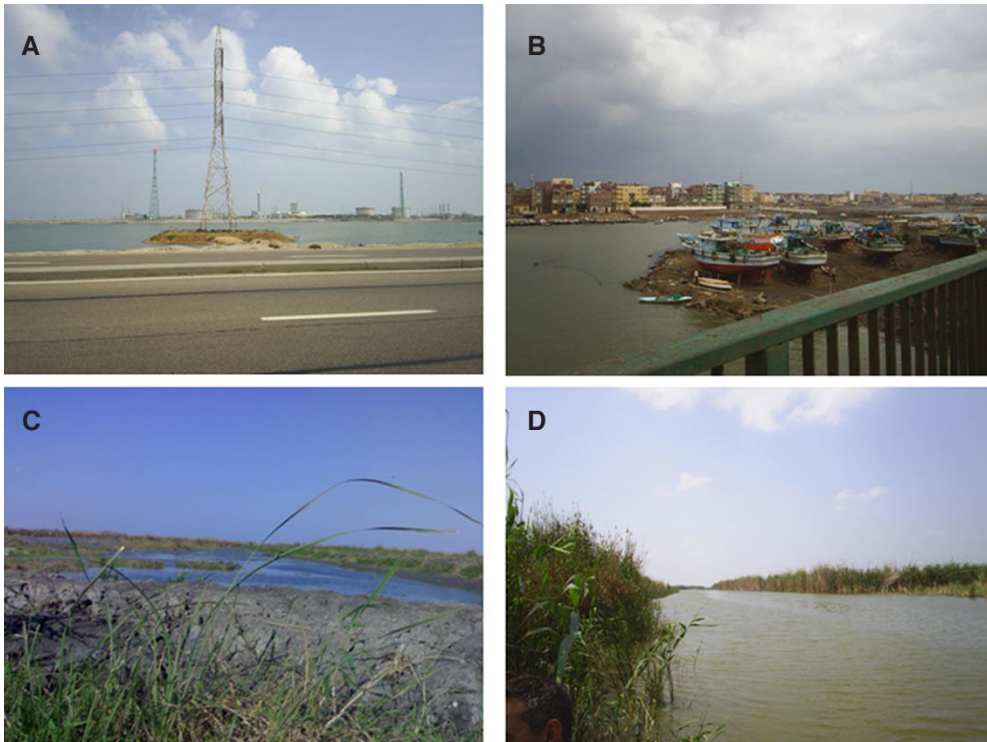


Fig. 3: Photographs of the study areas showing, (A) the international coastal road crossing Manzala lagoon, (B) the Burullus inlet, (C) drying processes inside the southern part of Manzala lagoon, (D) the height of reeds inside Burullus lagoon.

attributed to an increase in the size of the islands due to siltation and drying processes.

Results and Discussions

Manzala lagoon

By observing the spatial distribution of surface water area for Manzala lagoon (Fig. 4 and Table 2), it can be concluded that the lagoon has lost much of its water surface area due to drying processes, fish farms and land reclamation. The changes between 1972 and 1973 are insignificant compared with those between 1973 and 1984. These changes may be attributed to faster drying processes in the north of the lagoon instigated by building an alternative coastal road due to

the coastal erosion of the Damietta headland during this period. This coastal road connects the cities of Damietta and Port Said. Additionally, large areas in the northwest have been converted to fish ponds for intensive aquaculture. During the second decade, between 1984 and 1995, the water surface body of the Manzala lagoon suffered from greater shrinkage due to artificial drying to build a wastewater treatment plant on the eastern side of the lagoon. The changes during the third decade are attributed to the increase of human interventions, such as urban encroachment and land reclamation activities on the eastern and southwestern sides of the lagoon. The result of this study agrees with the study of ABDEL BAKY & EL GHOBASHY (1990), which used a differ-

