Are the Egyptian Coastal Lakes Sustainable? A Comprehensive Review Based on Remote Sensing Approach

Mohamed Elsahabi, Abdelazim Negm, and M. A. Bek

Abstract Lakes play pivotal roles in the biological and environmental systems and prove several ecosystem facilities. Unfortunately, in Egypt, there are many factors which directly or indirectly threaten the ecological system of the Egyptian coastal lakes (lakes Mariout, Edku, Burullus, Manzala, and Bardawil). For example, reduction of water bodies, deterioration of water quality, eutrophication, and climate changes are among the present common challenges. These challenges may potentially act against the sustainability of the coastal lakes. The use of the remote sensing (RS) data offers a better perception of analyzing water bodies (water quality and lake ecology) by providing synoptic and spatiotemporal ideas to help in assessing their present conditions. Moreover, it will promote the lakes sustainability by implementing the needed measures. This chapter provides an updated review of the present literature that applied the remote sensing (RS) technique for monitoring and assessing the sustainability conditions of the Egyptian coastal lakes. It covers different areas such as extracting lake surface areas and their changes, examining lake bathymetry (levels), and monitoring lake water quality. Meanwhile, a review of the worldwide-related studies is presented. The present chapter concluded that most of the Egyptian coastal lakes are suffering from lack of sustainability. In addition, urgent actions from the concerning authorities should be taken shortly to maintain the sustainability of these lakes.

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1 Introduction

RS is the art and science of obtaining information about an object without physical contact [1]. The availability of time series of RS data is considered as the primary source that provides wealth information concerned with environmental monitoring, especially in lakes. The essential environmental functions of lakes are represented in providing habitat for a comprehensive range of species and forming crucial components in carbon, nutrient, and hydrological cycles [2]. Climate change effects, inorganic and organic contaminants, morphological alterations, morphological alterations, and eutrophication are considered the main factors that threaten the ecological function of lakes all over the entire globe [3, 4]. Improving the ecological state of inland water areas are supported by implementing frequent and consistent long-term monitoring approaches for these water bodies [5–8]. Recently, there are various spatial and radiometric resolutions offered by earth observation satellite sensors, such as ESA's Sentinel-2, NASA's Landsat 8, etc. The integration of RS into water research and monitoring is aimed to benefit from these variations in different research applications (i.e., [9–16]).

The potential offered by remote sensing is strongly demanded, where the capacity of in situ lakes monitoring is limited. Lakes have innate differences in function and geomorphology, and some have undergone significant spatiotemporal changes. RS provides a rich body of spatial and temporal data for monitoring these changes. Whether concerning lake area, volume, temperature, water quality status, etc., RS has shown to be an appropriate tool for lake monitoring. To indicate the role of RS for lake monitoring and research, this review study, therefore, provides an overview of RS applications for lake monitoring which is considered as a foundation for future innovation in lakes researches. In this context, an extensive review of the salient features of available literature on lakes using RS is presented. In the last section, the use of RS to monitor the environmental features of coastal lakes of northern Egypt will be discussed and reviewed to decide their sustainability based on RS.

2 Application of Remote Sensing on Lake

RS in general help in deriving information of a specific ground object, such as obtaining information on lake properties via analyzing the measured radiation by a remote sensor [17]. The radiation passes the water surface and propagates through the water body, or it is reflected at the water surface. For lake with deep water, information on the water surface and water properties can be obtained using RS data; as in this case, water surface and water body are considered the primary sources of radiation from a lake. In a lake with shallow water, information on bottom substrate and bathymetry can be derived; as in this case radiation has been reflected at the bottom [18]. The reflected radiations from lake water bodies are affected by scattering and atmospheric absorption through its way toward the satellite sensors. More than 90% of the signals obtained by an RS sensor originate from the atmosphere and the water surface together [19]. The remaining signals of less than 10% include the obtained signals from water surface only. For this, it is essential to remove the effect of the atmosphere accurately to get accurate information about the water bod [18]. According to the difference in the spectral characteristics between water and land features, it can be easy to place the water pixels alone in separated classes. The spectral signatures of the separated classes (for each pixel location) can be used when differentiating between turbid, clear, and shallow water classes. Moreover, based on these spectral signatures, vegetation cover, bottom bathymetry, and other effects of land can be estimated for the water pixels within the area of the lake [20].

