

# The Lake Manzala of Egypt: an ambiguous future

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**Abstract** The Lake Manzala of Egypt has a relatively short history and its future, however, is uncertain. The lake which was the biggest coastal wetland along the Mediterranean Coast is moving toward its disappearance by two opposite forces, one of them is the shrinking of the water body by siltation of sediments coming from agricultural lands and the abundance of weeds and swamp vegetation as well as the drying practices for agriculture, whereas the other force incorporates the removal of the coastal sand bar separating the lake from the Mediterranean Sea by erosion, which should eventually lead to the conversion of the lake into a coastal embayment instead of being a closed coastal lagoon. The study provided a spatiotemporal change analysis of the lake using remotely sensed data.

**Keywords** Lake Manzala · MODIS · Landsat · Shrinking · Coastal erosion

## Introduction

The Egyptian coastal lakes

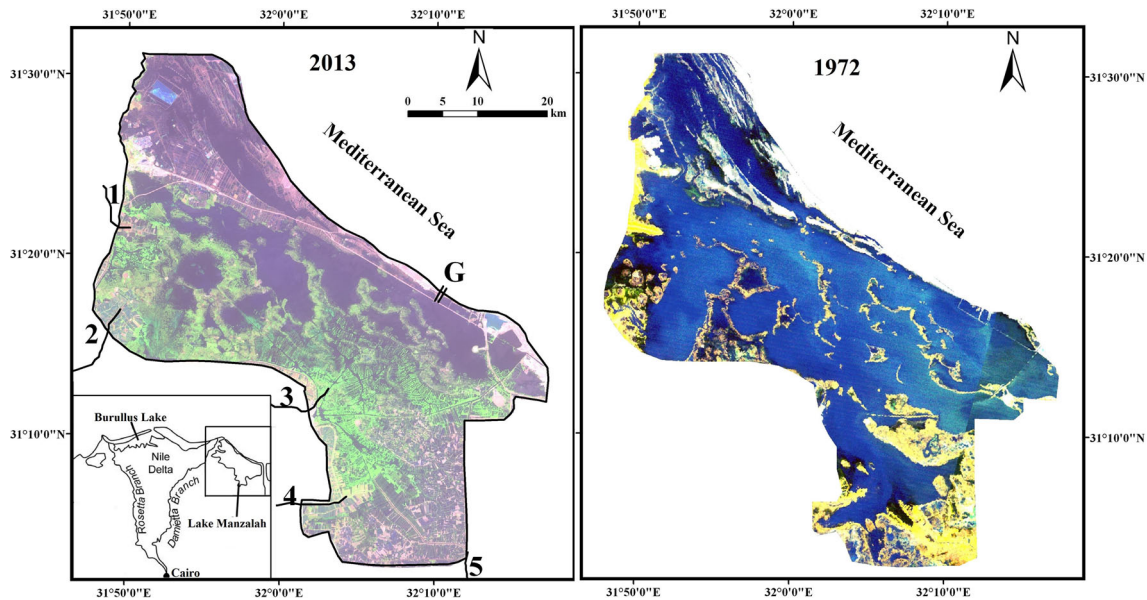
The modern Nile Delta was established some 6,000 years ago when the sea level had stabilized at its current stage after a long history of fluctuation up and down from the present level (Stanley and Warne 1994). The Nile delta, which was formed from the detrital sediments coming from the Ethiopian highlands with the Nile River flooding throughout its history comprise four coastal lakes, namely:

Manzala, Burullus, Edku and Mariut. Dumont and El-Shabrawy (2007) attributed the formation of these coastal lakes into two processes: subsidence and coastal erosion. The continuous compaction of the sediment column under the effect of weight has caused the delta to sink by a rate of 4–5 m per 1,000 years (Stanley 1988). Maximum subsidence (5 mm/year) was observed at the eastern part of the Lake Manzala (the lake under consideration). Delta subsidence is therefore responsible for the submergence of the coastal area. On the other hand, the sediments that once deposited along the Mediterranean Sea coast from the Nile River branches during flooding season had been reworked by the wave action and were eroded and moved by the eastward long shore currents under the effect of the northwesterly winds forming sand bars encompassing the previously formed swamps. Convergence of freshwater from the south with the saline water from the north has left four brackish coastal lagoons.

Barrages constructed since the 19th century and the two high and low Aswan Dams in southern Egypt constructed in the 20th century have dramatically changed the hydrology of the Nile River, where a controlled system of water utilization was adopted. During the last third of the 20th century, there was a year round irrigation system instead of a short flooding season that predominated throughout the previous history of the region. Simultaneously, the irrigation regime has been modified to disseminate water all the year. Concurrently, a group of drains have been constructed to gather agricultural waste effluents from the delta toward the Mediterranean Sea. The occurrence of the delta coastal lakes made them a final destination for the main drainage instead of being terminated at the sea, which eventually caused severe deterioration of these lakes (Flower 2001). Consequently, sedimentation rates increased (Benninger et al. 1998), salinity decreased

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**Fig. 1** The Lake Manzala as appears in Landsat OLI image of March 2013. Numbers refer to the location of the agricultural drains ending at the lake as 1 *El-Inaniya*, 2 *El-Serw*, 3 *Hadous*, 4 *Ramses* and 5 *Bahr*

*El-Baqar*. *G* refers to El-Gamil opening of the lake at the Mediterranean Sea. The right image shows the lake in 1972 with less distribution of aquatic vegetation compared with the 2013 status

(Zalat and Vildary 2007), nutrient levels also increased (Hamza et al. 2003) and heavy metal concentration increased (Siegel et al. 1994).

