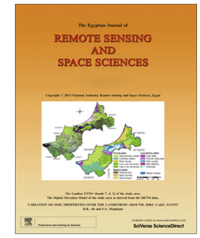
The Egyptian Journal of Remote Sensing and Space Sciences (2013) **16**, 119–123

National Authority for Remote Sensing and Space Sciences

The Egyptian Journal of Remote Sensing and Space Sciences

www.elsevier.com/locate/ejrs
www.sciencedirect.com



RESEARCH PAPER

Surface area change detection of the Burullus Lagoon, North of the Nile Delta, Egypt, using water indices: A remote sensing approach

Hesham M. El-Asmar [a], **Mohamed E. Hereher** [a], **Sameh B. El Kafrawy** [b,*]

[a] *Department of Geology, Department of Environmental Sciences, Faculty of Science, Damietta University, Egypt*
[b] *Department of Marine Sciences, National Authority for Remote Sensing and Space Science (NARSS), Cairo, Egypt*

Received 2 January 2013; revised 17 April 2013; accepted 19 April 2013
Available online 28 May 2013

KEYWORDS

Water Indices;
Burullus Lagoon;
Remote Sensing;
Nile Delta

Abstract The Burullus Lagoon is one of the most severely impacted water bodies in the Nile Delta. A set of six satellite images acquired between 1973 and 2011 was employed to map the change of the surface area of the Burullus Lagoon in the Nile Delta using the water indices approach. In this paper we applied the non-traditional normalized difference water index (NDWI) and the modified normalized difference water index (MNDWI) to quantify the change in the water body area of the lagoon during the study period. Results showed that the lagoon lost 42.8% of its open water area due to the severe anthropogenic activities, such as the reclaiming of its southern margins for agricultural purposes and the filling caused by the discharge of agricultural wastes. Proper management should be adopted to sustain the vitality of the Burullus wetland ecosystem.

1. Introduction

Great concern about changes in the size and quality of many of the world's wetlands has arisen mainly as a result of increased urbanization and agricultural development (Haack, 1996). Wetlands are typically regions of shallow standing water that support abundance of aquatic plants and animals, especially birds and fish (Ramsar, 2006). Wetlands are believed to play a considerable role in the global climate change by acting as a source of atmospheric greenhouse gases such as methane and a sink for carbon and nitrogen (Jansson et al., 1994). A key aspect of wetland management includes mapping and monitoring so that public managers and decision makers can be provided with reliable and relevant information.

The delineation of coastal wetlands using remote sensing is an ongoing research pursuit due partly to the availability of satellite data in different spatial, temporal and spectral resolutions and partly to the diversity of image processing tools and techniques. Satellite remote sensing can be appropriate

* Corresponding author. Tel.: +20 1003070074.
E-mail addresses: s_elkafrawy@yahoo.com, sameh@narss.sci.eg (S.B. El Kafrawy).

Peer review under responsibility of National Authority for Remote Sensing and Space Sciences.

ELSEVIER Production and hosting by Elsevier

1110-9823 © 2013 Production and hosting by Elsevier B.V. on behalf of National Authority for Remote Sensing and Space Sciences.
http://dx.doi.org/10.1016/j.ejrs.2013.04.004

for wetland mapping and monitoring in developing countries where funds are limited and information on wetland areas, surrounding land uses, and wetland losses over time are not available (Ozesmi and Bauer, 2002). Generally, the near infrared (NIR) and the middle infrared (MIR) bands are of high potential for detecting water bodies (Lillesand and Kiefer, 1994) and, therefore, would be useful in wetland detection and monitoring. Beyond classical digitization of the water body's boundaries, there are many other techniques used to delineate the peripheries of wetland systems. Image classification, principal component analysis (PCA), tasseled cap (TC) transformation, normalized difference water index (NDWI) and analysis of digital elevation models are examples. An unsupervised classification technique was applied to a series of Landsat images between 1973 and 2003 to explore changes in the Manzala Lagoon area in Egypt (Ahmed et al., 2009). Guirguis et al. (1996) applied a standardized and a non-standardized principal component analysis to highlight changes that occurred to the Burullus Lagoon (the lagoon under investigation) using Multi Spectral Scanner (MSS) images covering the periods 1983, 1985 and 1991. They observed that the standardized PCA could emphasize the changes that arose at this lagoon effectively. (Ouma and Tateishi, 2006) utilized the wetness component of the TC transformation compiled with water indices to map the boundaries of five African lakes in Kenya. El-Asmar and Hereher (2011) were the first to introduce the water index approach for mapping the surface area change of the coastal lakes of Egypt. They concluded that water indices are much accurate for mapping shallow and turbid coastal lagoons. In this study the Burullus lagoon was investigated and built upon earlier work.

