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Change detection for Lake Burullus, Egypt using remote sensing and GIS approaches

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Abstract Lake Burullus is the second largest natural coastal lake in Egypt. It has an economic importance for fish yield. However, several anthropogenic activities such as industrial, agriculture, and reclamation activities lead to a deterioration of its water quality and a decrease of the water body area of the lake. This study aims to detect the spatiotemporal changes of Lake Burullus in the period 1972–2015 using 12 Landsat {(1,3-MSS), (4,5-TM), and (7-ETM+)} imageries and water indices approach. To extract water feature from imageries, the Normalized Difference Water Index (NDWI) and the Water Ratio Index (WRI) were applied. The NDWI was applied to the MSS imageries. For other TM and ETM+ imageries, the WRI was applied. Obtained results show a significant decrease in the water area of the Lake Burullus, where it lost about (49%) of its surface area during the period from the year 1972 to the year 2015. A rapid decrease in the lake surface area was noticed through the period from 1972 to 1984. A prediction model was built depending on the calculated water area of the lake. Finally, the multi-temporal maps of the lake surface area are overlaid to produce a map for the changes of the lake surface area using Geographic Information System (GIS).

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Introduction

Surface water is a very important resource of water in the world, it is considered as one of the irreplaceable strategic resources for human survival and social development (Ridd and Liu 1998). However, the various anthropogenic activities such as industrial, agriculture, and reclamation activities lead to substantial degradation in quality and quantity of water in several water bodies. Lake Burullus is a coastal lake (lagoon) located in the north of Nile Delta, Egypt. It is one of the water bodies which subjected to serious environmental changes caused by various anthropogenic activities. The lagoon receives the agricultural, industrial, and biological wastes of the Nile Delta through some drains, which convey turbid agricultural wastes rich in suspended materials, fertilizers, and nutrients, causing enhanced eutrophication. Moreover, the drying of the southern and southwestern fringes of the lake for reclamation activities is increasing (El-Asmar et al. 2013). The deterioration of water quality status of Lake Burullus water was confirmed by chemical analysis of water by Ali (2011), where the author concluded that the lake was suffering from excessive nutrient concentrations, high concentrations of chlorophyll, ranges from 85 to 122 mg/m^3, low Secchi disk transparency, ranges from 0.15 to 0.50 m, and high total suspended matter. Such deterioration was also confirmed by the chemical analysis of the bottom sediments of the lake to find the concentrations of heavy metals in the sediments by Abdel-Moati and El-Sammak (1997) and Sammak et al. (1995), where the results showed that the lake sediments contain high values of metals especially in the southern part of the lake due to the drains outlets. Hereher et al. (2010a) were also confirmed such deterioration of the lake Burullus by the spatial analysis of water quality parameters using remote sensing and GIS.

The integration of Satellite Remote Sensing (RS) and Geographic Information System (GIS) technologies proved to be an efficient method for mapping and analysis of urban land use change (Hong-mei et al. 2001). The great development of the spatial, temporal, and spectral resolution of the Earth Observation systems (EO-systems), such as Landsat, GeoEye-1, MODIS, IRS spot, and ENVISAT; moreover, the longtime extent of the satellite data archives, leads to monitoring the changes on the earth easily and accurately.

There are different techniques which can be used to delineate the peripheries of wetland systems using satellite imageries, such as the simple visual interpretation method, single-band method (using a selected threshold value), classification techniques (supervised classification such as the maximum likelihood supervised classification and unsupervised classification), transformation techniques (Principal Component Analysis (PCA), tasselled cap transformation (KT), Gramm–Schmidt (GS), and Chi-square transformation), image rationing, and multi-band method. Multi-band method was reported as the most accurate approach for mapping shallow and turbid coastal lagoons (El-Asmar et al. 2013). It includes different indices, such as {Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Water ratio index (WRI), Normalized Difference Moisture Index (NDMI), Automated Water Extraction Index (AWEI), and Normalized Difference Vegetation Index (NDVI)}.

NDWI was first introduced by McFeeter (1996) to extract a water feature from Landsat imageries depending on the normalized relationship between the reflection in the green and the Near Infrared (NIR) portions of the spectrum, as shown in Eq. (1).

$$NDWI = (Green - NIR)/(Green + NIR) \qquad (1)$$

While Water Ratio Index (WRI) was provided by Shen and Li (2010). It depends on the spectral reflectance of green band, red band, Near Infrared (NIR) band, and Middle Infrared (MIR) band, as shown in Eq. (2).

