ORIGINAL PAPER

Using single-beam bathymetric data technique to estimate dredging: a case study in Lake Manzala (Egypt)

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Abstract

Marine dredging is an excavation activity carried out worldwide. Dredging is a critical component of most major infrastructure developments of the lakes. This research work was conducted, using two epoch data (year 2016 and year 2022), to investigate changes in the morphometry of Lake Manzala. Data acquisition was done using depth sounding with an echo sounder and GPS, and further processing was done using ArcGIS 10.7.1 software. Results obtained for dredging activities in Lake Manzala were as follows: a slight change in its surface area, the most aquatic macrophytes were removed, the inside fish farms have been completely removed, the appearance of mud islands, and a high amount of removed sediment. The total removed area is estimated at 524.94 million m^3 from Lake Manzala. With a continuous dredging process, the results of the manuscript serve as good reference material for decision and policy formulation relating.

Keywords Bathymetry · Dredging · GIS · Lake Manzala

Introduction

Dredging is a worldwide excavation activity that involves removing islands, aquatic plants, infringements, and sediment from a water body and sometimes relocating them elsewhere. Dredging activities are widely used in different water bodies by dry or wet excavation. In the dry excavation, the lake is drained, and the sediments are dewatered before being removed by traditional excavation equipment like backhoes, bulldozers, or draglines. This type of dredging gives a lot of visibility while working, but from its drawbacks, native flora and creatures are displaced when all water is drained. With regard to the working principles for wet excavation, dredges may be categorized into two broad categories: mechanical and hydraulic dredges. Dredging equipment and methods are chosen based on a variety of environmental factors including the volume, physical and geotechnical characteristics of the sediment to be removed, the presence of contaminants

at various depths of the bottom layers, the dredging depth, and the distance to the disposal area (Choppala et al. 2018).

Dredging is one of the lake's restoration techniques and is currently the most commonly selected option for maintaining aquatic ecosystems and making them safer and more esthetic appeal (Hadnagy et al. 2015). Through consulting available literature concerning the impact of dredging, it was confirmed that there are significant existing direct and indirect, negative and positive impacts on the lake's environment (Bridges et al. 2010). Dredging has many benefits for the water body: increases volume and depth, rid of water surface plants and deep-rooted plants, reduces or stops the excess growth of plants, thus staving off oxygen depletion in the lake, removes nutrient-laden sediments, improves water quality, supports native wildlife, and removes contaminants that occur due to chemical spills (Evans et al. 2012). But unfortunately, sometimes dredging poses a significant threat to the health, shoreline, and scenery of the water body. A severe detrimental influence on sensitive ecosystems' soil deposits is one of the environmental consequences. Existing species and organisms that rely on the original composition are endangered and may become extinct as a result of the alterations. Sediment removal can cause a lot of turbidities and contribute to heavy metal mobilization due to oxidation. As a result, dredging is a massive reengineering of a lake that should not be conducted without a thorough

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understanding of its full consequences (Gustavson et al. 2008). However, there is an ongoing debate among the proponents of negative effects on its environment as multiple potential stressors associated with dredging activities have been well documented (Rehman et al. 2016). Previous studies have demonstrated that the effect of dredging is influenced by a variety of elements, including dredging technique, dredging depth, external control, and the lake's natural parameters (Zhong et al. 2018). Therefore, Manap and Voulvoulis (2014) developed a decision-making framework to identify the best sediment dredging option. Options were based on four dredging aspects: environmental, socio-economical, managerial, and technical.

Many different methodologies have been used to estimate dredging in the lakes (Wenger et al. 2017; Vittori et al. 2020; Mateo-Pérez et al. 2021). Most of these include the use of a bathymetry survey as a valuable tool and a prerequisite in the planning and execution of nearly every form of a project to choose the correct equipment for the dredging operation and its accuracies. This methodology depends on comparing water bodies and bathymetries collected periodically. Hence, the pre-dredge bathymetric survey is an essential building block when computing dredging volume because it provides the baseline to determine the volume of dredging removed, as accurate bathymetry predictions would be invaluable in determining the dredging operations. Accurate interpolation when compiling bathymetric maps is essential in any water depth study. However, the problem with this methodology is that it requires numerous bathymetric surveys to produce a sufficiently significant analysis (Mateo-Pérez et al. 2021).