Manzala is the largest coastal lake along the Egyptian Mediterranean Sea coast (Fig. 1). It occurs between the Damietta Nile River branch and the Suez Canal with a maximum length of 50 km along the Mediterranean coast, where a narrow sand bar separates the lake from the sea. The lake is generally shallow, where more than 50 % of the area is shallower than 1.0 m (Shaheen and Yosef 1979) with hundreds of islands making the water body distinguished into tens of isolated basins with different water characteristics due to the discontinuity between these basins. Today, seawater enters the lake mainly from the north through an opening (El-Gamil inlet) within the coastal sand bar 5 km west of Port Said along the Mediterranean Sea. Although this sand bar is narrow and flat, it is the wall that protects the lake from being overwhelmed by seawater. Nevertheless, this coastal bar has experienced sever erosion, particularly along its western side (Frihy et al. 1998). In addition, some other minor openings pass seawater into the lake. Fresh water enters the lake from the south and west via five main drains conveying untreated agricultural and municipal wastes into the lake. These drains are (from west to east): *El-Inaniya*, *El-Serw*, *Hadous*, *Ramses* and *Bahr El-Baqar*. The latter contributes about 50 % of the inflow to the lake. Aquatic vegetation has been burgeoned significantly in the lake as a result of drainage water disposal (Ahmed et al. 2009). Fresh and brackish water vegetation species predominate the water

body such as *Zygodophyllum aegyptium*, *Phragmites australis*, *Juncus acutus*, *Juncus rigidus*, *Arthrocnemum macrostachyum*, and *Halocnemum strobilaceum* (Zahran et al. 1989). Comparing the situation of the lake in the two dates, 1972 and 2013 (Fig. 1) reveals a drastic shrinking of the water body. Green aquatic vegetation has flourished and substantial areas have been dried either for road construction or for reclamation. El-Asmar and Hereher (2011) estimated the gross area of the lake at three dates as obtained from satellite images during 1973, 1984 and 2003. They reported that the area had drastically reduced from 1,100 km<sup>2</sup> in 1973 to 1,052 km<sup>2</sup> in 1984 and finally became 720 km<sup>2</sup> in 2003. They attributed this shrinking to the reclamation activities and to the construction of the coastal highway.

The climate in the Lake Manzala region, as revealed by the nearest meteorological station (Damietta), is relatively arid (Table 1). Precipitation is scant and occurs mostly in winter months (December, January and February). The annual precipitation rate approaches 113 mm, which represents a desert pattern of rainfall. Temperatures are generally hot, where summer months are as high as 26 °C in July and August, and winter temperatures fall to 13 °C in January, with a mean annual temperature of 20 °C. Relative humidity of the region is generally high and ranges from 71 % in spring to 76 % in summer and winter months. The most obvious observation is the high rate of evapotranspiration (ET<sub>o</sub>), which approaches 198 mm in June and 45 mm in January, with an annual ET<sub>o</sub> of 1,375 mm. According to the UNESCO (1979) aridity index

**Table 1** Climatic parameters of Damietta

Month	<i>T</i> (°C)	<i>P</i> (mm)	ETo (mm)	<i>H</i> (%)
January	13	26	45	76
February	14	20	69	75
March	16	14	75	73
April	18	5	126	71
May	22	2	138	71
June	25	0	198	71
July	26	0	183	73
August	26	0	156	76
September	25	0	144	75
October	23	7	117	74
November	19	16	70	75
December	15	24	54	76
Annual	20	113	1375	74

Source: Egyptian Meteorological Authority and the Central Laboratory for Agricultural Climatology, Ministry for Agriculture and Land Reclamation

( $AI = P/ETo$ ), which is based on the annual precipitation (*P*) divided by the annual evapotranspiration (ETo), the Lake Manzala region has an AI of 0.08 revealing an arid climate ( $P/ETo = 0.03 - 0.2$ ).

#### Remote sensing of wetlands

Remote sensing, which affords a synoptic view with a wide geographic coverage and periodic imaging of the same region at multiple spectral information ranging from the visible to the microwave portions of the spectrum (Hereher 2011), has been widely used as a tool to monitor wetland environments (Islam et al. 2008). The availability of satellite data with different spatial, spectral and temporal resolution helped to provide ample of information about the extent, quality and dynamics of wetlands (Ozesmi and Bauer 2002). A plenty of satellite sensors have been operated to study coastal wetlands, including multi-spectral scanner (MSS), thematic mapper (TM), enhanced thematic mapper plus (ETM+), the moderate resolution imaging spectroradiometer (MODIS) and Radar satellites (MacAlister and Mahaxay 2009; Rutchey and Vilchek 1999; Kushwaha et al. 2000). There is a new generation of Landsat series, which was launched in April 2013 and is refereed as the Landsat-8 operational land imager (OLI), which affords an up-to-date monitoring of land resources with additional spectral enhancements over previous Landsat generations.

Vegetation indices obtained from satellite remote sensing are surrogates for vegetation condition in terms of quantity and vigor (Tucker 1979). These indices are mathematical models designed to enhance the vegetation signature at the pixel level depending on two or more band readings in the satellite image, probably including the infrared band. Among