$$WRI = (Green + Red)/(NIR + MIR) \qquad (2)$$

(KERÉNYI and PUTSAY 2006) used the classification technique and ASTER images to produce land use map for the Körös transboundary basin located across the Romanian–Hungarian border. NDVI and MODIS images were also used to detect the floodwater area inside the study area. Both land use map and flood water area were overlaid and considered as input layer in the GIS database with the other topographical, hypsographical and hydrological layers. Such GIS database was used for the improvement of the flood management in the study area. In 2011, NDWI and MNDWI were used to detect the changes in water area of Lake Manzala using three MSS, TM, and spot imageries acquired in the years 1973, 1984, and 2003, respectively. The results showed that the lake lost about 34.5% of its area during the period under consideration due to the control of the River Nile flooding and the effects of the various anthropogenic activities (El-Asmar and Hereher 2011). In 2012, the maximum likelihood supervised classification technique was used to detect the changes of land use/land cover of Lake Burullus during the two decades (from 1990 to 2009), and the results showed that the soil moisture areas were decreased during the studied period by the half of its area during the period (1990–2000) (Noha and Farag 2012). Moreover, they reported that the floating vegetation areas were increased inside the Lake Burullus water during the studied period. The NDWI and MNDWI were used to estimate the surface area changes of Lake Burullus using six satellite imageries between 1973 and 2011 (El-Asmar et al. 2013). The authors reported that the lake lost about 42.8% of its open water area during the study period. In 2014, NDWI, MNDWI, NDMI, WRI, NDVI, and AWEI were investigated to extract the surface water feature from Landsat imageries for Lake Urmia, Iran for the period (2000–2013) (Rokni et al. 2014). They concluded that the NDWI is the best water extraction technique, in addition to a new established approach based on Principal Components of multi-temporal NDWI (NDWI-PCs). NDWI and AWEI were used to assess the surface area changes of three Ethiopian lakes (Shala, Abjata, and Langano) located in the Central Rift Valley (CRV) region during the past four decades (1973–2014). The results showed a small decrease in area of Lake Shala and Lake Langano (-3.68 and -10.2 Km^2, respectively), as compared to the decrease of Lake Abjata (-68 Km^2) during the study period (Tefera 2015). The spatiotemporal changes of Lake Burdur, Turkey were evaluated for the period from the year 1987 to the year 2011 using multi-temporal TM and ETM+ imageries and Support Vector Machine (SVM) classification and spectral water indexing (NDWI, MNDWI, and AWEI). The results showed that the lake lost about 32.50% of its area during the study period (Sarp and Ozcelik 2016). Hossen and Negm (2016) used five Landsat (TM, ETM+, and OLI/TIRS) satellite imageries to detect the changes in Lake Burullus region for the period from the year of 1984 to 2015, using the maximum likelihood supervised classification technique. They concluded that the water bodies of the lake decreased by 44.97%, while the floating vegetation area was increased by the same amount. The sea water area is relatively stable and the agriculture area was increased by 45.52%, while the sand bar and urban area decreased by the same amount. Hossen and Negm have also developed a statistical prediction model and they predicted that the water bodies of the lake will be reduced by 58.95% by the year of 2030.

This study aims to detect the spatiotemporal changes of Lake Burullus in the period (1972–2015) based on 12

Landsat {(1,3-MSS), (4,5-TM) and (7-ETM+)} imageries, using water indices approach (NDWI and WRI), then using a GIS tool to produce a map of the changes area for the lake.

Problem statement

The quality and quantity of water in Lake Burullus are significantly affected by various anthropogenic activities. Agricultural drains, for example, are conveying turbid agricultural wastes into the lake, which alter the lake water quality. Moreover, drying of the southern and southwestern fringes of the lake is increasing due to reclamation activities. The objective of this study is to monitor the changes in the water area of the lake during the past four decades (from 1972 to 2015), using remote sensing and GIS techniques, to help the decision makers in taking urgent actions to restore the lake into life, by displaying the changed areas of the lake and addressing the causes of change, in addition to producing a prediction model that can predict with the water area of the lake in other periods.
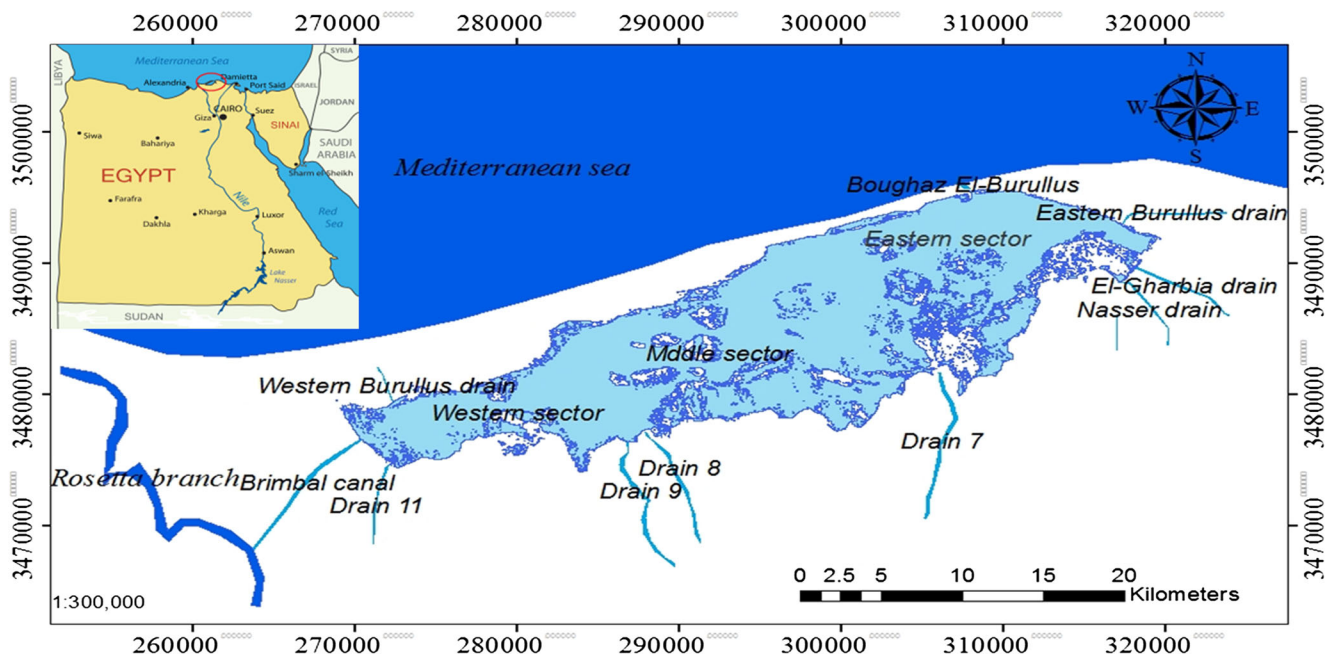
Study area