Demonstrating the unlimited use of geographic information systems (GIS) in bathymetric survey processing, from its acquisition stage to the production of the chart, the capability of extracting meaningful information, through querying of feature class data, for extraction of useful information relating to spatially distributed data (Chukwu and Badejo 2015). The amount of digital geographic data that dredging projects generate can seem quite extensive at times. Furthermore, given the importance of data, it frequently necessitates geographic data processing before it can be interpreted and used utilizing GIS.

Lake Manzala over the past decades was heavily influenced by environmental changes caused by both natural and manmade processes (Hossen et al. 2018). As a result of more intensive pollution, the situation has been aggravated, and it was predicted that if action is not taken, it will become a dead lake (Zaky and Salem 2015). Hence, the removal of the encroachments and aquatic plants, and then sediment removal within the lake, is a key component of Lake Manzala's restoration plan and is essential to allow the lake to survive ecologically. By 2016, the Egyptian government has launched a huge program for the sustainable development of Lake Manzala. It aimed to improve the quality of the lakes' water for the current and following generations (Abd Ellah 2021). Therefore, there became an urgent need to investigate and account for dredging works, so that proper planning responses can be implemented in Lake Manzala, by updating the bathymetric chart covering the lake which would be compared with the earlier bathymetric survey, for investigating the dredging. As a result, this study used two epoch data to investigate bathymetrical and morphometrical changes in the lake. The survey from 2016 depicts the lake before dredging, while the survey from 2022 depicts the lake through dredging. This study outlines a method for estimating dredge amounts and visualizing the results using a geographic information system (GIS).

Materials and methods

Study area description

Lake Manzala is one of the largest natural lakes in Egypt (Fig. 1) and is bordered by the Mediterranean Sea to the north and by fish farms, villages, and agricultural lands to the south. Lake Manzala is considered to be a water reservoir receiving water directly from five drains, namely: Bahr El Baqar, Hadous, Mataria, Elserw, and Faraskour, and indirectly from the adjacent fish farms and agricultural lands (Omran 2016). On the other side, two narrow inlets (called Bughazes) in the north that connect the lake to the Mediterranean Sea are El-Gamil and the new El-Gamil. In the lake literature, it is widely believed that tides play a tiny impact on the lake's water level, which fluctuates just a few centimeters near the two narrow inlets (Elshemy and Khadr 2015).

Lake Manzala is significant on a national and global scale. The lake is a well-known wintering spot for migrating birds around the world. It is an additional reservoir to absorb the predicted rise in the Mediterranean Sea level; it is expected to play a role in mitigating the effects of climatic change. Lake Manzala also aids in the protection of coastal cities from floods and storm surges. Lake Manzala, according to Ali and El-Magd (2016), has a high biodiversity value in the Mediterranean region and is a natural oxidation basin that works as a natural barrier between the Nile Delta's drainage system and the Mediterranean Sea. This is why the lake is regarded as a natural buffer zone that prevents saltwater from infiltrating agricultural lands and groundwater. Furthermore, the lake plays a significant role in promoting economic growth, accounting for almost 14% of total annual Egyptian fisheries production (Abd Ellah 2021).

Methodology and data processing

Bathymetric survey

To determine the geometric parameters and prepare the bathymetric maps, a detailed bathymetric survey was made