the most potential vegetation indices is the enhanced vegetation index (EVI), in which the  $EVI = (1 + L) \times (NIR - R)/(NIR + C1R - C2B + L)$ , where *NIR*, *R* and *B* are reflectance value in the near infrared, red and the blue bands, respectively; *C1* and *C2* are the aerosol resistance coefficients, and *L* is the vegetation canopy background factor (Huete et al. 2002). EVI correlates significantly with the chlorophyll in the green vegetation, and thus it is used extensively in plant studies (Wardlow and Egbert 2010). Theoretically, EVI ranges between  $-1.0$  and  $+1.0$ , where green vegetation always has positive values and non-vegetation objects have negative and close to zero values. Multi-temporal monitoring of areas covered by vegetation is useful to infer changes of the extent and vigor of the green cover (Hereher 2013a). In the case of wetland environment that receives agricultural wastewater rich in nutrients (phosphorous and nitrogen), such as the Lake Manzala, it is hypothesized that the increase in discharge of wastewater into the lake will lead to the augmentation in the aquatic vegetation and algal blooming in the water body that could be recorded by satellite images. Although, EVI obtained from MODIS data can be obtained very often, its spatial resolution (250 m) is one of the major limitations to this sensor, making traditional classification of MODIS images provides poor results as mixed pixels are inevitable. On the other hand, Landsat images have the advantage of providing images back to early 1970s and have a reasonable spatial resolution (30 m) for wetland studies. The launch of the Landsat-8 helped to afford up-to-date images from the OLI sensor. Radar remote sensing avoids the disadvantages of other passive sensors in that its waves work at day and night and not affected by the cloud cover. The shuttle radar topography mission (SRTM) during its 11-day mission in February 2000 provided a global data base of the earth's topography that has been provided in 30-, 90- and 1,000-m spatial resolution. These data were acquired using the radar c-band through the technique of interferometry. Digital elevation models (DEM) data obtained from the SRTM have been recently used to study lake levels (Pan et al. 2013). The main objective of the present study is to operate satellite remote sensing to analyze spatiotemporal changes of the lake. Specific objects include estimating and updating the area of the Lake Manzala, determine the depths of the lake basins, and analyzing the spatial change of the lake vegetation. The results of the present study will depict scenarios of the lake future.

#### Materials and methods

##### Satellite data

Three types of satellite dataset have been utilized in this investigation. (1) A DEM was acquired from the SRTM

dated February 2000 with 90-m pixel size in the Universal Transverse Mercator (UTM) projection. (2) Two satellite images from the very old Landsat-1 MSS sensor (path 190 and row 38) dated August 1972, and the most recent Landsat-8 OLI sensor (path 176 and row 38) dated May 2013. The MSS image has four spectral bands (two in the visible and two in the near infrared) with a 60-m spatial resolution. On the other hand, the OLI image contains eleven bands (5 bands in the visible, 4 bands in the infrared, and 2 bands in the thermal infrared) with a 30-m spatial resolution. The two images are in the UTM projection. (3) A series of 11 standard 16-day composite VI (MYD13Q1) product images were acquired for the period 2003 to 2013 from the *Aqua* sensor onboard the MODIS satellite on the basis of one image (dated 25th January) per year. No images before winter 2003 were available from this sensor. The MODIS images have the advantage of being pre-processed to remove atmospheric aerosols and were geometrically rectified at the origin. They were acquired in the same Julian day to eliminate any variation caused by the solar illumination angle. Each image has a pixel size of 250 m and consists of 12 bands including the EVI band in the Sinusoidal map projection. All these images were obtained from the United States Geological Survey (USGS) open access databases.

#### Data processing

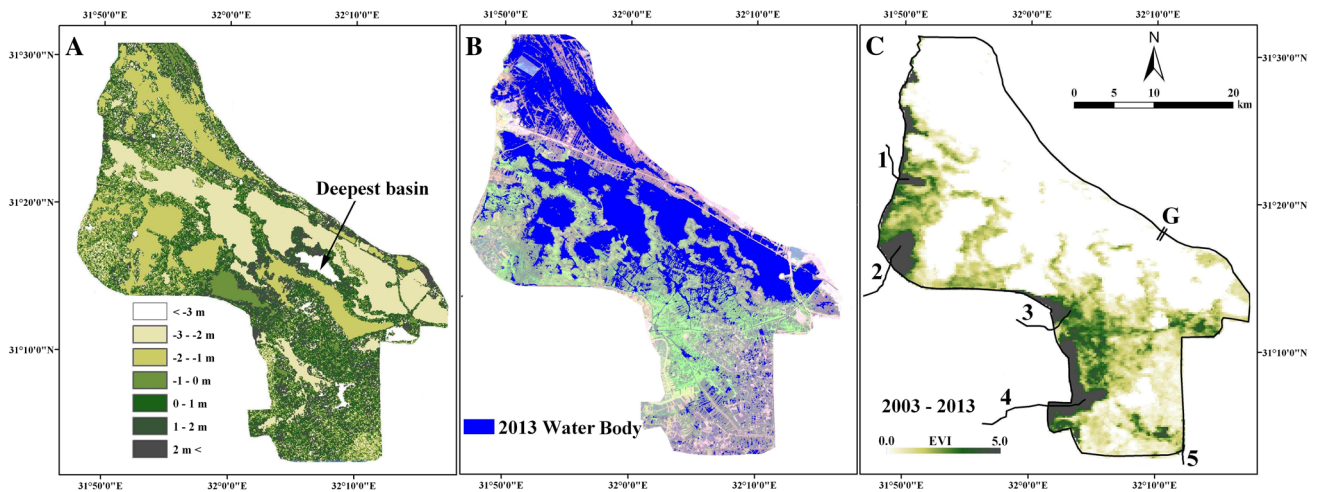
The first step in the image processing was to unify the projection of all images to the UTM projection using ERDAS Imagine Software. A subset image encompassing the Lake Manzala was then created from all images for subsequent processing. The DEM was classified in ArcGIS into four elevation levels at 1-m interval to identify the depth of each lake basin. In the Landsat images, the thermal and panchromatic bands were excluded from the analysis. An unsupervised classification algorithm was adopted to the OLI image of 2013 using the iterative self-organizing data analysis (ISODATA) to obtain 20 classes. A careful recoding for each class was then applied. As the water clusters were easily distinguished from non-water objects, all water classes were recoded and counted together. The area of the Lake in May 2013 was then estimated. The sand bar that separates the lake from the Mediterranean Sea was extracted in both MSS and OLI images and the two new subsets were classified individually to highlight the area and configuration of this bar in both 1972 and 2013. The two classified images were multiplied together to detect the “from-to” change (Jensen 1995) occurred during these 41 years. The 11 subset EVI images were stacked together to form one file containing 11 EVI layers, where a mean image was created, in which each pixel have a mean value of 11 pixels. As the EVI correlates