Lake Burullus is the second largest natural lake in Egypt; it has an elongated elliptical shape. It is located in the Nile Delta, between the two Nile River branches (Damietta and Rosetta), as shown in Fig. 1. It extends between longitudes 30° 31′ E and 31° 05′ E and latitudes 31° 25′ N and 31° 35′ N. It is considered as a valuable source for fish yield in Egypt. In 1998, Lake Burullus was declared as a national protected area,

and added to RAMSER sites. Burullus Lake is a shallow coastal lake, where its water depth ranges from 0.5 to 1.5 m. The lagoon surface is above the mean sea level with 25 to 60 cm. It is connected to The Mediterranean Sea through one outlet, which is called Boughaz El-Burullus, at its northeastern side. This outlet gives the chance for water exchange and for the renewal of the lake ecosystems. The length of the lake is about 53 km and its width is about 13 km (Frihy and Dewidar 1993). There are seven agricultural drains which discharge its drained wastewater into the lake, in addition to the Brimbal canal, a source of freshwater, which is located at the western part of the lake (Hereher et al. 2010b). The average discharge of these drains into the lake fluctuated between 78,000,000 m^3/month to 272,000,000 m^3/month in January and July 2002 (Okbah and Hussein 2006). Brimbal canal was provided the lake with about 50% of the lake's water before building the Aswan high dam, while after building the dam the contribution of the canal does not exceed 5% (Dumont and El-Shabrawy 2007). The climate conditions of Burullus area is arid Mediterranean, with mean annual rainfall less than 200 mm and the temperature ranges from 9 °C in winter to 30 °C during summer (El-Adawy et al. 2013).

Approach and methodology

To detect the changes in water area of Lake Burullus, 12 Landsat satellite imageries were downloaded from the US Geological Survey (USGS) Earth explorer viewer. These imageries have been geometrically, atmospherically, and radiometrically corrected as they have some defects due to the

Fig. 1 Location of the study area in the Nile delta, Lake Burrulus

position of the satellite on its orbit, haze, dust, and sun angle. Then two water indices (NDWI and WRI) were applied on the corrected imageries to extract water feature from it and change detection of the water area of the lake.

Remote sensing data

Landsat owns the longest continuously acquired collection of space-based moderate-resolution remote sensing data, where they take imageries for the earth from the year 1972 till now (Bhandari et al. 2012). Twelve Landsat satellite imageries for Lake Burullus were downloaded from the US Geological Survey (USGS) Earth explorer viewer (United States Geological Survey (USGS)) for the period (1972–2015). Table 1 shows the date, path and row, type of the sensor, and cloud cover percentage of each imagery used in this study. All imageries were obtained for two sequent seasons at most (spring and summer) to avoid the seasonal changes. The Multispectral Scanner (MSS) imageries contain four bands in green, red, and Near Infrared (NIR) of the electromagnetic field with spatial resolution of 79 m, while the Thematic Mapper (TM) and the Enhanced Thematic Mapper Plus (ETM+) imageries contain seven bands in blue, green, red, Near Infrared (NIR), Mid Infrared (MIR), and thermal of the electromagnetic field with spatial resolution of 30 m, except for the thermal band, where it has a spatial resolution of 120 m for TM imageries and 60 m for ETM+ imageries.

Processing of satellite data

Due the position of the satellite on its orbit, haze, dust, and sun angle, satellite imageries have some defects which should be processed. Satellite imageries should be geometrically, atmospherically, and radio-metrically corrected to become ready for extracting the required data. For that; a satellite imageries

Table 1 Specifications of the imageries which used in the study

ID	Satellite	Date	Path/Raw	Sensor	Cloud cover
1	Landsat 1	August 1972	190/38	MSS	0%
2	Landsat-3	May 1978	190/38	MSS	0%
3	Landsat 5	June 1984	177/38	TM	10%
4	Landsat 5	May 1987	177/38	TM	10%
5	Landsat 4	August 1990	177/38	TM	0%
6	Landsat 5	August 1998	177/38	TM	0%
7	Landsat 7	June 2002	177/38	ETM+	0%
8	Landsat 7	August 2004	177/38	ETM+	0%
9	Landsat 7	June 2008	177/38	ETM+	0%
10	Landsat 7	May 2009	177/38	ETM+	3%
11	Landsat 7	July 2011	177/38	ETM+	0%
12	Landsat 7	July 2015	177/38	ETM+	0%

processing software (ENVI, 5.1), (Harris Geospatial Solutions (previously Exelis VIS)), and a GIS tool (ARCGIS 10) (Environmental Systems Research Institute (ESRI)) were used to correct the collected satellite imageries. The correction procedure was as follows:

1. Geometric correction aims to remove the effects caused by the satellite position, and the rotation of the earth around its axis or around the sun during image acquisition or due to the curvature of the earth (Richards and Richards 1999). This correction was applied for one image only, August 1972 as the other downloaded imageries were geometrically corrected. Image to image registration technique in ENVI software was used to rectify the image. First order polynomial transform algorithm and nearest neighboring resampling method were applied to warp the image, the root mean square error (RMSE) after rectification does not exceed 0.5 pixel.