Applications of RS in lake research and monitoring are divided into two main categories; the first category is related to lakes' water amount, and the other one is related to lakes' water properties. The first category contains studies that are interested in measuring lake area using RS data throughout visible and near-infrared (NIR) bands for lake boundaries delineation, thermal imagery for differentiating lake area from surrounding land, and active microwave sensors for detecting water surface changes in the presence of cloud cover. Moreover, this category includes studies concerned with examining lake bathymetry throughout: active altimetric (microwave) sensing, gravimetric sensing, and indicators of bathymetry. The second category reflects the use of RS for detecting the physical characteristics via the thermal observations for lake surface temperature. The results include the physical aspects related indicators (an indicator of temperature, ice phenology, and transparency). Also, it is possible to detect the biological properties throughout visible and NIR bands for monitoring macrophyte extents, microwave sensors for classification of lakes' vegetation cover, and visible wavelength images for trophic condition determination via measuring euphotic depth and chlorophyll-a. Few of the studies reviewed here concerned only with one of the above RS applications; most papers make use of a combination of two or more of these applications. For example, one that uses altimetric observations to estimate lake bathymetry changes might also use visible and NIR bands to detect the changes in the lake area.

2.1 Surface Water Area of Lakes

2.1.1 Lake Boundaries Delineation by Visible and NIR Bands

Visible and near-infrared (NIR) images are considered as one of the most straightforward and earliest applications of RS in lake monitoring to analyze the lake's extent changes. Most literature are concerned with detecting changes in lake boundaries by visible and NIR bands implemented on Africa lakes (i.e., [21–25]). Harrris [21] used the NIR band of AVHRR to estimate changes in the shoreline of Lake Abiyata, Ethiopia. Birkell [22] proposed an approach to map lake extension changes, in general, using the AVHRR's NIR Channel 2. He used a classification technique relying on a simple histogram technique of the digital number (DN) values to estimate changes in the lake extents. Bohme et al. [23] applied maximum likelihood classification (MLC) technique depending on visible and NIR bands from MSS, TM, ETM+, and ASTER satellite data to observe the annual changes in the area of Lake Urema, Mozambique, in the period 1979–2000. Ouma and Tateishi [24] developed a new water index (WI) and normalized difference water index (NDWI) by using visible and NIR bands from Landsat TM and ETM+ images to map shorelines changes in five lakes in Kenya in the period from 1986 to 2001. Also, Turada [25] used visible and NIR bands from the European Space Agency (ESA) satellite Envisat data, to detect changes in land cover classes (soil, vegetation, and water) in the Lake Chad basin.

2.1.2 Differentiating Lake Area from Surrounding Land by Thermal Imagery

Delineation of lake boundaries depends on the spectral differences between the lake water and its surrounding land area in the visible and NIR bands as indicated in the previous section. It is also possible to use thermal bands of the satellite images to achieve the same work. The main benefit of using thermal imagery is to work at night since the received electromagnetic radiation by the satellite sensor is emitted from the target and not reflected from the sun. Leblanc et al. [26] used Meteosat data (10.5–12.5 μm) to sense water under vegetative cover thermally during the period from 1986 to 2001. They reported that it was difficult to apply the thermal technique during the rainy season due to producing a signature that is similar to open water by the high-water content of non-lake areas.

2.1.3 Extraction of Lake Water Bodies Using RS Techniques

There are numerous water extraction methods have been applied in studies that concerned with lake water body extraction via using the RS satellite sensors. These methods are mainly depending on the electromagnetic (EM) spectrum covered by the sensors that include the shortwave infrared (SWIR), the thermal infrared (TIR), the long-wavelength infrared (LWIR), and the visible and near-infrared (NIR) bands. These methods involve an automatic extraction method to extract water area from high-resolution satellite image [27]: decision tree and programming method for extracting water areas within regions that affected by the flood [28]; the conceptual clustering approach [29]; the semiautomated change detection technique [30], the original entropy-based method [31]; the multivariate regression technique [32]; thematic classification, supervised and unsupervised classification techniques [33–35]; the unsupervised classification technique alone [36]; and single-band thresholding [37]. Furthermore, recently some popular spatial water indices were applied to discriminate between the water and land in multispectral satellite images [38–43]. Sundal et al. [44] applied a set of fuzzy logic membership functions which is considered as an automatic method to map lakes boundaries. To track lakes' changes, a semiautomatic approach was developed [45]. Liang et al. [46] proposed an automatic method for mapping lake and tracking its changes. Johansson and Brown et al. [47] applied the adaptive lake classification (ALC) method to identify the types of the changes in lakes and their surroundings.