significantly with the green vegetation (Huete et al. 2002), areas of high EVI in the mean EVI image represent accelerated greenness throughout the 11 years of investigation. As the lake consists mainly of water, aquatic vegetation, islands, and bare soil, traditional classification of lake vegetation in MODIS images with the coarse spatial resolution (250 m) yields poor results due to the limitations caused by mixed pixels. Thus, it was better to apply a certain threshold in the EVI band of the MODIS images to highlight the pixels of minimum EVI value and pertaining to vegetation. Beyond this threshold are the pixels of non-vegetation objects, and above this threshold are the pixels of green vegetation. Consequently, the area of the green vegetation was estimated in MODIS images between 2003 and 2013.

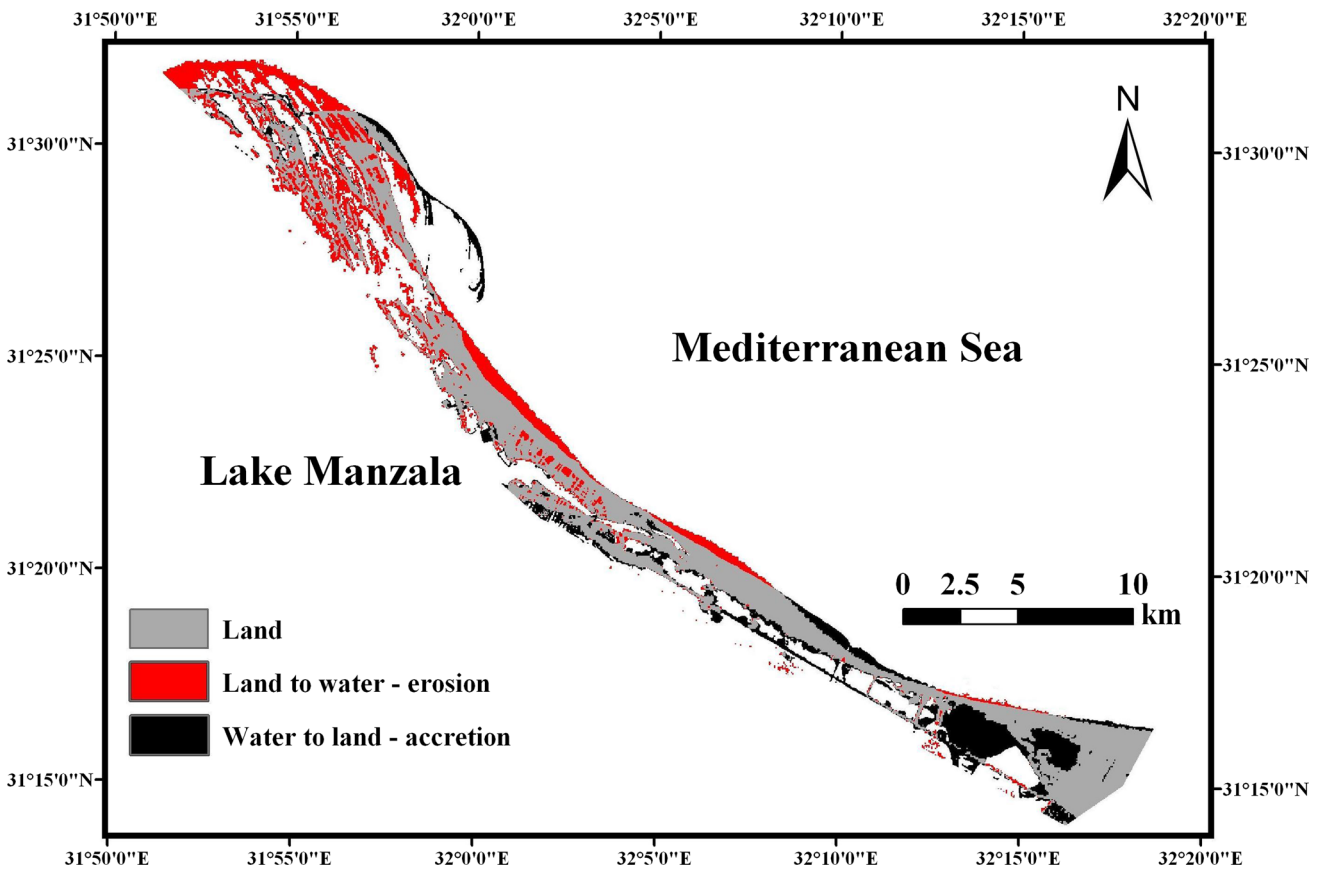
#### Results

There are significant changes occurred on the Lake Manzala environment during the last four decades (Fig. 1). The construction of the Aswan High Dam in the 1960s has changed the hydrology of the Nile Delta that the control of irrigation water entailed the construction of agricultural drains transporting agricultural wastewater northward to the Mediterranean Sea and the northern lakes including Manzala, which receives wastewater from five drains. The continuous discharge of such wastes lead to the considerable degradation of the lake. The Lake Manzala is generally very shallow (Fig. 2a) and is composed of discontinues basins with different depths. Basins, which are less than 100-cm depth are the dominant and occupy a total area of 468 km<sup>2</sup> (67 % of the lake area) and occur mainly along the southern, western and northwestern sides. These areas are the most closer to receive turbid wastewater from agricultural drains at the south, which might accelerate sedimentation and eutrophication in these basins. The lake depth (100–200 cm) accounts for 115 km<sup>2</sup> (16 %) of the lake area representing 4–7 major basins in the middle and northern parts, whereas the basins which have depths of (200–300 cm) occur as elongated discontinuous 3–4 basins from west to east occupying 103 km<sup>2</sup> (15 %). The deepest basin in the lake (more than 300 cm) occurs at its eastern section with an area of 17 km<sup>2</sup> (2 %). Generally, it is observed that deep basins occur at the seaside of the lake, which are far from contamination by agricultural drains.