2. Atmospheric correction—The Dark Object Subtraction (DOS) method (Chavez 1996) was applied on all images to remove the effects of the atmosphere, which affect the radiance received at the satellite sensor. This correction method is considered suitable for the change detection studies due to the lack of the historical in-situ atmospheric measurements.

3. Radiometric calibration; as all images were acquired in two different seasons (spring and summer), so they have different solar zenith angle. The radiometric calibration was applied to all imageries, in order to convert the digital number (DNs) of the image to reflectance. This step requires some information such as earth-sun distance, solar zenith angle, and mean exo-atmospheric solar irradiance which acquired from the meta data file attached with Landsat imagery (Chander et al. 2009).

4. For ETM+ images acquired after 31th of May 2003, the ETM+ sensor had a failure of the Scan Line Corrector (SLC), which leads to thin black lines on both edges of the scene resulting in an approximately 22% data loss. So, local linear histogram matching technique (Scaramuzza et al. 2004) was applied on five images which acquired on August 2004, June 2008, May 2009, July 2011, and July 2015, using Landsat gap fill tool to remove the bad lines.

Water feature extraction

Images digitizing technique was used to create a lake boundary shape file for every separate image to build the lake mask. Then all masks were used to extract the entire area of the lake from the images. Normalized Difference Water Index (NDWI) was applied on the MSS images of 1972 and 1978, as this sensor contains only the red, green, and near infrared (NIR)

bands and does not have the mid infrared (MIR) band. For other TM and ETM+ images of 1984, 1987, 1990, 1999, 2002, 2004, 2008, 2009, 2011, and 2015, Water Ratio Index (WRI) was applied, whereas such sensors contain the (MIR) band.

Then threshold values for both indices, NDWI and WRI, were assigned to all images by trial and error and visual inspection to extract water feature from the images. Where, the pixel values greater than the threshold value is considered as a water pixel. Water pixels are collected together to calculate the water area of the lake in each image. The non-parametric Mann–Kendall test (Kendall 1975; Mann 1945) was performed on the water area of the lake for the period from 1972 to 2015 in order to investigate the temporal trend in the water area of the lake statistically. Excel software was used to calculate the Mann–Kendall test statistics based on the methodology followed by (Aziz et al. 2003). Whereas Aziz et al. reported that the Mann–Kendall test for trend analysis relies on three statistical metrics; (S) (Mann–Kendall statistic–S) which is the total summation of the differences between sequential events, which indicates whether the trend is generally decreasing (negative S value) or increasing (positive S value), (CF) is the Confident Factor which indicates the degree of confidence in the trend result, as in "Decreasing" vs. "Probably Decreasing" or "Increasing" vs. "Probably Increasing," and (COV) is the Coefficient Of Variation which used to distinguish between a "No Trend" and "Stable" results. They also stated that when the CF is greater than 95% the data, demonstrate a strong trend, either "Increasing" or "Decreasing" trends according to the sign of S. When the CF falls between 90 to 95%, the H_0 is rejected and a trend is indicated; however, due to the lower confidence in the trend,

the qualifier "Probably" is applied, as in "Probably Increasing" or "Probably Decreasing according to sign of S also. If the CF is less than 90%, the H_0 is accepted and either a "No Trend" condition or a "Stable" condition is indicated, depending on the COV value.

A temporal linear regression for the lake water area was done, using Excel software, in order to produce a prediction model for the water area of the lake. Finally, the multi-temporal lake surface area maps were overlaid to produce the map of the lake surface area changes, using ARCGIS software.

Results and Discussions

A significant change has occurred in the water area of Lake Burullus during the considered period from 1972 to 2015 as shown in Fig. 2. The lake has lost about 48.91% of its total surface water area. The statistical results of Mann-Kendall test were (S) = −66, (CF) > 99.99% and (COV) = 0.22, According to the stated rules by Aziz et al., S is negative value with CF greater than 95%, which indicates a significant decreasing trend in the water area of the lake during the study period. The surface water area of the lake was estimated by about 434.64 Km^2 in 1972, while it is estimated by about 222.065 Km^2 in 2015. Table 2 shows the values of the surface water area of the lake, the changes in the area between successive years in Km^2 and percentage, and the threshold values of water indices (NDWI & WRI). Figure 3 shows the changes in lake surface water area, from 1972 to 2015. It can also be noticed that a rapid decrease in water area of the lake occurred from 1972 to 1984, due to the