The NDWI was introduced by McFeeters (1996) to delineate the surface water body depending on the normalized relationship between the reflection in the green and the near infrared (NIR) portions of the spectrum [NDWI = (Green – NIR)/(Green + NIR)]. This index was applied successfully using Landsat data to mark out the change of the surface area of the Lake Manzala, Egypt (El-Asmar and Hereher, 2011). Xu (2006) substituted the reflectance in the near infrared by the reflectance in the middle infrared (MIR) and suggested a modified NDWI termed as the modified normalized difference water index [MNDWI = (Green – MIR)/(Green + MIR)]. Xu (2006) observed that the MNDWI is more accurate in delineating wetland boundary than the NDWI because the former could eliminate the noise pixels representing the urban landscape occurring in the background of wetlands. The main objective of the present study is to estimate the surface area change of the Burullus Lagoon, Egypt in the past four decades using water indices as obtained from Landsat satellite images.

2. Materials and Methods

2.1. The study area

The Burullus Lagoon (also known as Lake Burullus) along the deltaic Mediterranean coast of Egypt is one of the largest Egyptian coastal wetlands located in the Nile Delta between the two Nile River branches: Damietta and Rosetta (Fig. 1). Its importance arises not only from its fishing resources but also from being a habitat for domestic fauna and a route for wintering migratory birds. The Burullus lagoon is one of the sites of the International Conventions on Wetlands (known as Ramsar) and was declared as a national protected area in 1998 (Shaltout and Al-Sodany, 2008). The lagoon is separated from the Mediterranean Sea by a narrow sandy bar covered by sand dunes, sabkhas and sand flats. The only connection with the sea occurs through a narrow strait (~250 m) at its northeast section making the northern part of the lagoon of much saline water than the rest of the water body (Hereher et al., 2011). In addition, there are six drains collecting agricultural and municipal wastes and pouring them into the lagoon. Water salinity at the southern part is mainly brackish (~2000 ppm) due to mixing of the fresh water from

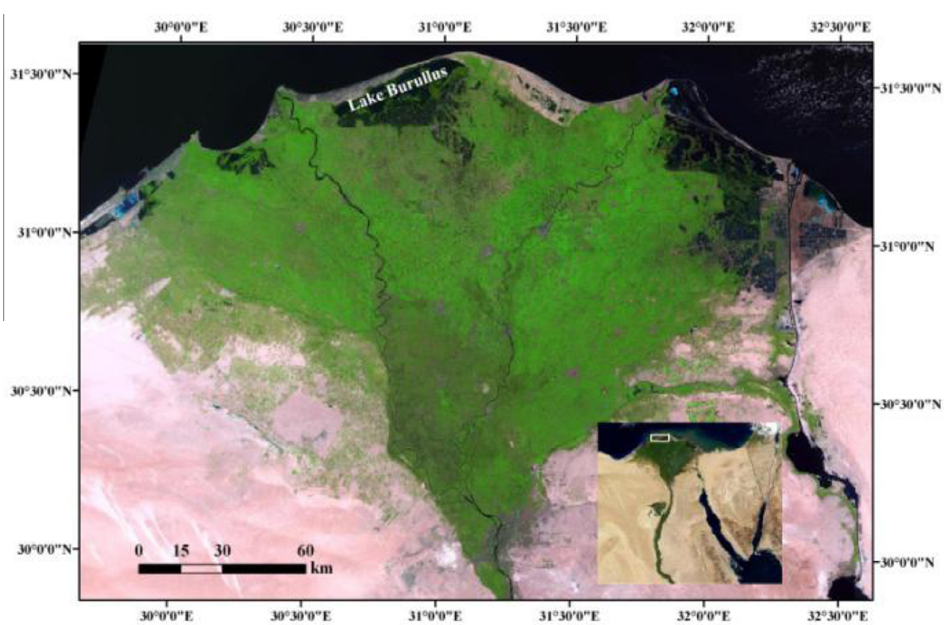


Figure 1 A Landsat image of the Nile Delta (2003) showing the location of Lake Burullus.