The area of the water body in March 2013 as estimated from the unsupervised classification is 385 km<sup>2</sup> (Fig. 2b). This area represents the summation of the discontinuous basin areas as revealed in the Landsat-8 OLI image. Comparing this area with the area estimated by El-Asmar and Hereher (2011) in 1973 (1,100 km<sup>2</sup>) reveals that the lake has lost 65 % of its water body between 1973 and



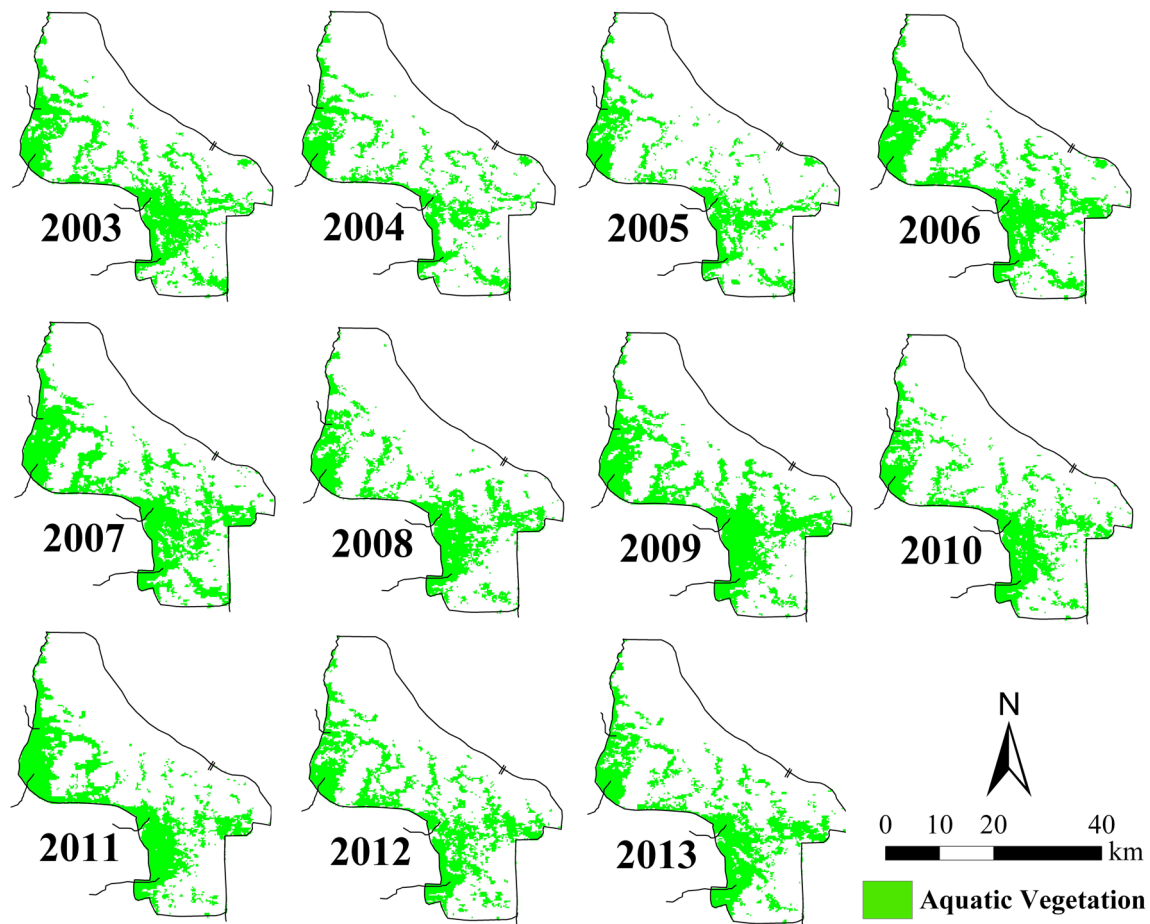
**Fig. 2** **a** Refers to the depths of the lake basins as obtained from the radar interferometer SRTM image, **b** refers to the extent of the water body in March 2013 as obtained from the Landsat OLI image classification, and **c** is a mean EVI image of the lake obtained from 11 MODIS images and showing the distribution of greening sites resulted from agricultural waste discharge



**Fig. 3** The coastal sand bar separating the Lake Manzala from the Mediterranean Sea as occurs in two Landsat images, MSS (1972) and OLI (2013), with 41 years apart. *Red color* refers to areas eroded in the *sand bar*, whereas the *black color* highlights the areas filled by sediment accretion

2013. The mean EVI image (Fig. 2c) shows clearly that the locations where the agricultural drains end at the lake have the maximum EVI values due to the accelerated

eutrophication and algal blooming. Most areas of high mean EVI are encountered at Ramses drain (#4 in Fig. 2c) followed by El-Serw drain (#2 in Fig. 2c), where



**Fig. 4** The change in the vegetation cover within the lake between 2003 and 2013, as revealed by MODIS images. Note that most vegetation occurs close to the agricultural drain sites