Fig. 2 Twelve Landsat false color satellite images for Lake Burullus during the period 1972 to 2015
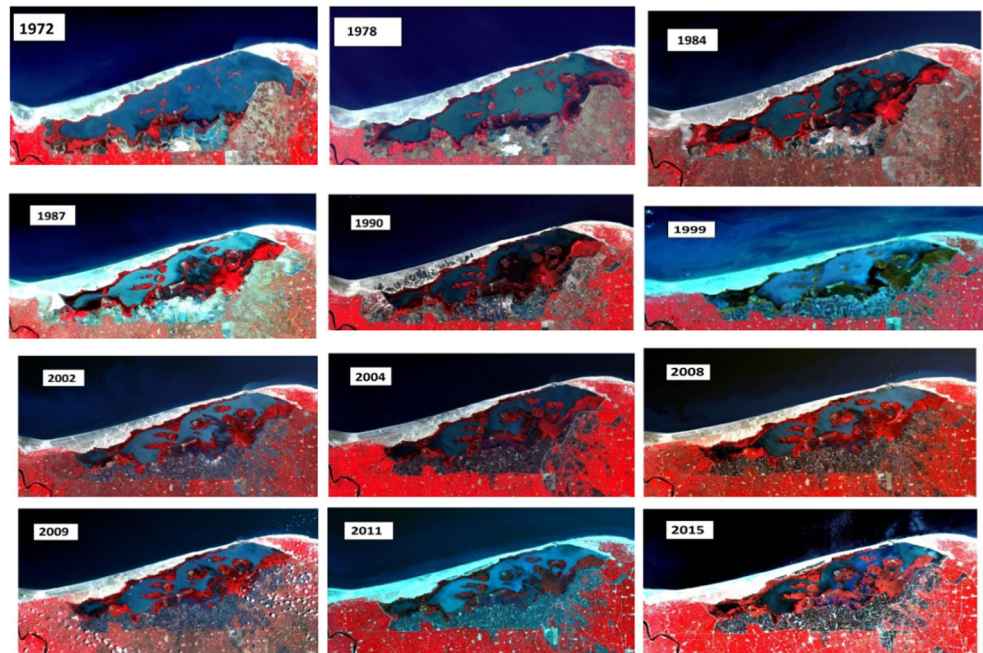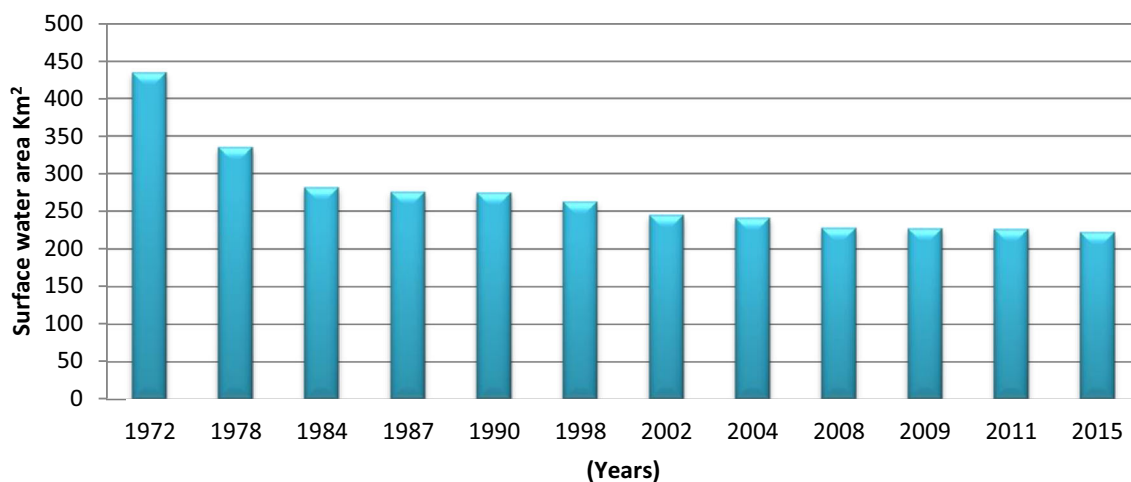
Table 2 Surface water area of Lake Burullus for the period from the year 1972 to the year 2015, changes in area between the successive years in Km² and % and the threshold values of water indices

| ID	Date	Sensor	Water area (Km²)	Change in area (Km²)	% of change in area	Threshold
1	1972	MSS	434.6 ± 8%	–	–	0.15
2	1978	MSS	335.2 ± 5%	99.3	22.85	0.05
3	1984	TM	281.7 ± 10%	53.5	12.31	1.6
4	1987	TM	275.9 ± 12%	5.8	1.33	1.2
5	1990	TM	274.8 ± 11%	1.0	0.24	1.75
6	1998	TM	262.7 ± 7%	12.1	2.78	1.85
7	2002	ETM+	245.0 ± 8%	17.7	4.08	1.35
8	2004	ETM+	241.2 ± 8%	3.7	0.86	1.5
9	2008	ETM+	228.0 ± 9%	13.1	3.02	1.25
10	2009	ETM+	227.1 ± 6%	0.918	0.21	1.23
11	2011	ETM+	226.2 ± 8%	0.918	0.21	1.49
12	2015	ETM+	222.0 ± 8%	4.19	0.96	1.5
Σ				212.58	48.91	

reclamation activities and discharging of drained wastewater into the lake, due to the absence of authorities. While from 1984 to 2015 no substantial decreases have been observed, as the authorities' crime encroaching on the area of the lake. The calculated water area of the lake for 12 years was used to construct a statistical prediction model using the trend line function in Excel software. As the prediction of the lake area requires a lot of information about various future anthropogenic activities and climatic changes, the developed prediction model is considered as a rough model; it does not take the effects of future climatic changes or other unexpected factors into consideration; it considers that the past pattern of the human activities will constantly continue in the future. The rate of decrease in the water area of the lake for the period from 1972 to 1984 is very high and bigger than the rate of decrease for the other period from 1984 to 2015, so the years of 1972 and 1978 were excluded due to their extreme rates, while the remaining 10 years (1984, 1987, 1990, 1998, 2002, 2004, 2008, 2009, 2011, and 2015) were used to develop the prediction model. The exclusion of the years of 1972 and 1978, returns to the abnormal activities which happened in this period. These abnormal activities led to a substantial loss in the water area of the lake due to the absence of suitable legislations and authorities control. However, starting from 1980s, the infringement of area of the lake was reduced, as a result to the restricted application of the legislations by the Egyptian government. The prediction model and the coefficient of determination R^2 of the model have been shown in Fig. 4. The prediction model can be applied for future periods as long as the current conditions of the lake are continuing without changes. Based on this prediction model, the lake will be completely filled and the water area is vanished by the year 2116, if there are no actions have been applied by the decision makers. The prediction model was applied to predict the water area of the lake by the year of 2030; the results showed that the water area of the lake will be equal to about 186.05 Km². The multi-temporal maps of the lake surface