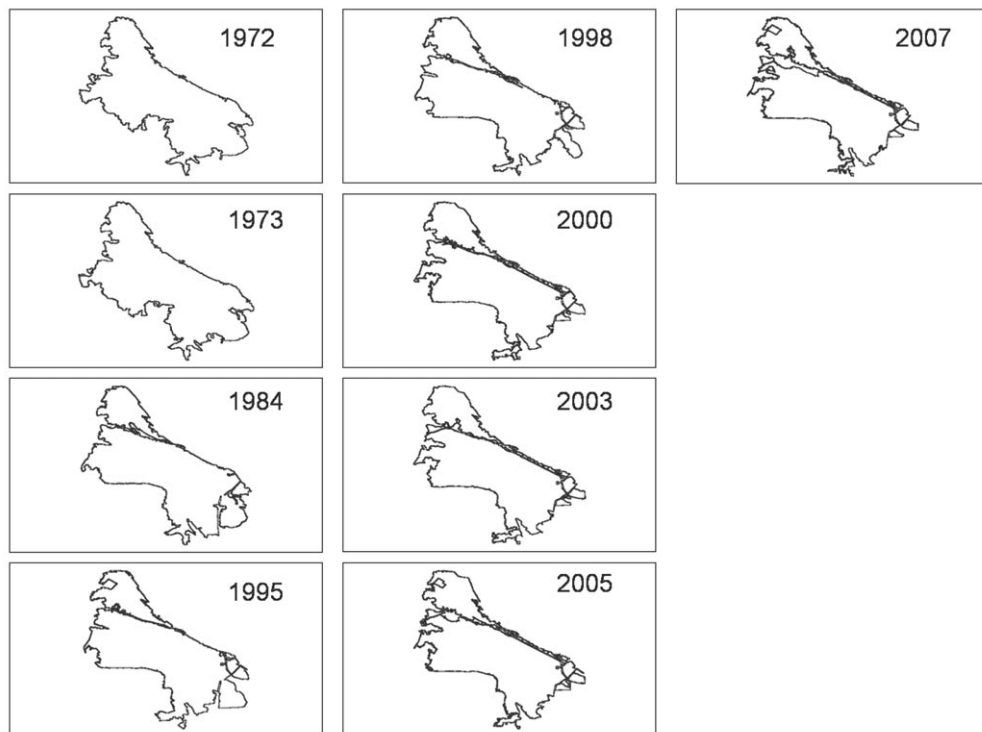


Fig. 4: Vector layers of Manzala lagoon derived from satellite time series data.

ent approach. The results of this study also indicate that the rate of Manzala's aquatic surface area loss over 35 years is $-7.3 \text{ km}^2/\text{yr}$ (Fig. 5A). This result means that the Manzala lagoon has been heavily impacted by eutrophication caused by wastewater from the drainage system and by the drying processes of land reclamation and urban encroachment due to the expansion of the Dameitta governorate to the east of the lagoon. By comparing the results of this study with other studies (AHMED, *et al.*, 2009), there is general agreement in the trend and pattern of shrinkage for the water surface area of Manzala lagoon.

The above situation justifies the creation of improvement works to maintain the present area of the lagoon water body without

further area loss. These improvement works could include dredging to create three parallel radially submerged channels that are 4 m deep and approximately 17 km in total length. This dredging plan can lead to a decrease of reed areas in the lagoon and contribute to the establishment of equilibrium between the reed areas and the free water surfaces of the lagoon system. These channels would facilitate the movement of water and sediment in the lagoon, thus preventing siltation processes. Second, a built up boundary buffer zone around the lagoon could be constructed to prevent random access and drying processes by fishermen or others. These suggestions have been discussed with the stakeholders in the study area to keep Manzala lagoon a healthy ecosys-

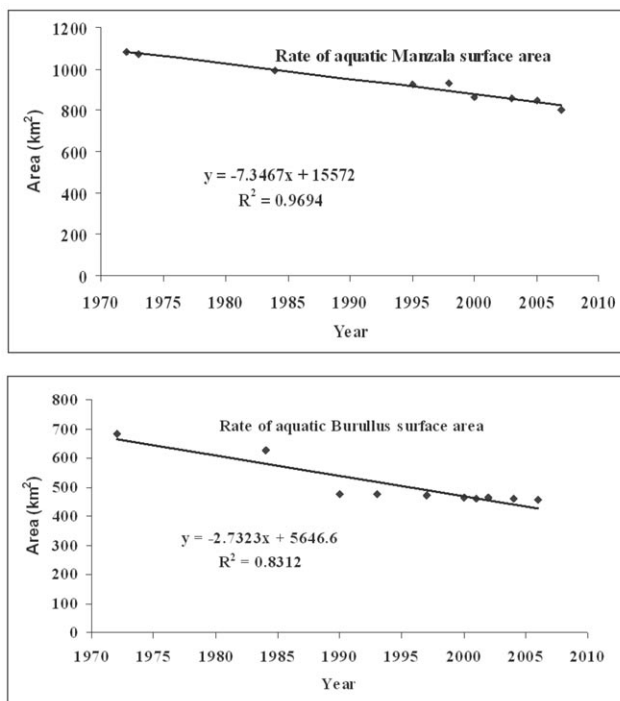


Fig. 5: Rate of Manzala (A) and Burullus (B) aquatic surface area change.

tem. Finally, some stakeholders have suggested using new technologies for waste management to decrease pollution loads.