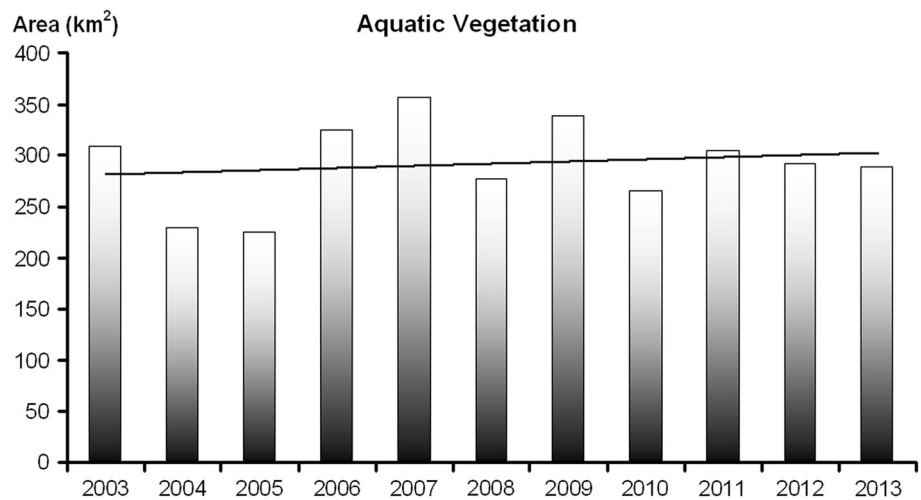
agricultural and domestic wastes are discharged directly without treatment into the lake body. Bahr El-Baqar drain (#5 in Fig. 2c), which is the largest drain to discharge into the lake was unexpectedly not the most significant affecting the vegetation growth of the lake.

The 1972 and 2013 change in the coastal sand bar (Fig. 3) reveals a significant reduction either in the sea side or the lake side. The area of the sand bar is 97 km<sup>2</sup> in 1972 and reached 91 km<sup>2</sup> in 2013. Although both erosion and accretion have occurred simultaneously, the “from-to” change matrix shows that accretion (“from water-to land”) accounts for 25 km<sup>2</sup>, and this accretion occurred mainly along the eastern side of the sand bar near Suez Canal. On the other hand, erosion (“from land-to water”) is obvious mainly along the western side of the sand bar near Damietta Nile branch and approaches 31 km<sup>2</sup>. The net change reveals a removal of 6 km<sup>2</sup> of land by erosion of this sand bar that borders the lake.

The threshold value of the EVI that discriminates between vegetation and non-vegetation pixels is found to be 0.1 in the MODIS EVI images. Change of the vegetation

cover in the Lake Manzala between 2003 and 2013 (Fig. 4) reveals that aquatic vegetation occupies the majority of the water body leaving discontinuous basins of water free from vegetation. It is obvious that the southern and western parts of the lake witnessed flourishing of aquatic vegetation, whereas the northern side, which receives seawater shows lower changes. The average area of vegetation cover in the lake for the study period accounts for 292 km<sup>2</sup> (Fig. 3). The change in the area of vegetation cover between 2003 and 2013 reveals a maximum area of vegetation cover in 2007 (357 km<sup>2</sup>), whereas the minimum area is encountered in 2005 (224 km<sup>2</sup>). Although, exceptional vegetation growth is observed during 2003 and 2007, which may reflect a change in the nutrient load discharged into the lake from agricultural drains during these 2 years, the mean tendency of vegetation cover as represented by the net trend line reveals an increase in the aquatic vegetation cover in the lake between 2003 and 2013 (Fig. 5). The average lake vegetation area between 2003 and 2007 is calculated as 289 km<sup>2</sup>, while between 2008 and 2013 the average vegetation area is 294 km<sup>2</sup>.

**Fig. 5** The area of the vegetation cover within the lake, as obtained from MODIS images. Note that there are three peaks of greening at 2006, 2007 and 2009



**Discussion and conclusions**

The Lake Manzala, which has a short history that does not exceed 6,000 years, since the sea level had become steady at the current level (Stanley and Warne 1994) is a dynamic water body in terms of spatial changes caused by natural and/or anthropogenic influence. The lake occurs in the arid zone of the world (UNESCO 1979), where evapotranspiration much exceeds the precipitation rates. This climate makes the lake receive insignificant contribution from rainfall at the time where it loses up to 1,375 mm of water annually by evapotranspiration. Consequently, the water budget within the lake is contingent mostly to the inflow of saline water from the north, the freshwater discharge from the south, and the losses of water by evapotranspiration. During summer months, high salinity was recorded due to the high evaporation rates compared with low-evaporation winter months (Randazzo et al. 1998). One of the most earliest studies on Lake Manzala carried out by Montasir (1937) reported that until the seventh century, three of the defunct Nile River branches traversed the lake before terminating at the Mediterranean Sea. After the closure of the Aswan High Dam, freshwater enters the lake only from agricultural drains. The result of these inputs and output patterns of water exhibited a spatial and temporal salinity variation throughout the lake, which might interpret why water salinity in the lake is not homogenous. Wahby et al. (1972) classified the lake water salinity into three regions: northern (2,900 ppm in October–10,000 ppm in July), eastern (680 ppm in December–2,000 ppm in July), and a western (1,210 ppm in December–3,120 ppm in August). The low salinity along the southern and western parts is attributed to the inflow of the agricultural wastewater, which dilutes water salinity and favors the flourishing of freshwater aquatic vegetation along these regions. Later studies on the water quality report that there is severe

pollution either in water or in sediments (Siegel et al. 1994; ElKammar et al. 1999). Although the Lake Manzala has been starved for its natural sediment supply from the Nile River due to the construction of the Aswan High Dam, the rates were increased again by the end of the twentieth century. Gu et al. (2011) reported that sedimentation rates were as high as 0.51 cm/year before 1960s and dropped to 0.2 cm/year after the dam construction, then the rates increased again to 0.4–0.7 cm/year since 1980s. Benninger et al. (1998) also reported that sedimentation rates increased from 0.7 to 1.2 cm/year. All these studies attributed this siltation to the human intervention into the lake environment, such as drying for agricultural and highway construction, and to the discharge of agricultural wastewater that carries sediments and nutrients from farmlands toward the lake. By the time, the lake was shrinking as it became a sink of sediments (Randazzo et al. 1998).