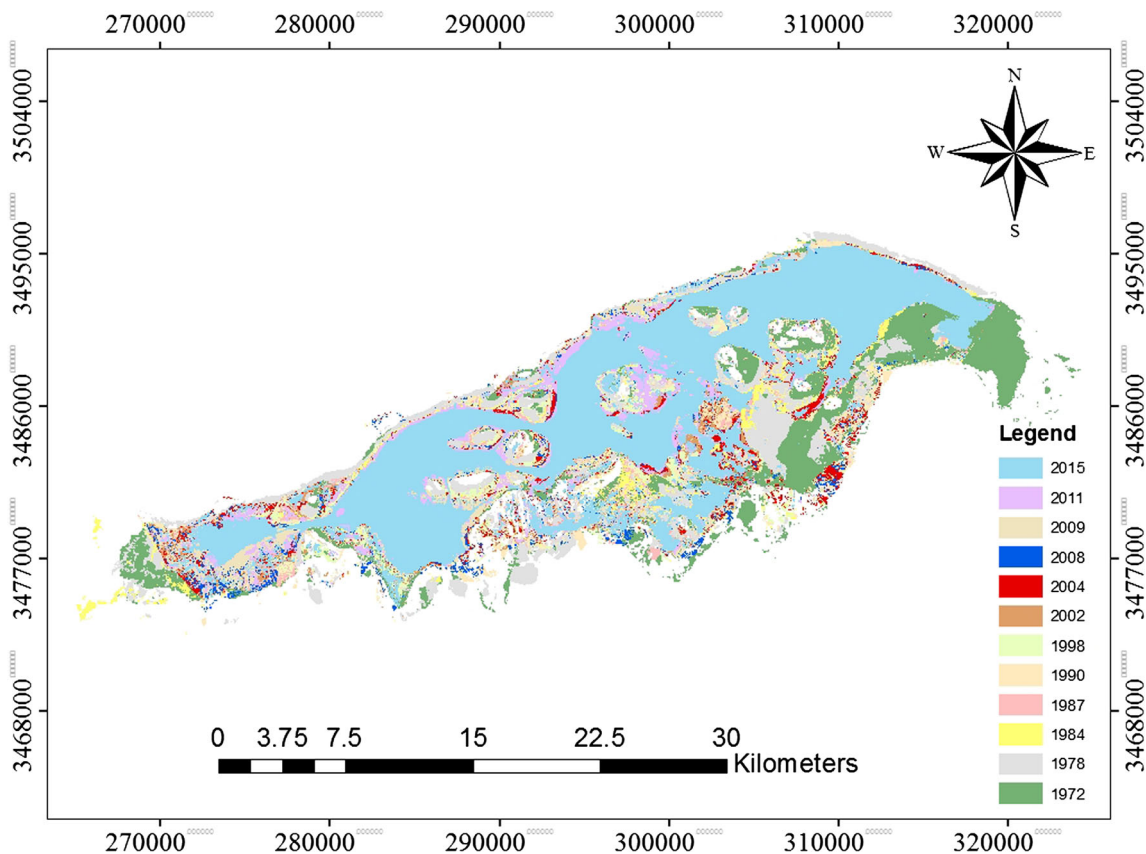**Fig. 3** Changes in surface water area of Lake Burullus for the period from 1972 to 2015

Fig. 4 The trend line for the water area of lake from 1984 to 2015, the prediction model, and R^2

Surface area = (-2.1417 × year) + (4533.7)
R^2 = 0.97
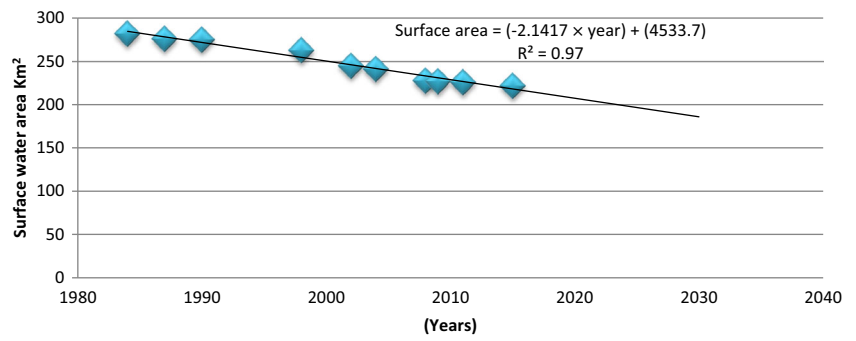
water area were overlaid to produce the changes map of the lake surface area as shown in Fig. 5. The changes map of the lake shows the progressive decrease in the water area of the lake during the study period, the increase in the numbers and the areas of the forming islands, and the infringement of large areas in the southern, southeastern, and southwestern parts of the lake. Figure 5 shows also a great decrease in the water area of the lake in the western and southeastern parts of the lake between the years of 1972 and 1984, which returns to the infringement of these areas for reclamation activities for agriculture and/or aquaculture in addition to the siltation from the agriculture drains. While from the year of 1984 to 2015, the lake water area maps are almost identical with small decrease in such areas. The northern part of the lake is relatively stable, with small decreases in the sand bar. GIS proved its ability as a good tool for detecting the spatiotemporal changes in lakes.