Fig. 1 A satellite image was taken in the middle of January 2022, which was processed through the GIS program, of the study area and its features
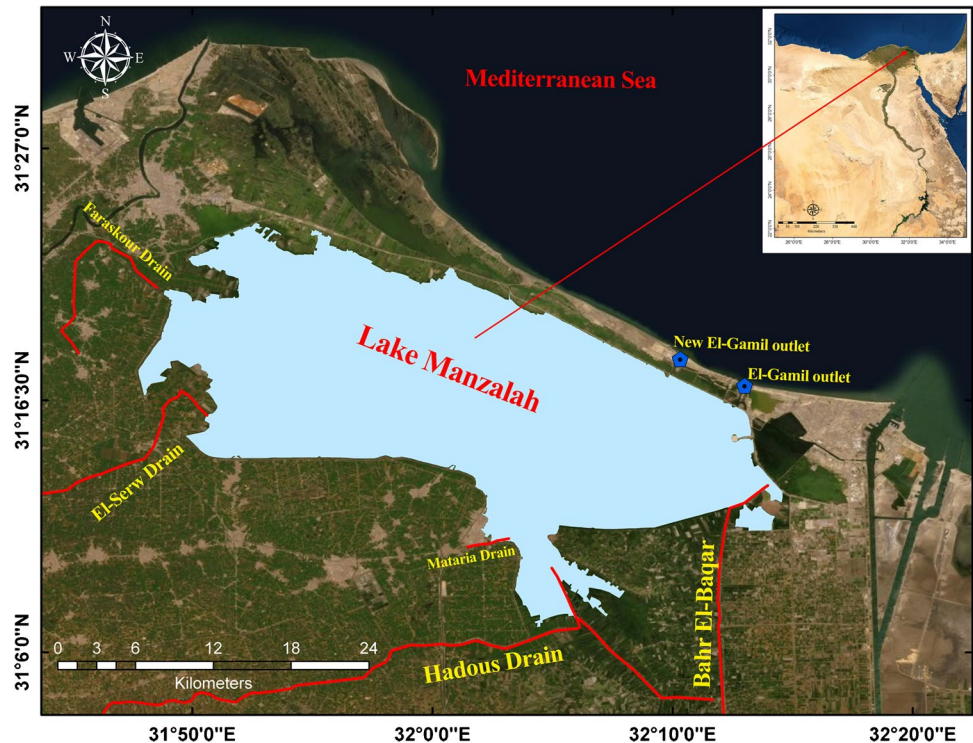
of Lake Manzala in the two periods: January 2016 and January 2022. The lake bathymetry was based on global positioning systems (GPS) and portable sonar sounders mounted on small boats. A GPS device, GARMIN 78, was used to determine the positions and record the location coordinates (latitudes and longitudes) in the study area. The satellite signal was strong, and then, the GPS position was accurate up to 3 m, according to GARMIN's manual. Let us stress that this accuracy is smaller than the size of boats used for the survey. The depths of Lake Manzala were measured using a digital Echo Sounder single beam (NAVMAN FISH 4500). The instrument operates in the dual frequency of 50 and 200 kHz for depth measurement. Basically, the low frequency is more accurate at a larger depth, whereas the higher frequency is reliable at a smaller depth. For the calibration of the instrument, the specific procedure indicated by the manual was performed. The survey of Lake Manzala was made in very tranquil conditions, with no wind and negligible surface ripples less than 0.1 m high. The vertical oscillation of the boat was consequently within the sensitivity of the used sonar instrumentation. The uncertainty of the position sounder was maintained within 0.1 m.

Data processing

RS and GIS techniques Landsat 8 data were downloaded from the website Earthexplorer.usgs.gov and were used to determine the outline of the lake's surface as well as its features: macrophytes, illegal fish enclosures, and mud

islands. The satellite images are those corresponding to the days of in situ survey. After a geometrical correction, the satellite images became a subset in the domain of collected in situ bathymetry maps, prepared in situ hydrometric surveys. A classification technique was used to determine those areas in Lake Manzala. The survey data were analyzed, and also obtained image (raster data) of the lake area was processed, using ArcGIS 10.7.1 software. This uses randomly located X–Y–Z data on bathymetry to fit a rectangular gridded surface over the lake. This included a definition of spatial reference, georeferencing, database creation, digitizing of the lake area, and identification of relevant features. All the available data were referenced to WGS 1984 (UTM zone 36 N). The storage and query of data that represents objects defined in a geometric space, principally as points, lines, and polygons, as well as their characteristics, were optimized using a geo-database. By selecting names, feature types, and spatial references, geographic feature layers were produced with the help of Arc-Catalog (see Fig. 2).