The lake Manzala has witnessed alteration of its aquatic vegetation composition as a consequence of the change in the hydraulic regime of the Nile, and the conversion from annual to perennial irrigation system in late 1960s and constructing numerous irrigation and drainage canals. As mentioned earlier, the salinity of the lake has decreased drastically due to the dilution by the freshwater from agricultural drainage (Reinhardt et al. 2001), which lead to the decline of salt-marsh vegetation in the lake as proved by the pollen analysis (Peglar et al. 2001). On the other hand, Bernhardt et al. (2011) observed significant increases in freshwater vegetation pollens, such as *Typha* and *Phragmites* species since the early 1970s. Figure (1) shows clearly the lake in 1972, just after operating the High Dam, with low aquatic vegetation coverage compared with the situation in 2013, where aquatic vegetation occupies the majority of the lake area, which supports the previous findings of Bernhardt et al. (2011). In addition, the EVI distribution (Fig. 2c) highlights clearly that the aquatic

vegetation is most abundant at the terminals of agricultural drains along the lake body. Moreover, the average trend of the aquatic vegetation area between 2003 and 2013 reveals an increasing pattern of greenness throughout the lake, which may compete for water in the lake that may evacuate the lake from water.

Drying is a substantial factor for lake shrinking. The southern side of the lake was the target of a national reclamation project planned to reclaim about 0.6 million acres south of the lake and extends to north Sinai. There, significant sectors of the lake have been dried up and were converted to agricultural areas. Water was secured by building a huge canal, El-Salam (peace) Canal, running parallel to the southern boundary of the lake and transport fresh water from the Nile mixed with drainage water in a 1:1 ratio and passes under the Suez Canal to Sinai. Drying of the lake has eventually shrunk the area to attain its least value ever as estimated from this study (385 km<sup>2</sup> in May 2013). Vegetation change reveals that the locations of drain mouths within the lake experienced excess greenness (high EVI values) (Fig. 2c), except the famous Bar El-Baqar drain (#5 in Fig. 2c), which conveys as much as 50 % of the total drainage into the lake. This is attributed to the nature of the water in this drain, which is rich in metals from industrial wastes coming from Greater Cairo governorates (Siegel et al. 1994). The other drains carry mostly agricultural drainage rich in nutrients, which resulted in thriving vegetation status of the lake.

The construction of the Aswan High Dam not only prevented natural fluvial sediments from reaching the Lake Manzala, but it also deprived these sediments from their access to the Mediterranean Sea coast, that lead to an accelerated erosion of the entire Nile Delta coast. The sand bar, which is a part of the Nile Delta coast and survives the existence of the Lake Manzala (Dumont and El-Shabrawy 2007) was influenced by the coastal erosion since early 1970s (Frihy et al. 1998; El-Asmar and Hereher 2011). In addition, this bar is severely vulnerable to sea level rise due to its low level, sedimentary nature and high erosion rates (Hereher 2013b). Comparing the area of this bar in very old and very recent satellite images (Fig. 3) reveals that erosion predominates to accretion and about 6 km<sup>2</sup> of this narrow sand bar has been lost to seawater. Most erosion occurred at the western side of the bar, which is closer to the Nile River, whereas, areas witnessed accretion occur mostly at the eastern side near the Suez Canal. In addition to the coastal erosion of the sand bar, the Lake Manzala is experiencing tectonic subsidence of the sediment column beneath its floor by an annual rate of 5 mm (Stanley 1988).

There is an important concern regarding the existence of the Lake Manzala in the near future. However, the coastal zone of the lake is under extensive industrial use by gas companies. It is now obvious that the lake is under the

influence of two significant forces working against each other. (1) A natural process incorporating the removal of the coastal sand bar that separates the lake from the sea by erosion. This force is triggered by an accelerated subsidence of the sediment column beneath the lake floor. If this force predominates, the lake will lose its sand bar and eventually will transform to a coastal embayment as the seawater will invade the northern frontier. Sea level rise can accelerate such process, particularly the area that has relatively a low topography. (2) An anthropogenic process including drying the lake and converting the swamp to agricultural landscape. This force of shrinking the water body is also activated by siltation caused by agricultural waste rich in sediments discharge into the lake. Augmentation of aquatic vegetation has a tremendous effect in losing lake water by transpiration. If the second force predominates, the lake will be fragmented and eventually converted to a dry land and will be dramatically lost; a same fate is reported to the nearby Burullus Lake (Dumont and El-Shabrawy (2007).