2.1.4 Water Surface Area Changes Using RS

Temiz and Duduran [48] used multispectral Landsat images from the years of 1985, 2000, and 2015 to detect the coastline change of Acıgöl Lake, Turkey, with the help of geographic information systems (GIS). The results showed that there was a significant decrease in Acıgöl Lake in between 1985 and 2000. At the end of their study, they detected significant coastline movements for a period of 30 years. Feyisa et al. [40] mapped the change in the water surface area of the Vembanad Lake, India, by using four Landsat satellite images acquired between 1973 and 2015. They applied the normalized difference water index (NDWI) and modified normalized difference water index (MNDWI) to estimate the water area changes inside the lake. The results showed that the total decrease in the estuarine area was about 6.93% during the study period. Jeihouni et al. [49] in their study depended on time series images from Landsat satellites, GIS, 3D modeling, and water level field measurements to assess and monitor Urmia Lake, Iran, status over a period from 1984 to 2014. The results indicated that during the study period, about 86% of the lake became a salt desert, and the volume of the lake water decreased by about 99.17% in the period from 1998 to 2013. Sultan et al. [50] detected the changes in the area of Lake Malaha, Egypt, which is considered one of the most important fisheries resources along the northern coast of Egypt by utilizing a set of Landsat ETM+

and OLI/TIRS images acquired in 2005, 2010, 2015, 2016, and 2017. The results of their study showed the area of the lake decreased by about 11.7 km^2 within 12 years from 2005 to 2015. Acharya et al. [51] applied three spatial water indices to detect the change of lakes in Pokhara city, Nepal, utilizing Landsat data of 25 years' gap from 1988 to 2013. Normalized difference water index (NDWI), modified NDWI (MNDWI), and normalized difference vegetation index (NDVI) were used to extract the water surface areas from Landsat data and to detect the changes in the extracted water surfaces. The results showed that there was an increase in the areas of Rupa and Dipang Lakes, whereas the water area of Lake Phewa decreased. The results also indicated that Began Lake suffered from few changes. They highlighted that the obtained results considered helpful tools to reclaim and restore the area of lakes under investigations, consequently to maintain and preserve the wetland ecosystem in Pokhara city. Xie et al. [52] proposed an unsupervised water extraction method based on the Operational Land Imager (OLI) imagery (Landsat 8). Darwish et al. [53] estimated the geomorphologic changes along the coastline of Nile Delta, Egypt, in between 1945 and 2015. They used Landsat satellite images obtained between 1973 and 2015 and old topographic maps generated in 1945 by the Egyptian Geological Survey. The results showed that there was a significant change along the coastline (erosion) during this period, particularly at Rosetta and Damietta promontories. El-Hattab [54] used the post-classification approach of RS satellite images, during the period from 2004 to 2013, for assessing and detecting land cover changes within Abu Qir Bay zone, Egypt. The results showed that the rates of change increased dramatically during the study. Also, the results indicated that rapid urbanization was observed along the coastline of Abu Qir Bay accompanied with a rapid decrease in the water area of this bay.

2.2 Bathymetry of Lakes

2.2.1 Bathymetry Detection by Active Altimetric Sensing

Developing online databases that process the obtained raw data from various sensors fostered the use of altimetric data obtained by the active altimetric sensing. The main ones are divided into three altimetry websites [55]. The first one is the US Department of Agriculture (USDA) website [56] that uses data obtained from TOPEX/Poseidon, Envisat, Jason-1, Jason-2, and GFO. The second one is the ESA's River and Lake website (ESA) [57] that uses data from Envisat, Jason-1, and Jason-2. The third is the Laboratoire d'Etude en Géophysique et Océanographie Spatiale (LEGOS) website [58] that uses data from the European Remote Sensing 1 and 2 (ERS-1 and ERS-2), satellites Envisat, Jason-1, Jason-2, Geosat Follow-On (GFO), and TOPEX/Poseidon. Munyaneza et al. [59] monitored the water level of Lake Kivu, Congo, by using ERS-2 and Envisat from ESA website. Velpuri [60] validated the hydrological models for Lake Turkana, Kenya, by using Envisat, Jason-1, and TOPEX/Poseidon from the USDA website.