The results of the present study agree with the study of El-Asmar et al. (2013), where (NDWI) and (MNDWI) were used to change detection of Lake Burullus for the period from 1973 to 2011 using six satellite images. The authors reported that the lake lost about 42.80% of the water area. In the present study, the loss of the water area of lake from 1972 to 2011 is about 47.94%. The calculated water area of the lake by El-Asmar et al. (2013) equals to 385 and 330 Km^2 in 1984 and 1990, respectively. While the calculated area in this study equals to 281.75 and 274.86 Km^2 in same years. The difference in the water area values of the lake may return to the

Fig. 5 Multi-temporal changes in the surface water area of Lake Burullus during the period (1972–2015)

difference in the used water detection index; El-Asmar et al. (2013) used the MNDWI while WRI was used in the present study. Selecting the threshold value and the digitizing method may also make changes in the water area of the lake. The results of this study agree with some extent of the study of Hossen and Negm (2016). Whereas Hossen and Negm used the maximum likelihood supervised classification technique to detect the changes in Lake Burullus region, using five Landsat satellite imageries acquired in the years of 1984, 1990, 1998, 2003, and 2015. Moreover, they presented a prediction model for the water area of the lake. They reported that the water body of the lake has lost about 44.97% of its area during the study period (from 1984 to 2015), while in this study, the lost in water area reaches to about 21.19% during the same period. The calculated water area of the lake in the years of 1984, 1990, 1998, and 2015 was 322.51, 286.29, 229.96, and 177.47 Km^2, respectively, in Hossen and Negm study, while its water area equals to 281.7, 274.8, 262.7, and 222.0 Km^2 in this study. The difference in the water area values of the lake may return to the difference in the used change detection technique. The results of the prediction model for predicting the water area of the lake in the year of 2030 in Hossen and Negm are very close to the predicted area in this study. It is predicted to be equal to 190.11 and 186.05 Km^2 in Hossen and Negm study and in the present study, respectively.

The results of this study agreed also with (Dewidar 2011) study. Whereas, Dewidar used the automated shoreline change detection technique to monitor the temporal changes of the surface water area of the Burullus and Manzala lagoons during the period from 1972 to 2006. The author reported that the surface water area of lake Burullus has decreased by 61.9%, during the study period, while in this study, the lost in water area reaches to about 47.5% during the nearest period to Dewidar study, from 1972 to 2008.

The substantial loss of the surface water area of the lake returns to the infringement of large areas of the southern and southwestern parts of the lake due to reclamation activities for agriculture and/or aquaculture, in addition to discharging of the drained wastewater from the seven considered drains into the lake. The drained wastewater has two effects on the area of the lake; the first one is the clay siltation in front of the mouth of the drain which leads to drying these parts of lake and also increase in number and area of islands inside the lake. The second effect is the increase in the bed level of the lake which reduces sea water coming from tides to enter the lake, which leads to increase in the amount of jungle, woven, and water hyacinth inside the lake. Climate change and Sea Level Rise (SLR) have a great effect on the hydrodynamic characteristics of lake. Whereas, climate change expected to increase saltwater intrusion into the lake and also, it is expected to increase the salinity and water temperature of lake which leads to changes in the lake ecosystem (SOLIMAN and USHIJIMA 2013) and (Eladawy et al. 2013).

Conclusions and recommendations

Remote sensing and GIS techniques were used for this study to investigate the change detection of Lake Burullus for the period from 1972 to 2015. Two water indices, NDWI and WRI, were applied to extract water feature from remote sensing imageries. The results showed that the loss in surface water area of the lake is significant, about 49%. Mann–Kendall test showed a significant decreasing trend in water area of lake. A rapid decrease in the lake surface area can be noticed through the period from 1972 to 1984; 36.51%. The loss in the water area of the lake returns to the infringement of large areas of the southern and southwestern parts of the lake for reclamation activities. Moreover, discharging of the drained wastewater from the seven drains into the lake leads to increase in number and area of islands inside the lake and to a progressive growing of aquatic plants. A rough prediction model was also produced depending on the calculated water area of the lake for the past four decades, without taking into considerations the future climatic changes or unexpected anthropogenic activities. The water area of the lake predicted to be equal to about 186.05 Km^2 by the year of 2030, according to this model. Urgent and effective actions should be taken to stop the continuous infringements on the surface water area of the lake. Management plans should be implemented to restore the lake to life. This study also proved the ability of remote sensing and GIS to monitor the changes on the earth, economically and effectively.