Determination of the dredged areas and their volume The collected bathymetry data was used to create an upper surface with fine grid spacing. The upper surface was given in a constant value to specify the level of the planar surface to calculate the volume. The area between two consecutive contour lines was determined from the GIS database of lake bathymetric maps (Rout et al. 2020). The dredged areas (A) were calculated using the below representation:
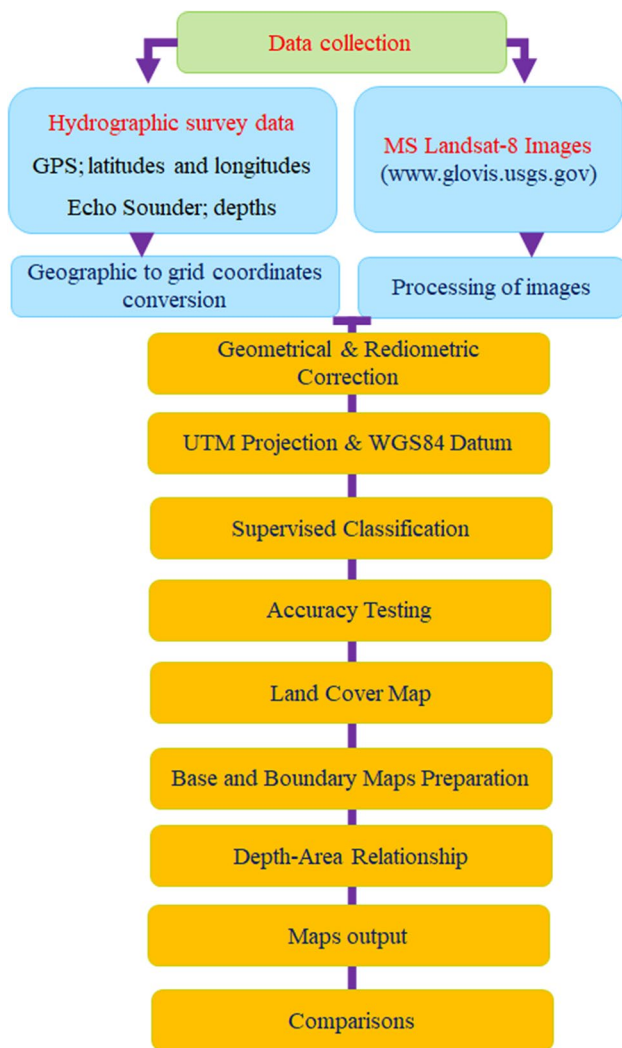
Fig. 2 Flowchart showing the processing steps used to estimate water depth, area, and also volume dredge in Lake Manzala

$$A = B - C \qquad (1)$$

B   is the estimated area at a certain depth in 2022.

B   is the estimated area at the same depth in 2016 (before dredging).

The areas between two consecutive contour lines were determined as follows (Chukwu and Badejo 2015):

$$A_d = \sum_{dmin}^{dmax} \left(B_d - C_d \right) \qquad (2)$$

d   is the depth of the area.

The dredged volume (V) was calculated by multiplying the dredged area (A) by its thickness (T) as follows:

$$V_d = \sum_{dmin}^{dmax} \left(T * A_d \right) \qquad (3)$$

In a recent study of Lake Manzala, the thickness is 0.5 m; the formula (3) can be written as follows:

$$V_d = \sum_{dmin}^{dmax} \left(0.5 * A_d \right) \qquad (4)$$

From the above formula, in areas where dredging occurred, the volume is positive, whereas in accretion places, the volume is negative.

Results and discussions

Dredging was confirmed to have taken place a dramatic change in the morphometry features. Results presented are in form of a table, charts, and graph of relevance which depicts the processed dataset analysis takes. The results of this study covered the morphometric and bathymetric survey's dataset for 2016 and 2022 covering the lake area (Figs. 3, 4, 5, 6, and 7). The summary of significant morphometric characteristics of Lake Manzala, for 2016 and 2022, was given in Table 1, and the computed dredge areas and volumes are given in Table 2. Concerning the lake's area differences between the present pair of surveys, it is clear that the lake's area slightly expanded. This slight rebound in the lake's area is considered one of the most important dredging process results, as the dredging stopped the encroachments that led to a decrease in its area in the recent decades.