2.2.2 Lake Bathymetry Indicators

RS is a valuable method to derive water levels (water depths or bathymetry) by applying empirical detection methods of bathymetry. Empirical estimation of bathymetry utilizing multispectral satellite data with high spatial resolution is considered an appropriate method in areas with homogenous water characteristics (e.g., [61, 62]). Mohamed et al. [63] used data from Landsat 8 and Spot 6 satellite images to evaluate the performance of three proposed empirical models for bathymetry derivation in three different areas: Lake Nubia entrance zone, Sudan; Shiraho, Ishigaki Island, Japan; and Alexandria port, Egypt. The results of the applied models to obtain bathymetric maps from the reflectance of red, green, green/red, and blue/red band ratios showed that applying the bagging algorithm was the most accurate method for bathymetry estimation. Mohamed et al. [64] used SPOT-6 imagery to detect bathymetric information at the entrance of Lake Nasser/Nubia. They applied the least square boosting (LSB) and the bagging algorithms for bathymetry detection. The results showed that the bagging approach was the accurate approach for detecting depths of up to 6.5 m within the shallow water.

2.3 Water Quality by RS

In recent years, RS techniques are widely used in monitoring water quality due to the low cost of satellite data and its capability of covering remote and large areas with a spectral, spatial, and temporal resolution [65, 66]. Nas et al. [65] and Alparslan et al. [67] indicated that for analyzing the water quality from RS data, empirical relationships could be established between the in situ measurements of water quality and Landsat reflectance values. Vignolo et al. [68] correlated Landsat 7 ETM+ with the water quality index of surface water. Most of the studies concerned with monitoring the water quality of lakes via RS data used various spectral bands (single band, band ratio, and band combinations) as independent variables when building models for predicting water quality parameters. Recently, RS is integrated with GIS in water quality studies [69].

3 Egyptian Coastal Lakes

Survey of the literature on the applications of RS to the Egyptian northern coastal lakes indicates that there is a wide range of lakes' aspects that were investigated such as bathymetry, water properties and quality, environmental conditions, and water surface area of the lakes. This means that an extensive survey of the available published articles should lead to a conclusion about the conditions of sustainability of the Egyptian coastal lakes. Consequently, through this section, we will present and discuss the findings of related studies which utilized the satellite RS data from various sensors, such as the Systeme Pour l'Observation de la Terre (SPOT), Enhanced Thematic Mapper Plus (ETM+), Multispectral Scanner (MSS), Thematic Mapper (TM), etc. In this context, analyses of area, bathymetry, and water quality of the lakes under investigation throughout RS data are discussed within the available literature.

3.1 Lake Mariout

Considering Lake Mariout, there are few studies concerned with monitoring of this lake using RS data (i.e., [70, 71]). El-Hattab [70] used three Landsat images of 1991, 2004, and 2013 and one scene of the SPOT-HRV image acquired in 1995 to detect changes that occurred in Lake Mariout. He classified the images using maximum likelihood classification (MLC) algorithm for change detection. The results showed that in the last few years, severe land cover changes occurred in different land cover classes of the lake basin due to political and socioeconomic problems. Also, Ahmed and Barale [71] used a series of Landsat MSS, Landsat TM, SPOT HRV, and EgyptSat-1 acquired in 1972, 1985, 1999, and 2007, respectively, to monitor changes in the water surface shape and extension of Lake Mariout. Changes in the lake basin surface, over the last four decades, were quantified utilizing GIS as presented in Fig. 1 [71].

This plot indicates that there is a decrease in the water surface area of the lake. They concluded that the reduction in the water surface area of Lake Mariout was occurred due to the growth of urban areas. This indicates that the water body of the lake is not sustainable and actions should be taken to maintain the lake water body.

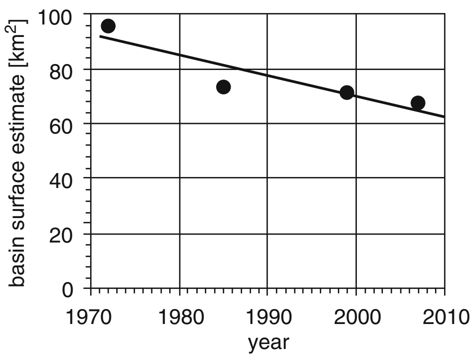

Fig. 1 Estimated Lake Mariout total basin surface area and their changes from MSS (1972), TM (1985), Spot (1999), and EgyptSat-1 (2007) data after [71]

3.2 Lake Edku

There are few studies regarding the monitoring of Lake Edku using RS data (i.e., [71, 72]).