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## References

- Ahmed MH, El Leithy BM, Thompson JR, Flower RJ, Ramdani M, Ayache F, Hassan S (2009) Applications of remote sensing to site characterization and environmental change analysis of North African coastal lagoons. *Hydrobiol* 622:147–171
- Benninger LK, Suayah IB, Stanley DJ (1998) Manzala lagoon, Nile delta, Egypt: modern sediment accumulation base on radioactive tracers. *Environ Geol* 34(2/3):183–193
- Bernhardt C, Stanley D, Horton B (2011) Wetland vegetation in Manzala lagoon, Nile delta coast, Egypt: rapid responses of pollen to altered Nile hydrology and land use. *J Coastal Res* 27:731–737
- Dumont H, El-Shabrawy G (2007) Lake Burullus of the Nile Delta: a short history and an uncertain future. *Ambio* 36:677–682
- El-Asmar H, Hereher M (2011) Change detection of the coastal zone east of the Nile Delta using remote sensing. *Environ Earth Sci* 62(4):769–777
- ElKammar M, Eweida A, El Kashotti M (1999) Hydrogeochemistry and environmental assessment of Manzala Lake, Egypt. *Egypt J Geol* 43:237–252
- Flower RJ (2001) Change, stress, sustainability and aquatic ecosystem resilience in North African wetland lakes during the 20th Century: an introduction to integrated biodiversity studies within the CASSARINA Project. *Aquatic Ecol* 35:261–280
- Frihy O, Dewidar Kh, Nasr S, El Raey M (1998) Change detection of the northern Nile delta of Egypt: shoreline changes, Spit evolution, margin changes of Manzala lagoon and its islands. *Int J Remote Sens* 19:1901–1912
- Gu J, Chen Z, Salem A (2011) Post-Aswan dam sedimentation rate of lagoons of the Nile Delta, Egypt. *Environ Earth Sci* 64:1807–1813
- Hamza WP, Tamsalu ER, Zalensy V (2003) Physical and ecological 3D model of the Egyptian Mediterranean Sea. *J Aquatic Ecol* 37:307–324



- Hereher M (2011) Mapping coastal erosion at the Nile Delta western promontory using Landsat imagery. *Environ Earth Sci* 64: 1117–1125
- Hereher M (2013a) The status of Egypt's agricultural lands using MODIS Aqua data. *Egypt J Rem Sens Space Sci* 16:83–89
- Hereher M (2013b) Coastal vulnerability assessment of Egypt's Mediterranean coast. *Geomatics Natural Hazards Risk*. doi:10.1080/19475705.2013.845115
- Huete A, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Rem Sens Environ* 83:195–213
- Islam M, Thenkabail P, Kulawardhana R, Alankara R, Gunasinghe S, Edussriya C, Gunawardana A (2008) Semi-automated methods for mapping wetlands using Landsat ETM+ and SRTM data. *Int J Rem Sens* 29:7077–7106
- Jensen RJ (1995) *Introductory digital image processing*. Prentice Hall, Englewood Cliffs
- Kushwaha S, Dwivedi S, Rao B (2000) Evaluation of various digital image processing techniques for detection of coastal wetlands using ERS-1 SAR data. *Int J Rem Sens* 21:565–579
- MacAlister C, Mahaxay M (2009) Mapping wetlands in the Lower Mekong Basin for wetland resource and conservation management using Landsat ETM images and field survey data. *J Environ Manag* 90:2130–2137
- Montasir A (1937) *Ecology of Lake Manzala*. Bull Faculty of Science, the Egyptian University, Cairo, pp 1–50
- Ozesmi S, Bauer M (2002) Satellite remote sensing of wetlands. *Wetlands Ecol Manag* 10:381–402
- Pan F, Liao J, Li X, Guo H (2013) Application of the inundation area lake level rating curves constructed from SRTM DEM to receiving lake levels from satellite measured inundation area. *Comput Geosci* 52:168–176
- Peglar SM, Birks HH, Birks HJB, Appleby PG, Fathi AA, Flower RJ, Kraiem MM, Ramdani M (2001) Terrestrial pollen record of recent land-use changes around nine North African lakes in the CASSARINA Project. *Aquat Ecol* 35:431–448
- Randazzo G, Stanley D, Geronimo S, Amore C (1998) Human-induced sedimentological changes in Manzala Lagoon, Nile Delta, Egypt. *Environ Geol* 36:235–258
- Reinhardt EG, Stanley JD, Schwarz HP (2001) Human-induced desalinization of Manzala Lagoon, Nile Delta, Egypt: evidence from isotopic analysis of benthic invertebrates. *J Coastal Res* 17:431–442
- Rutchev K, Vilchek L (1999) Air photointerpretation and satellite imagery analysis techniques for mapping cattail coverage in a northern Everglades impoundment. *Photogram Engin Rem Sens* 65:185–191
- Shaheen AH, Yosef SF (1979) The effect of the cessation of Nile flood on the fishery of Lake Manzala, Egypt. *Archiv fur Hydrobiol* 85:166–191
- Siegel FR, Slaboda ML, Stanley JD (1994) Metal pollution loading, Manzalah Lagoon, Nile Delta, Egypt: implications for aquaculture. *Environ Geol* 23:89–98
- Stanley DJ (1988) Subsidence in the northern Nile Delta: rapid rates, possible causes and consequences. *Science* 240:497–500
- Stanley DJ, Warne AG (1994) Worldwide initiation of Holocene marine deltas by deceleration of sea-level rise. *Science* 265:228–231
- Tucker C (1979) Red and photographic infrared linear combination for monitoring green vegetation. *Remote Sens Environ* 8:127–150
- United Nations Educational, Scientific and Cultural Organization (UNESCO) (1979) *Map of the world distribution of arid regions: Map at scale 1:25,000,000 with explanatory note*. MAB Technical Notes 7, UNESCO, Paris
- Wardlow B, Egbert S (2010) A comparison of MODIS 250-m EVI and NDVI data for crop mapping: a case study for southwest Kansas. *Int J Rem Sens* 31:805–830
- Wahby SD, Youssef SF, Bishara NF (1972) Further studies on the hydrography and chemistry of lake Manzala. *Bull Inst Oceanogr Fish, ARE* 2:401–418
- Zahrán MA, Abu Ziada ME, El-Demerdash MA, Khedr AA (1989) A note on the vegetation on islands in Lake Manzala, Egypt. *Vegetatio* 85:83–88
- Zalat A, Vildary SS (2007) Environmental change in Northern Egyptian Delta lakes during the late Holocene, based on diatom analysis. *J Paleolimn* 37:273–299