Although aquatic macrophytes are an important part of the aquatic environment, however, its increase leads to environmental problems, when they grow in unwanted abundance and disturb the management of water resources (Haroon and Abd Ellah 2021); the current dredging process may be an ideal way to limit those aquatic macrophytes' growth. Results, obtained for dredging activities in Lake Manzala, show the aquatic macrophytes in most parts of the lake were removed, as part of catch areas improvements, which will be positively impacted bu the functions and biodiversity of the lake ecosystem and thus the lake's sustainability.

Illegal fish enclosure activities inside Lake Manzala have negatively impacted the functions and biodiversity of the lake ecosystem and consequently threatened the lake's sustainability. Those fish enclosures divided the water body of the lake into several sub-basins with different water and sediment characteristics and limitations in its water circulation (El-Shazly et al. 2016). Discharging huge amounts of nutrients from the enclosures caused eutrophication and excessive plant growth in the lake (Ekubo and

Fig. 3 Differences in Lake Manzala areas, between the pair of surveys for 2016 and 2022, after processing using the GIS program. The green color of the areas decreased, while the turquoise color in the areas increased
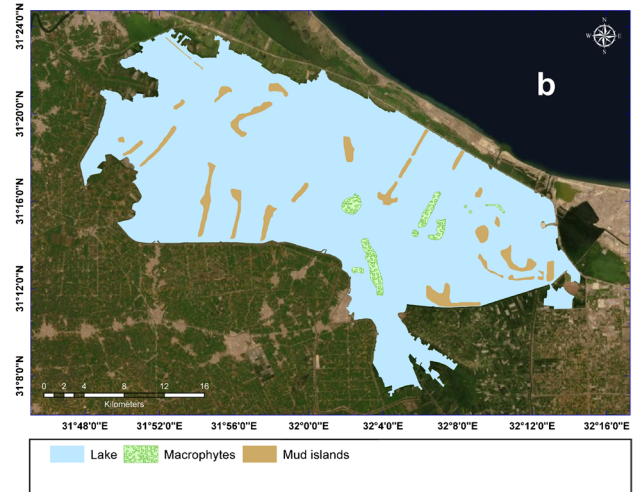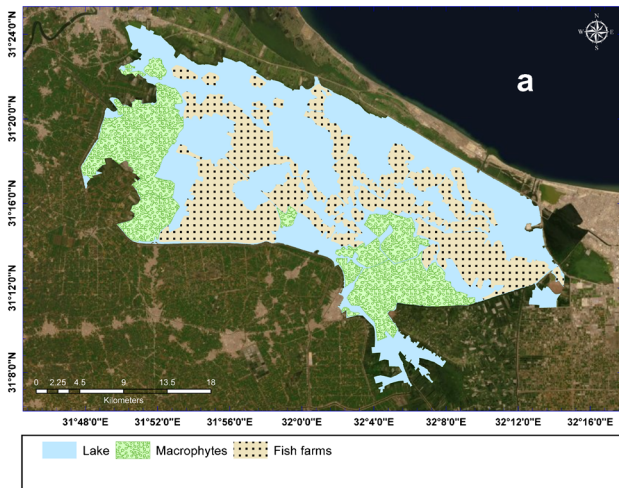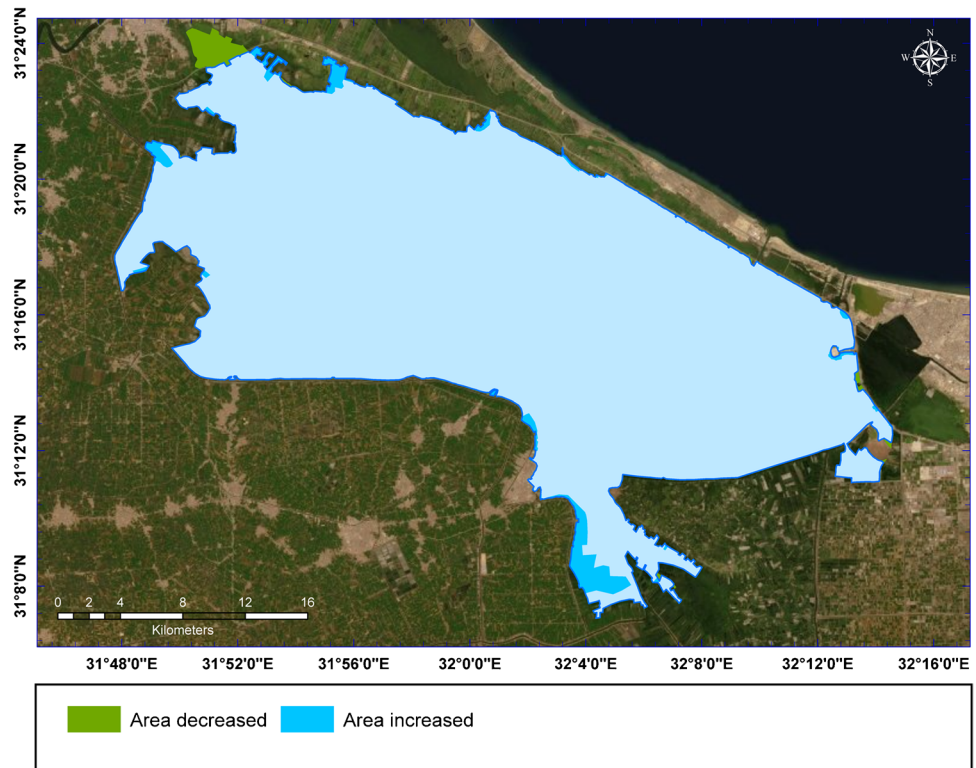