Ahmed and Barale [71] estimated the changes occurred within Lake Edku during the period from 2003 to 2009 using SPOT HRG images. The quantitative results are represented in Fig. 2 [71], which represents the land cover classes within the lake basin. This figure indicates that the water surface area decreased from about 62.12 km^2 in 2003 to 61.06 km^2 in 2009, while the lake area that covered by floating and submerged vegetation increased from 38.82 km^2 in 2003 to 40.04 km^2 in 2009. Also, the sites of aquaculture increased from 59.17 km^2 in 2003 to 65.98 km^2 in 2009. Also, the figure shows that a part of the lake area was replaced by fish farms within the same period.

Hossen and Negm [72] monitored changes in Edku Lake to assess the water body sustainability. To achieve the change detection process, they applied the maximum likelihood supervised classification to subsets of the Landsat TM, ETM+, and OLI/TIRS images acquired in 1984, 1990, 1998, 2003, and 2015. The results indicated that water bodies of the lake decreased by 25.33% in the period from 1984 to 2015, while there was an increase in the floating vegetation area by 108.65% in the same period. They concluded that the increase of the floating vegetation and reclamation of a large area for cultivation purposes are the main reasons for the decrease in water body of Edku Lake.

3.3 Lake Burullus

There are many studies concerned with monitoring of this lake using RS data (i.e., [71, 73–78]).

Ahmed and Barale [71] presented the changes occurred in Lake Burullus from 1984 to 1997 and 2000 utilizing a series of Landsat TM images. They detected the

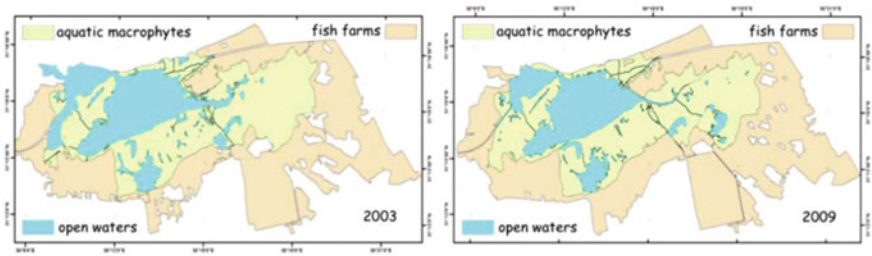

Fig. 2 Mapping of Lake Edku and surrounding area, based on 2003 (left panel) and 2009 (right panel) SPOT data after [71]

changes in the lake via the classified satellite images shown in Fig. 3 [71]. Their results indicated that most of the substantial changes in the lake occurred due to barrier erosion, rising sea level, and inlet siltation.

EL-Zeiny and El-Kafrawy [73] detected the most vulnerable areas for water pollution within Lake Burullus using Landsat OLI image acquired in 2015. Results indicated that there are multiple sources for pollution. They concluded that using of RS in water quality studies help in lakes assessment and management with a cheaper and easier manner than traditional methods.

El-Kafrawy et al. [74] used RS data, represented in Landsat ETM+ image acquired in 2014, and a geographic information system (GIS) for monitoring water quality of Lake Burullus. They generated maps for surface water quality conditions of the lake based on the correlation between reflectance values of the ETM+ image and the measured water quality parameters. The results showed that in the eastern and southern parts of the lake suffer from deterioration in the water quality more than the other parts, due to the discharged wastewater and polluted drainage water into these parts. In general, they confirmed that the integration of RS with GIS is considered an appropriate approach for water quality mapping.