Table 1 Satellite data used in the present study.

	Sensor	Path/row	Date	Resolution (m)
1	MSS	190/38	May 1973	60
2	TM	177/38	September 1984	30
3	TM	177/38	August 1990	30
4	TM	177/38	February 1999	30
5	ETM +	177/38	March 2005	30
6	Spot + 4	110 K/186 J	July 2011	20

agricultural drainage with saline water. The southern sector of the lake contains reed swamp vegetation, mainly *Phragmites australis* and *Juncus* spp. This sector has witnessed drying for agricultural expansion. The lagoon is generally shallow, where water depth ranges from 0.5 to 1.5 m for the majority of the lagoon. Climate conditions prevailing at this coastal part is generally arid, where annual precipitation does not exceed 200 mm. Northwestern winds is most frequent throughout the year.

2.2. Satellite data

Six satellite images are used in this study. Table 1 shows the sensor type, its resolution and the date of image acquisition.

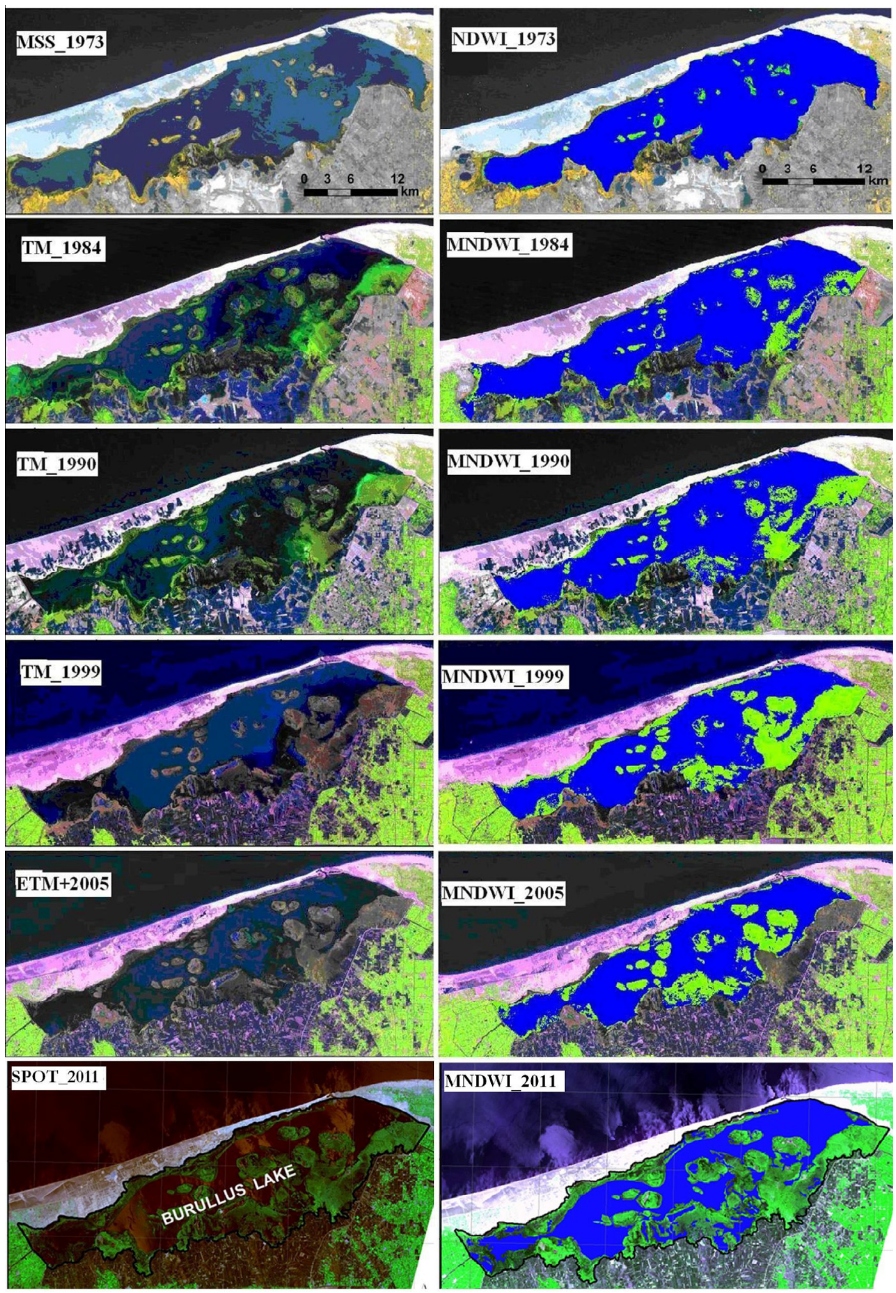


Figure 2 The left column shows the Lake Burullus as appears in six raw MSS, TM, ETM + and SPOT images. Black color refers to water, green refers to vegetation and pale refers to coastal flats. The right column shows the water body (blue color) in these five dates as estimated from the NDWI and the MNDWI.

The MSS image includes four bands in the green, red and near infrared portions of the spectrum. The TM and the ETM+ images have additional spectral bands in the middle and thermal infrared portions. The SPOT image consists of four bands (two in the visible and two in the infrared spectra). All satellite images cover a ground area of 185 × 185 km, except SPOT image which covers a nadir swath width of 120 km. The images have a minimum cloud cover.

2.3. Image processing

ERDAS Imagine and ArcGIS Software were used to process and visualize satellite data in the present study. The satellite images were originally rectified to the Universal Transverse Mercator (UTM) projection. However, as the images were acquired in different seasons, it was crucial to make an atmospheric correction and radiometric normalization to all images in order to eliminate effects of dust, haze and smoke as well as the solar angle variations. Atmospheric correction was carried out to all images by subtracting the minimum pixel value from the pixel matrix of each