Fig. 4 Differences in features of Lake Manzala after processing using the GIS program. **a** In the year 2016 and **b** in the year 2022. The highly reducing of aquatic macrophytes, completely removing of fish farms, the appearance of muddy islands, and an increase in open water can be seen clearly

Abowei 2011) and reduce the free fishing areas and the productivity in the lake by reclamation and collection of fish fry to stock their illegal fish enclosures. Results, obtained for dredging activities in Lake Manzala, show the illegal fish enclosures have been completely removed from the water body of Lake Manzala, as part of catch area improvements.

The appearance of muddy and sandy islands during the dredging process is considered a natural matter with continuing the removal of sediment from a water body and relocating them elsewhere using mechanical dredging (Chen et al. 2020). Perhaps those artificial islands needed to dry out to become stable enough for heavy equipment. Therefore, among the associated consequences of the dredging process
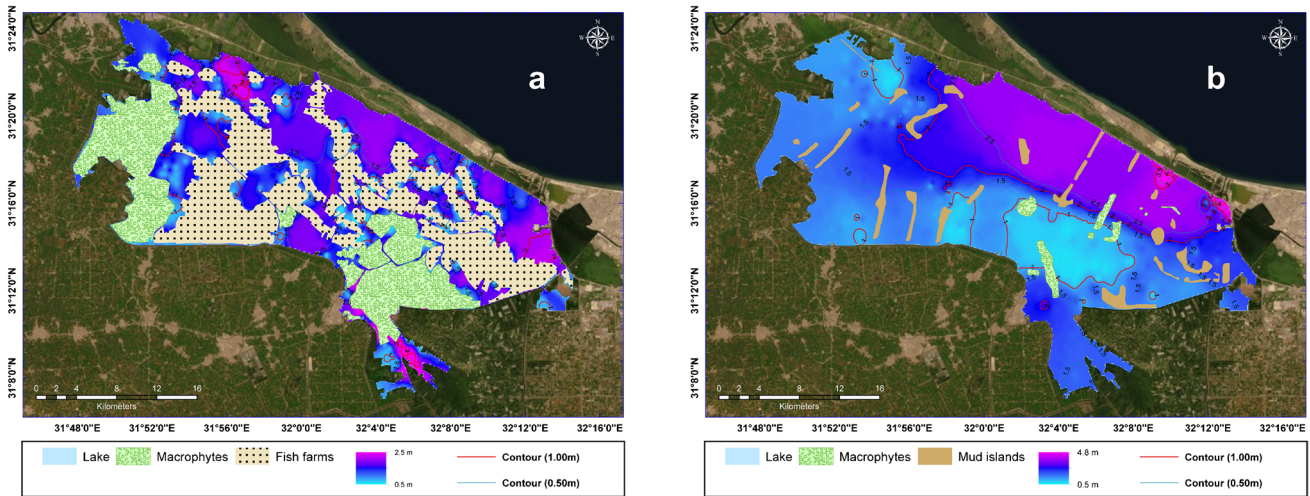
Fig. 5 Bathymetric map of Lake Manzala after processing using the GIS program. **a** In the year 2016 and **b** in the year 2022. Maps have been prepared with a three-dimensional perspective-view-shaded rendering. In the color scale, the green color represents the lake surface, whereas the red color indicates the deepest layer of the lake, in addition to the contour interval, which is 0.5 m
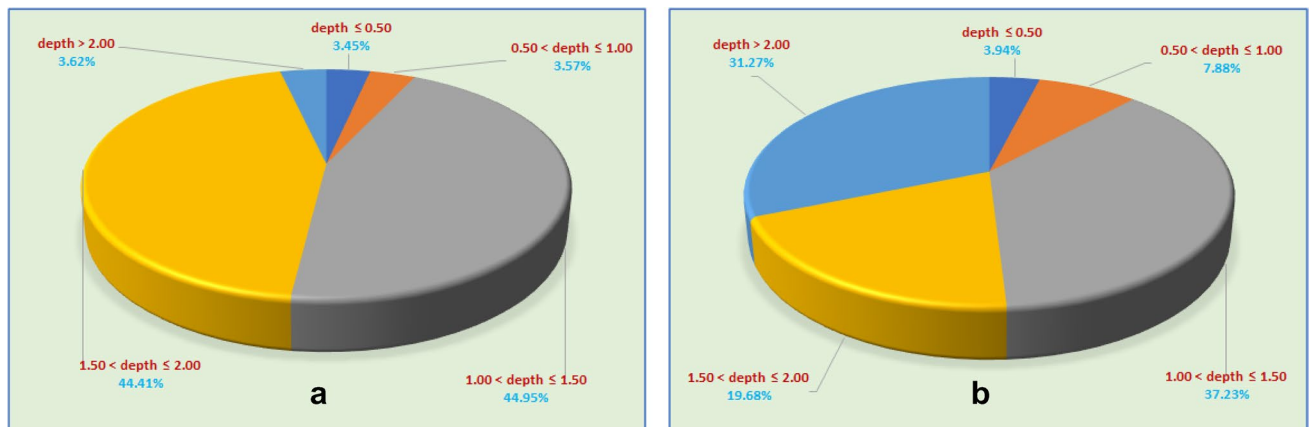

Fig. 6 Histogram showing the ratio of the water depths related to open water. **a** In the year 2016 and **b** in the year 2022. It is clear to see the extensive growth of the water depths in most of the layers of Lake Manzala, due to the dredging process

at the present time, a chain of muddy islands located in the central part with different sizes was created in Lake Manzala. Despite easily estimating the area of these islands, it was practically difficult to determine their quantity due to their different heights.

Tidal inlets are extremely dynamic environments, governed by natural processes which control their morphological variations that are often strongly modified by an anthropogenic intervention (Toso et al. 2019). The spread of illegal fish enclosures in front of the inlet and consequently the restriction of water movement in the inlet channel caused a general change of the inlet sedimentary regime from erosive to deposition in Lake Manzala. Sedimentation in the lake had a measurable impact on flow reduction and tidal damping of the inlets (El-Naggar et al. 2016). As part of those improvements, the illegal fish enclosures, which were widely spreading, have been completely removed, additionally, and the depth of the main area of those inlets was extended inside the lake. Those increases in the inlets' depths are expected to increase the discharge in the inlet channels and would increase tidal (El-Adawy et al. 2013), to give several species of fish a chance to move from the Mediterranean Sea to the lake.