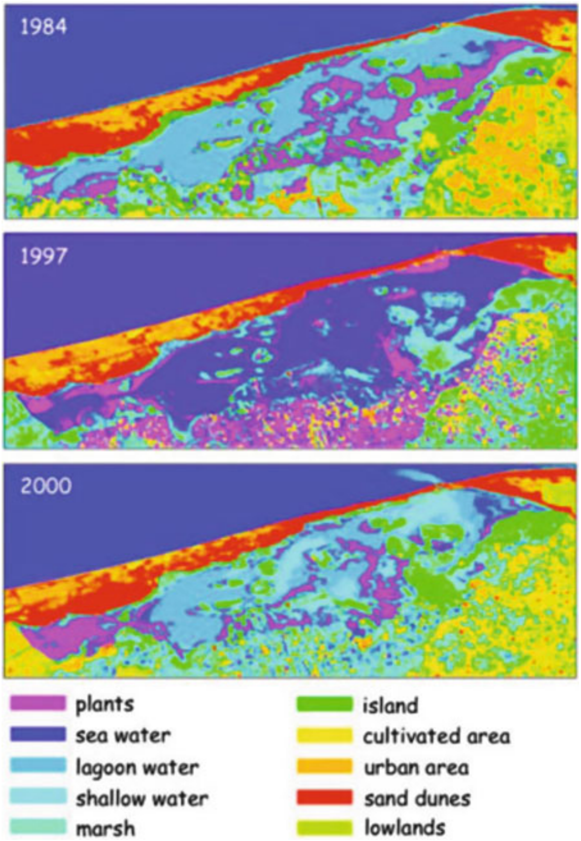

Fig. 3 The classified Landsat TM images of Lake Burullus and surrounding area for the period from 1984 to 2000 [71]

Dewidar and Khedr [75] utilized a combination of field data measurements and Thematic Mapper (TM) data in 2004 to map the depth, salinity, sand, and sediment in the Lake Burullus.

Hossen and Negm [76] monitored the changes in Lake Burullus by applying the maximum likelihood supervised classification technique to subsets of Landsat TM, ETM+, and OLI/TIRS images captured in 1984, 1990, 1998, 2003, and 2015. Their results showed that there was a decrease in water bodies of the lake by 44.97% during the period from 1984 to 2015, while there was an increase in the floating vegetation area by the same amount during the same period. They reported that results of their study should help the decision-makers to take the necessary measures to sustain the water area of the lake against further reduction.

Mohsen et al. [77] used 12 Landsat {(1,3-MSS), (4,5-TM), and (7-ETM+)} images in addition to water indices approach to monitor the spatiotemporal changes within Lake Burullus in the period from 1972 to 2015. They applied the water ratio index (WRI) and the normalized difference water index (NDWI) to extract water area from the satellite images. The authors concluded that there was a significant decrease in water surface area of the lake by about 49% during the period under consideration. This finding is with a good agreement with [76].

Negm et al. [78] used four approaches from the most popular bathymetry detection approaches to be applied in Lake El-Burullus using SPOT-4 satellite image. The corrected satellite image bands from atmospheric and sun glint systematic errors, which effect on the accuracy of bathymetry detection, were used within the four approaches.

3.4 Lake Manzala

There are many studies concerned with monitoring of Lake Manzala using RS data (i.e., [71, 79–83]). Ahmed and Barale [71] used a group of Landsat MSS, TM, and ETM + images, captured in 1973, 1978, 1983, 1987, 1990, 2000, and 2003, to examine the changes of Lake Manzala. Their results indicated that there was a decrease in the total area of this lake by more than 50% in the period from the year 1973 to 2003 as shown in Fig. 4 [71].

They also analyzed the 1987 and 2000 TM images of the lake to assess the lost in lake area due to land reclamation for agricultural purposes. They pointed that this loss in the lake surface area was about 100.73 km^2 between the year 1987 and 2000. Also, they indicated that the rate of land reclamation was about 7.75 km^2 per year within this study period. Also, El-Asmer and Hereher [79] utilized a set of four satellite images from the Systeme Pour l'Observation de la Terre (SPOT), Thematic Mapper (TM), and Multispectral Scanner (MSS) sensors for estimating the spatiotemporal changes that occurred in Lake Manzala between 1973 and 2007. Results showed that the Lake Manzala water surface area was reduced by about 34.5% within this period. Additionally, Ahmed et al. [80] used six Landsat images for Lake Manzala, including three Landsat MSS images of years 1973, 1978, and 1983, two

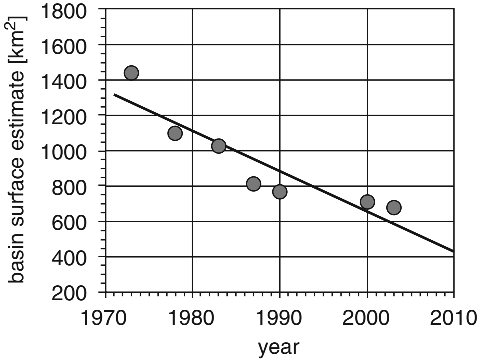

Fig. 4 Cumulative percent decrease of total Lake Manzala area in the period 1973–2003 after [71]

Landsat TM images of years 1987 and 1990, and a Landsat ETM+ image of the year 2003 to monitor changes within this lake from the year 1973 to the year 2003. These changes are indicated in Fig. 5 [80], which shows the classified images of Lake Manzala into three land cover classes of vegetation, land, and water. According to these classified images, there was a decrease by 50% in the total lake area from the year 1973 to the year 2003. The significant change occurred in the areas of open water and emergent vegetation. However, the proportion of vegetation, concerning the total lake area, has the same over the period 1973–2003. Also, the percentages of both land and water have remained relatively stable in the same period.