image (dark object subtraction) (Chavez, 1996). The dark object was chosen to represent the clear deep water of the Mediterranean Sea. As the solar angles are different in all images, it was crucial to normalize these angle variations as if they all have been acquired in the same season, i.e. summer. Thus all the images, except the MSS (acquired in May) were subjected to radiometric normalization taking into account the earth–sun distance, the solar elevation angle, and the dark object (minimum pixel digital number). The radiometric correction was applied using the COST Model in ERDAS Imagine producing normalized images of reflectance values and ready for subsequent processing.

Because the MSS image lacks a middle infrared band (MIR), only the NDWI was applied using the Modeler Function in ERDAS Imagine. The NDWI was formulated as (Green − NIR)/(Green + NIR), where the green and NIR represent the digital number of the green and near infrared bands in the MSS image of 1973. The resultant NDWI images highlight water bodies present in the study area. This index ranges from −1 to +1 with water bodies of high values (close to +1). As TM, ETM+ and Spot+ four images have spectral bands within the visible, near and middle infrared spectra, thus the MNDWI was applied using the Modeler Function in ERDAS Imagine in order to eliminate any noise pixels (Xu, 2006). The formula of the MNDWI is (Green − MIR)/(Green + MIR), where the green and MIR represent the reflection values in the green and the middle infrared bands, respectively. The output MNDWI images which range from −1 to +1 reveal the lake water in the images. Aquatic plants (floating and submerged) occupy substantial area of the lake and can produce misleading results of the water body area. However, the study of (El-Asmar and Hereher, 2011) reported that water indices are efficient to highlight turbid water bodies, which have submerged plants. The threshold value of water, which is the least pixel value that represents lake water, was then assigned. Lower values than the threshold are considered non-water bodies. The threshold was calculated in each NDWI and MNDWI map and recoded in blue color. The number of pixels above the threshold value was counted together to represent the water body. The surface area was then calculated.