References

Abdel-Moati M, El-Sammak A (1997) Man-made impact on the geochemistry of the Nile Delta lakes. A study of metals concentrations in sediments Water, Air, and Soil Pollution 97:413–429

Ali EM (2011) Impact of drain water on water quality and eutrophication status of Lake Burullus. Egypt, a southern Mediterranean lagoon African Journal of Aquatic Science 36:267–277. doi:10.2989/16085914.2011.636897

Aziz JJ, Ling M, Rifai HS, Newell CJ, Gonzales JR (2003) MAROS: A decision support system for optimizing monitoring plans Ground Water 41:355–367

Bhandari S, Phinn S, Gill T (2012) Preparing Landsat Image Time Series (LITS) for monitoring changes in vegetation phenology in Queensland. Australia Remote Sensing 4:1856–1886

Chander G, Markham BL, Helder DL (2009) Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sens Environ 113:893–903

Chavez PS (1996) Image-based atmospheric corrections-revisited and improved Photogrammetric engineering and remote sensing 62: 1025–1035

Dewidar KM (2011) Monitoring temporal changes of the surface water area of the Burullus and Manzala lagoons using automatic

techniques applied to a Landsat satellite data series of the Nile Delta coast Mediterranean Marine Science 12:462–478

Dumont HJ, El-Shabrawy GM (2007) Lake Burullus of the Nile Delta: a short history and an uncertain future AMBIO. A Journal of the Human Environment 36:677–682

El-Adawy A, Negm A, Elzeir M, Saavedra O, El-Shinnawy I, Nadaoka K (2013) Modeling the hydrodynamics and salinity of El-Burullus Lake (Nile Delta, Northern Egypt) Journal of Clean Energy Technologies 1

El-Asmar H, Hereher M (2011) Change detection of the coastal zone east of the Nile Delta using remote sensing. Environmental Earth Sciences 62:769–777

El-Asmar HM, Hereher ME, El Kafrawy SB (2013) Surface area change detection of the Burullus Lagoon north of the Nile Delta, Egypt, using water indices: a remote sensing approach. The Egyptian Journal of Remote Sensing and Space Science 16:119–123

Eladawy A, Negm AM, Valeriano OCS, El-Shinawy I (2013) Assessment of Climate Change Impacts on El-Burullus Lake, Egypt, Based On Hydrodynamic Modeling International Water Technology Journal 3

Environmental Systems Research Institute (ESRI) ARC GIS http://www.esri.com/. Accessed 2 July 2015

Frihy OE, Dewidar KM (1993) Influence of shoreline erosion and accretion on texture and heavy mineral compositions of beach sands of the burullus coast, north-Central Nile delta. Egypt Marine Geology 114:91–104. doi:10.1016/0025-3227(93)90041-S

Harris Geospatial Solutions (previously Exelis VIS) Environment for Visualizing Images (ENVI). http://www.harrisgeospatial.com. Accessed 2 July 2015

Hereher M (2010a) Salem, Darwish M. Mapping water quality of Burullus Lagoon using remote sensing and geographic information system Journal of American Science 7:138–143

Hereher M, Salem M, Darwish D (2010b) Mapping water quality of Burullus Lagoon using remote sensing and geographic information system. Journal of American Science 7:138–143

Hong-mei Z, Cheng-hu Z, Wei-qiang G, Jin-cai D (2001) Spatial distribution characteristics of urban thermal conditions: application of GIS and remote sensing. J Geogr Sci 11:261–270

Hossen H, Negm A (2016) Change detection in the water bodies of Burullus Lake. Northern Nile Delta, Egypt, Using RS/GIS Procedia Engineering 154:951–958

Kendall M (1975) Rank correlation methods

KERÉNYI J, PUTSAY M (2006) Land Use Map from Aster Images and Water Mask on Modis Images. In: Transboundary Floods: Reducing Risks Through Flood Management. Springer, pp 45–55

Mann HB (1945) Nonparametric tests against trend Econometrica: Journal of the Econometric Society:245–259

McFeeters SK (1996) The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features International. Journal of Remote Sensing 17:1425–1432. doi:10.1080/01431169608948714

Noha SD, Farag H (2012) MONITORING BURULLUS LAKE USING REMOTE SENSING TECHNIQUES

Okbah MA, Hussein NR (2006) Impact of environmental conditions on the phytoplankton structure in Mediterranean Sea lagoon. Lake Burullus, Egypt Water, air, and soil pollution 172:129–150

Richards JA, Richards J (1999) Remote sensing digital image analysis vol 3. Springer

Ridd MK, Liu J (1998) A comparison of four algorithms for change detection in an urban environment. Remote Sens Environ 63:95–100. doi:10.1016/S0034-4257(97)00112-0

Rokni K, Ahmad A, Selamat A, Hazini S (2014) Water feature extraction and change detection using multitemporal Landsat imagery Remote Sensing 6:4173–4189

Sammak EAA, El-Sabrouti M (1995) Assessment of metals pollution in the sediments of lake burullus, se Mediterranean, egypt

Sarp G, Ozcelik M (2016) Water Body Extraction and Change Detection Using Time Series: A Case Study From Lake Burdur, Turkey Journal of Taibah University for Science

P Scaramuzza, Esad Micijevic, Gyanesh Chander (2004) SLC Gap-Filled Products Phase One Methodology

Shen L, Li C Water body extraction from Landsat ETM+ imagery using adaboost algorithm. In: Geoinformatics, 2010 18th International Conference on, 2010. IEEE, pp 1–4

SOLIMAN M, USHIJIMA S (2013) CLIMATE CHANGE IMPACT ON EL-BURULLUS LAKE SALINIZATION PROCESS 水工学論文集 土木学会水工学委員会 編 57:1_253–258

Tefera AS (2015) Multi-temporal Landsat Image Based Surface Area Change Detection of Water Bodies in the Central Rift Valley (CRV) of Ethiopia

United States Geological Survey (USGS) U.S. Department of the Interior U.S. Geological Survey http://earthexplorer.usgs.gov. Accessed 15 August 2015