Ahmed et al. [81] estimated the ecological changes in the Lake Manzala, particularly in aquatic vegetation type and cover, as well as in open water areas during the past two decades over the period 1973–2003 by using a combination of Landsat MSS, TM, and ETM+ data. They analyze these changes to evaluate the human activities effects on the lake. To detect the changes within the lake, they applied some of image processing techniques such as unsupervised classification and enhancement. Their results indicate that there were numerous biological and physical changes occurred within Lake Manzala due to the different human activities, which threaten its quality and its ecological parameters. The main objective of this research was to use remote sensing techniques to measure the spatial distribution of aquatic and marginal vegetation and open water areas in Lake Manzala. Also, they indicated that there was a decrease in the total area of the lake by about 50% from 1973 until 2003. Also, Donia [82] analyzed GeoEye satellite (Google Earth) images to estimate the long-term changes in the physical characteristics of the lagoon during the period from the year 2002 to 2012. The results indicated that there was an annual decrease in the overall size of the lake by the rate of 200,000 square meters. The most changes within the lake are represented in decreasing the water area due to landfill. The lake water area changes were detected by delineating the changes in the lake boundaries using on-screen digitizing.

Negm and Hossen [83] estimated the changes in Lake Manzala during the period from 1984 to 2015 by applying the maximum likelihood supervised classification to a group of the Landsat TM, ETM+, and OLI/TIRS images. The results show that there was a decrease in water bodies of Lake Manzala by 57.06%, while there was an

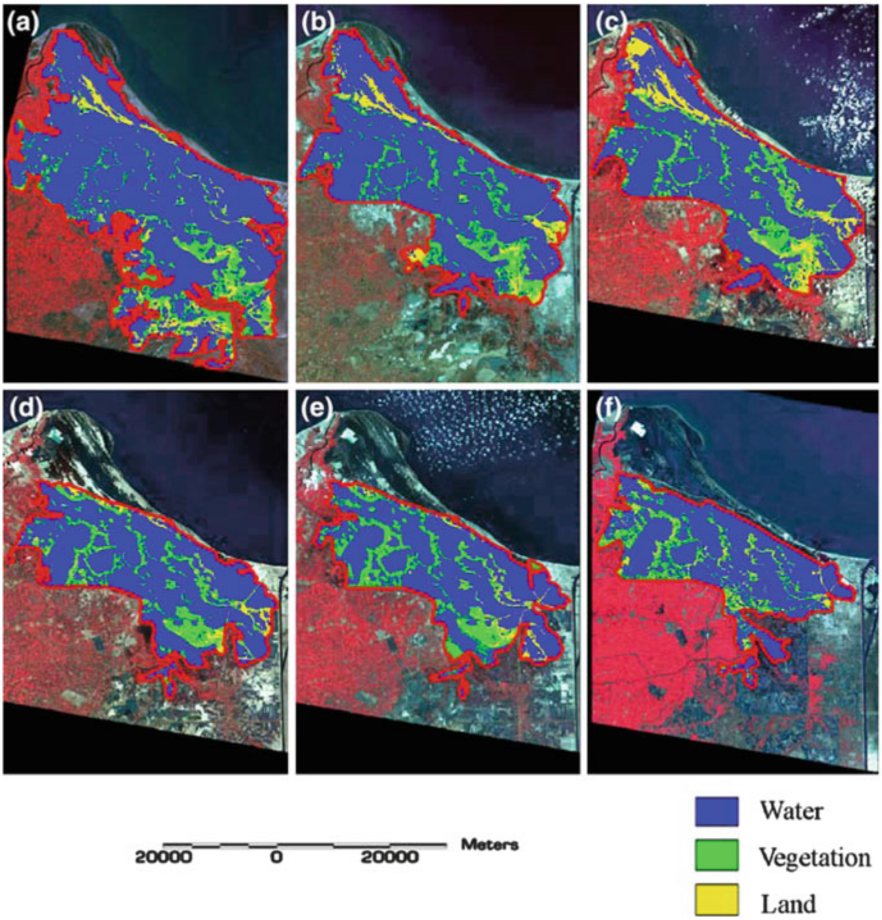

Fig. 5 The classified RS images of Lake Manzala: (**a**) image of 1973; (**b**) image of 1978; (**c**) image of 1983; (**d**) image of 1987; (**e**) image of 1990; (**f**) image of 2003 [80]