3. Results

As shown in Fig. 2 there are obvious changes occurred at the lagoon water body at the six dates of investigation. Most shrinking of the lake water body occurred from the siltation and island formation within the lake. The raw satellite data show that aquatic plants (floating and submerged) flourished significantly throughout the water body. Drying of the southern part of the lake is also observed in the raw images.

Floating plants showed a lower index value and are considered non-water body as they grow and form islands capturing sediments from the lake. Areas with submerged plants, such as the western side of the lake are treated as turbid water since results showed that NDWI and MNDWI values are high. The threshold value of water as obtained from the NDWI image of 1973 is 0.18. On the other hand, the threshold values of water as obtained from the MNDWI are 0.43, 0.67, 0.64, 0.63 and 0.71 for the years 1984, 1990, 1999, 2005 and 2011, respectively. This large difference in the threshold values between the NDWI and the MNDWI is attributed to the optical properties of the surface water in terms of its relationship with the electromagnetic radiation.

The near infrared radiation is generally less absorbed by the water body than the middle infrared band at the time where the green band absorption is constant giving this difference in the threshold values. The change in the lagoon surface area (Fig. 3) reveals a drastic shrinking during the 38 years of investigation. In 1973, the lagoon area was 430 km^2 and in 1984 it was 385 km^2. The lagoon area continued shrinking to 330 km^2 in 1990, 280 km^2 in 1999 and 260 km^2 in 2005. Finally, the lagoon approached only 246 km^2 in 2011 with a total loss of 184 km^2 (42.8%) of its area between 1973 and 2011. It is obvious that the number and area of islands have also increased in the lake.

4. Discussion and Conclusions

The Burullus lagoon has an elongated elliptical shape. It is separated from the Mediterranean Sea by a narrow sand bar covered by sand mounds and sand dunes approaching up to 3 m above sea level (a.s.l.) at its northeast corner. Sand drift direction at the northern coastal strip of the lake has a southeast trend (Hereher, 2009). The southern fringes of the lagoon are mainly barren lands under reclamation activities.

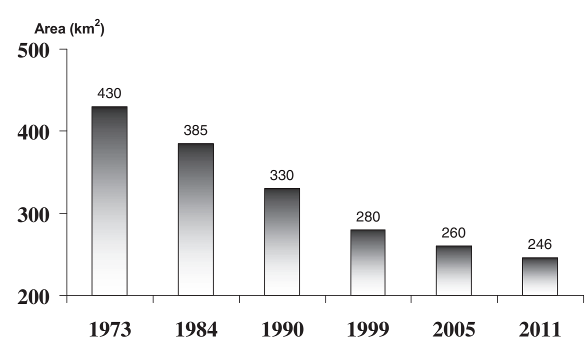


Figure 3 Surface area change of the Lake Burullus between 1973 and 2011.

Agricultural areas occur mainly at its southeast corner. During 1970s, the lagoon body was quite far from human intervention and the lake was considered one of the least polluted coastal lagoons in Egypt. The construction of the High Dam tremendously affected the hydrology of the region. The irrigation regime in the Nile Delta had changed from one season of basin irrigation (flooding season) to a year-round permanent irrigation which entailed the construction of irrigation canals and drainage network. Unfortunately, there are six of these drains that end at the Burullus Lagoon transporting untreated turbid wastewater into the lagoon environment. Agricultural wastes have been reported to increase sedimentation in wetlands and consequently diminish their sizes (Rebelo et al., 2009).

The decrease in the open water surface area is attributed mainly to many factors, including: (1) Drying of the southern and southwestern fringes for reclamation activities either for agriculture or for aquaculture. (2) The landward movement of sand dunes and drifted sand from the coastal sand bar which would potentially reduce the lake area from the north. (3) The agricultural drains at southern periphery of the lagoon conveying turbid agricultural wastes rich in suspended materials. (4) Agricultural wastes entering the Burullus Lagoon are rich in fertilizers and nutrients, causing enhanced eutrophication and vegetation growth. Deterioration of the Burullus Lagoon has been confirmed either by chemical analysis of bottom sediments (Abdel-Moati and El-Sammak, 1996) or by spatial analysis of water using remote sensing and GIS (Hereher, 2010). (5) The newly constructed coastal highway along the sandy bar separates the lake from the Mediterranean Sea. This highway not only entailed drying of the lake water along its tract, but also facilitated accessibility and consequently population stresses upon the lagoon setting.