Lake Manzala, once a major problem, has been relegated to minor importance with land reclamation and the transformation of considerable parts of its area into fish farms (Abd Ellah 2021). The environmental situation of Lake Manzala has begun to worsen in past decades due to poor

Fig. 7 Photographs showing eight aspects of Lake Manzala. **a** Aquatic macrophytes, **b** illegal fish enclosures, **c** muddy islands, **d** mechanical dredging using a crane and barge, **e** the hydraulic dredging with a pipeline, **f** the cleanliness of open water, **g** in front of El-Gamil inlet, and **h** in front of the new El-Gamel inlet. Notice that photos **a** and **b** were taken in 2016, while the rest photos were taken in 2022

Table 1 Summary of significant morphometric characteristics of Lake Manzala estimated using the lake bathymetric measurements with GIS

Features	Unit	2016	2022
Water level	Above MSL	1	1
Latitudes range	Deg., min, s	31° 07′ 02.7″ N–31° 24′ 27.1″ N	31° 07′ 03.2″N– 31° 23′ 53.7″ N
Longitudes range	Deg., min, s	31° 47′ 44.8″ E–32° 14′ 34.2″ E	31° 47′ 45.4″ E–32° 14′ 35.0″ E
Length	km	43.6	43.6
Mean width	km	13.0	13.1
Surface area	km^2	565.91	571.96
Open water	km^2	260.12	532.58
Macrophytes	km^2	123.42	10.19
Illegal fish enclosures	km^2	182.37	0
Mud islands	km^2	0	29.19

water exchange with the sea, aquatic macrophytes' growth extensively (Haroon 2002), and reduced depth (Elshemy and Khadr 2015). Lake Manzala was characterized by its very shallow water due to silting up of sediment originating from the high load of discharged particles from the drains. However, the current results show the results of the dredging process yet. The water depth varies across the lake, from the higher depths near the entrance to the Mediterranean Sea to the lower depth in the southern zone. As the pie charts (bathymetry ratios) for the years 2016 and 2022 revealed changes in the bathymetry ratios due to dredging that occurs at the bottom of the lake, the results indicated the presence of growth for most depths. Where the extensive growth of the water depths in recent years is supposed to be allowed allows the lake water circulation. As one of the most important results of bathymetric applications to evaluate the dredging process, bathymetric maps formed to show a clear high amount of sediment removal, with a focus on the northern and the middle area of Lake Manzala. According to volume calculations based on the change grids during the dredged period from 2016 to 2022, approximately 524.94 million m^3

Table 2 Calculation of dredging areas of Lake Manzala, of surveys for 2016 and 2022, estimated using the lake bathymetric measurements with GIS

Depths range (m)	2016		2022		Volume change (million m^3)
	Area (km^2)	Volume (million m^3)	Area (km^2)	Volume (million m^3)	
Depths ≤ 0.50	9.00	2.25	20.99	5.25	3.00
0.50 ‹ depths ≤ 1.00	9.28	6.96	41.98	31.49	24.53
1.00 < depths ≤ 1.50	116.92	146.15	198.27	247.84	101.69
1.50 < depths ≤ 2.00	115.51	202.14	104.84	183.47	− 18.67
Depths > 2.00	9.41	21.17	166.49	435.56	414.39
Sum	260.12	378.67	532.58	903.61	524.94
The removed dredging	524.94 million m^3				

were dredged and were removed (including aquatic plants, fish enclosures, and sediments) and disposed of outside of Lake Manzala. Recent results, obtained for dredging activities in Lake Manzala, show the ability to support technical choices during the planning and operational phases and protect the lake for years to come.

Conclusion and recommendation

Dredging is a common practice in lake environments. The present review investigates Lake Manzala's morphometrical changes and possibly the cause. The stages of this review include the following: data acquisition, processing analysis, and documentation. The study has shown that with the availability of sophisticated data processing equipment and software, it is possible to measure and monitor changes in morphometrics with greater accuracy and spatial detail, output the data in a visually appealing and useful format, and then manipulate the data easily. Therefore, it serves as good reference material for decision and policy formulation relating to the lake management. However, this article should not be interpreted as a carte blanche endorsement of findings; rather, it should be interpreted as a demand for more rigorous research into the occurrences presented. Then, it is strongly recommended that an integrated lake management plan needs to be embraced, by which activities of the dredgers would be monitored, and environmental impact analysis has been strictly adhered to.

Declarations

Ethical approval Not applicable.

Conflict of interest The author declares no competing interests.

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