increase in the floating vegetation and island by the same amount during the period under investigation. They concluded that the free water body of the lake would disappear by the year 2040 if the increase in the floating vegetation is continued. Also, in this case, actions are needed to maintain the lake water body.

3.5 Lake Bardawil

The most previous studies are concerned with traditional methods in studying water properties of this lake (i.e., [84–88]). Nevertheless, there are few studies that deal with monitoring of Bardawil lake using RS data (i.e., [71, 89, 90]).

Ahmed and Brale [71] monitored the characteristics of both water surface and land around Lake Bardawil utilizing a series of Landsat TM images, collected in 1993, 1996, and 2000.

They used the 1996 image for geo-referencing the other satellite images, while they used the 1993 and 2000 images to detect changes in lake size. The derived change map between 1993 and 2000 is shown in Fig. 6 [71].

The results indicated that the size of the lake was decreased with an annual rate of 0.71 km^2 within the period from 1993 to 2000. Additionally, Khalil et al. [89] used a combination of in situ water measurements and Landsat 8 Operational Land Imager (OLI) data to derive the water quality indicators of Lake Bardawil to sustain its management. They proved the usefulness of Landsat 8 data in quantifying water quality dynamics. They concluded that the applied methods in their study for retrieval of water quality indicators from Landsat 8 could frequently be applied for sustainable water quality monitoring of Bardawil lake. On the other hand, Embabi and Moawad [90] proposed a semiautomated method for mapping the geomorphological forms within Lake Bardawil and its surrounding areas utilizing RS and GIS techniques. To achieve their aim, Landsat ETM+ data and fieldwork were integrated with the aid of GPS device to map the morphological forms, estimate bathymetry, and reveal the sediment movements into this lake.

4 Conclusions

To investigate the sustainability of the coastal lakes, the current chapter presents a comprehensive review of the published literature on monitoring of lakes with a special attention of the coastal lakes in Egypt. The covered areas include water surface area extraction, bathymetry detection, and water quality of the lake. The technique used for monitoring was basically the remote sensing because the RS data become an essential source of many ways for monitoring vast water bodies including the lakes.

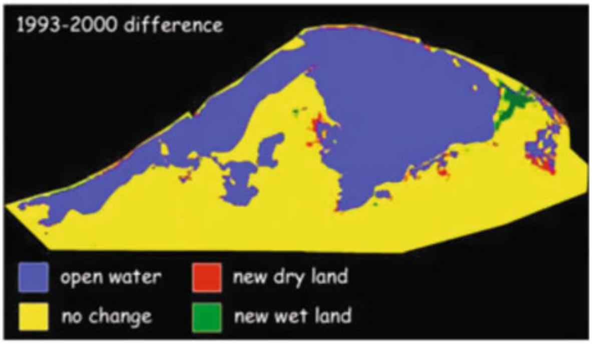

Fig. 6 Map of changes of Lake Bardawil derived from Landsat TM (1993, 2000) data after [71]

To sum up, monitoring the Egyptian coastal lakes using RS showed that most of the Egyptian coastal lakes are suffering from a remarkable reduction in water surface area, increasing quantities of agricultural drainage, massive amount of anthropogenic damages, eutrophication and pollution, land reclamation, urban encroachment, waste dumping, loss of biodiversity, and aquaculture challenges, and even recreational uses are reduced. Most of these environmental challenges are directly or indirectly connected to the exponentially expand of the local population and the loose applications of the law and the related environmental regulations. Consequently, they continue to threaten the sustainability conditions and the usefulness of these lakes as a source of the national income.

5 Recommendations

- To improve the water quality of the Egyptian coastal lakes, regular monitoring of these water bodies using both field visits and RS technique is an entire crucial issue.
- The Egyptian authorities should enforce the applications of the law and the concerned regulation associated with the protection and development of the coastal lakes in Egypt. Fortunately, Egypt stated to implement several measures to improve the lake's environment and to increase its overall usefulness to the society and its fish productively as well.

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