The coastal sand dunes bordering the lake from the north act as a first guard against any anticipated sea level rise, i.e. natural shore protection measures. Unfortunately, local people destroy these dunes for reclamation purposes, which would have a devastating impact not only upon the lagoon itself but also the entire coastal strip if the sea rises above its current level by 100 cm (Hereher, 2010). The lower lands at the southern boundary of the lake have been extensively utilized by local people for agricultural purposes. Some of these low-level areas had been logged with groundwater and local people use them for aquaculture.

The primary conclusion of the present study is that the Lake Burullus is under the direct threat of environmental degradation due to the continuous human-induced shrinking. Another threat arises from the removal of the coastal sand dunes bordering its coastal face. This delicate coastal ecosystem requires appropriate management and protection as the country is moving toward sustainable use of its natural recourses.

References

Abdel-Moati, M., El-Sammak, A., 1996. Man-made impact on the geochemistry of the Nile Delta lakes. A study of metals concentrations in sediments. Water Air Soil Pollut. 97, 413–429.

Ahmed, M.H., El Leithy, B.M., Thompson, J.R., Flower, R.J., Ramdani, M., Ayache, F., Hassan, S., 2009. Applications of remote sensing to site characterization and environmental change analysis of North African coastal lagoons. Hydrobiologica 622, 147–171.

Chavez, P.S., 1996. Image-based atmospheric correction – revised and improved. Photogramm. Eng. Remote Sens. 62, 1025–1036.

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.

Guirguis, S.K., Hassan, H.M., El_Raey, M., Hussain, M.A., 1996. Multi-temporal change of Lake Burullus, Egypt, from 1983 to 1991. Int. J. Remote Sens. 17 (15), 2915–2921.

Haack, B., 1996. Monitoring wetland changes with remote sensing: an East African example. Environ. Manage. 20, 411–419.

Hereher, M., 2009. Sand drift potential along the coastal area between Baltim and Gamasa, the Nile Delta, Egypt. Sedimentol. Egypt 17, 143–151.

Hereher, M., 2010. Vulnerability of the Nile Delta to sea level rise: an assessment using remote Sensing. Geomatics, Nat. Hazards Risk 1, 315–321.

Hereher, M., Salem, M., Darwish, D., 2011. Mapping water quality of Burullus Lagoon using remote sensing and geographic information system. J. Am. Sci. 7 (1), 138–143.

Jansson, M., Andersson, R., Berggren, H., Leonardson, L., 1994. Wetlands and lakes as nitrogen traps. Ambio 23, 320–325.

Lillesand, T.M., Kiefer, R.W., 1994. Remote Sensing and Image Interpretation. John Wiley & Sons, New York.

McFeeters, S.K., 1996. The use of normalized difference water index (NDWI) in the delineation of open water features. Int. J. Remote Sens. 17, 1425–1432.

Ouma, Y.O., Tateishi, R., 2006. A water index for rapid mapping of shoreline changes of five East African Rift Valley lakes: an empirical analysis using Landsat TM and ETM+ data. Int. J. Remote Sens. 27 (15), 3153–3181.

Ozesmi, S., Bauer, M., 2002. Satellite remote sensing of wetlands. Wetlands Ecol. Manage. 10, 381–402.

Ramsar, 2006. The Ramsar Convention Manual, a Guide to the Convention on Wetlands (Ramsar, Iran, 1971), forth ed. Ramsar Convention Secretariat, Gland, Switzerland.

Rebelo, L.M., Finlayson, C.M., Nagabhatla, N., 2009. Remote sensing and GIS for wetland inventory, mapping and change analysis. J. Environ. Manage. 90, 2144–2153.

Shaltout, K., Al-Sodany, Y., 2008. Vegetation analysis of Burullus Wetland: a RAMSAR site in Egypt. Wetlands Ecol. Manage. 15, 421–439.

Xu, H., 2006. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int. J. Remote Sens. 27, 3025–3033.