Burullus lagoon

By comparing the change of water surface area between 1972 and 1984, the surface water area has decreased by 55.9 km² (Fig. 6 and Table 3) in Burullus lagoon. During the period between 1984 and 1997, the water surface body of the Burullus lagoon suffered from more shrinkage due to drying processes and land reclamation at the eastern side and the southern part of the lagoon (Table 3). By comparing the results of this study with other studies of area changes of the Burullus lagoon (GUIRGUIS *et al.*, 1996; MOUFADDAL *et al.*, 2008), there is gen-

eral agreement in the trend and pattern of shrinkage of the water surface area. During the period between 1997 and 2006, the rate of shrinkage decreased due to the Burullus lagoon becoming a conserved area under the International Ramsar convention of 1988. The rate of surface water area shrinkage is -2.7 km²/yr (Fig. 5B) during the entire period of approximately 35 years. The islands inside the Burullus lagoon have only been slightly changed, which may be attributed to seasonal changes and changes in the density of reeds. Presently, the main problem the Burullus lagoon faces is the increase in the tallest reeds inside the lagoon (Fig. 3D), which may be attributed to the harvesting of reeds by fishermen and an increase in the eutrophication of the

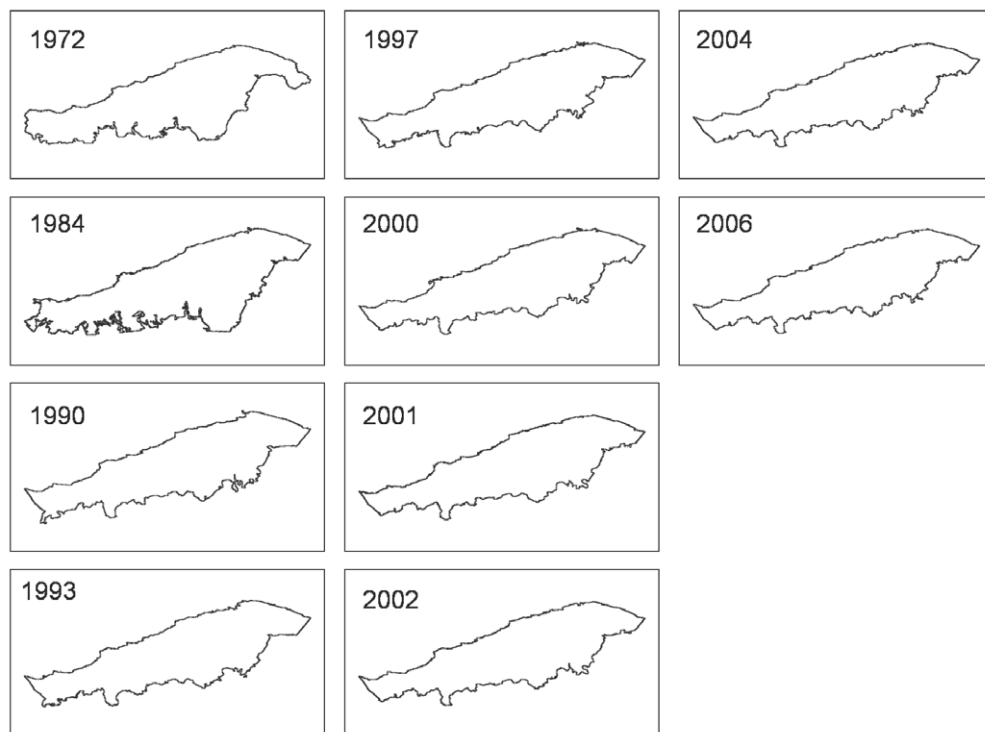


Fig. 6: Vector layers of Burullus lagoon derived from satellite time series data.

southern part of the lagoon. To overcome this problem, harvesting and dredging processes should be alternated.

Conclusions

The results of the present study show that automated shoreline techniques can be used as a tool for monitoring long-term changes of surface water areas of the northern Nile Delta lagoons. The results of this study may also be important for decision makers to manage the north coastal lagoons for future generations and to conserve them as a natural defence against expected climate change. The accuracy of this technique is more than 95% for the detection of the surface water areas across the study area. The changes detected in this study indicate that the surface water area of the Manzala and Burullus lagoons has decreased by 62.6% and 61.9%, respectively, from their original size in 1972 over 35 years. The above situation justifies the creation of improvement works to maintain the area of the Manzala lagoon water body without further loss.

The results of this study may allow the decision makers to visualise the temporal changes of the Burullus and Manzala lagoons. Furthermore, the study may be an alarm for all stakeholders who are concerned with north Egyptian coastal lagoons. The resource value of the Nile Delta coastal lagoons has brought about the need to protect and conserve them. These lagoons should be continuously monitored so that temporal changes in their environment can be analysed. The importance of determining the cause, extent, and spatial distribution of these changes can be used in different aspects of environmental studies, land suitability analyses and environmental management in Egypt.

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