Investigating the Improvement of Water Circulation of the Egyptian Northern Lakes, Case study "Al-Manzala Lake"

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Abstract – Lake Manzala is the largest lake along the Egyptian Mediterranean coast. It is in northeastern Egypt on the Nile delta near Port-Said City. The lake is long, quite shallow and suffering from severe ecological problems during the last years. The discharge of polluted water from five main drains is drained in the lake causing negative ecological, health, social and economic impacts. The main goal of this paper is to investigate the effects of excessive drainage water on both water levels and salinityin the lake. A 3-D hydrodynamic numerical model was developed for the lake using Delft 3D modelling system. Mitigation process has been studied to enhance the mixing between lake water and seawater. The optimum mitigation was achieved by reducing the water level in the lake through decreasing the effluents from Bahr El-Baqrdrain and enhancing the density current from seawater to the lake via increasing water depth inside the lake by dredging the total area of the lake. Also, all obstacles due to human interaction such as fish cages, weeds, and islands inside the lake must be removed.

Keywords: hydrodynamic model, Delft 3D, lake salinity, Bahr El-Baqr drain.

1. INTRODUCTION

Manzala Lake is the largest shallow lake located in the Northern shoreline of the Nile deltaof latitudes (31°10" to 31°40" N) and longitudes (31°50" to 32°25" E), (El-Badry, 2017).Its length is about 60 km with average water depth of about 1 m.The lake is bounded from the north by the Mediterranean Sea, from the east by the Suez Canal. Also, the lake is bounded through Dakahlia and Sharkia provinces from the south and Damietta governorate from the west,(Hossen and Negm, 2016 and Mageed, 2007).The lake is connected to the Mediterranean Sea through a three-outlet opening calledBoughaz, which are El-Soffara, El-Gamil, and the new El-Gamil, (Elewa et al.,2007).The three Boughaz are responsible for exchanging water between the lake and the Mediterranean Sea, in addition to refreshing the lakes' ecosystems, (Abdel Azim et al., 2018).Also, the lake is connected to the Suez Canal via a verynarrow connectingchannelcalledEl-Qabuty channel. Otherlaterals enrich the lake by Nile freshwater originating from the Damietta branch, which areAl-Enania and Al-Rotma canals, (Abdel Azim et al., 2018).Due to the aggressive encroachment (fishcatchers, islands, reclamation activity and construction of the coastal highway), the surface area of Manzala Lake had drastically reduced from1100 km^2 in 1973to 1052 km^2 in 1984 and finally became 720 km^2 in 2003 with an average depth of 1.15m, (Hereher, 2014). The lake includes over 1000 islands (15% of the lake's area) distributed over the whole areawhich divides the lake into approximately 30 basins with a total area of 1318 ha andmost of these islands are inhabited by fishery grounds and farmers, (Randa et al., 2017). The shallow water lakes in Egypt are considered the most valuable sources of fish especially Lake Manzala as it contributed about 35% of the total country fish production during the 1980s, (Khalil, 1990). Currently, it contributes about 36-50% of the total annual production of the Egyptian lakes, (Randa R. Elmorsi et al., 2017).

Manzala Lake is a dynamic aquatic system that has turned from a brackish to a more freshwater state over the past 50 years, (Khalil, 1988). This change had greatly accelerated due to the increase in drain water inflows. The lake receives drainage water fromfive heavily polluted drains. These drains are Bahr El-Baqar, Hadous, Al-Serw, Matareya and Faraskur which considered the main important sources of pollution with total discharge about 4000 Million m^3/year, (Wael H. Hegazyet al., 2016).Bahr El-Baqar drain is the most polluted drain pumped to lake Manzala,(Abdel-Shafy and Aly, 2002), as it contributes about 45% of the total discharge, (Stahl et al., 2009). This drain receives polluted water from two lateral drains Belbeis drain and Qalubiya drain, (M.K. Abdel-Fattah, and A.M. Helmy, 2015).The drain has different sources of pollution of industrial wastewater both treated and raw,treated sewage andland drainage of some cultivated areas, (El-Kiki, 2018).

For the current situationManzala Lake can be divided into two main regions according to salinity.The first region is the southern region of the lake which characterized by lower values of salinity, high concentration of nutrients and heavy metals due to the existence of drains. The second regionis the north part of the lake near to the lake-sea connections which characterized by relatively high salinity values and low nutrient concentration as a result of seawater interaction through the outlet openings, (El-Gawady, 2002 andShakweer, 2005).Nutrients from the drains have created eutrophic conditions, which have changed the aquatic biota lending to a less diverse but highly productive system,(Khalil, 1988).Due to the increase in nutrients loading and freshwater inputs mullet and other marine species declined significantly, (Bayoumi, 1988). Delft3D-flow module was utilized in several studies to develop a field validated hydrodynamic models. Issues related to hydrodynamicswere investigated in Lake El-Burullus, which is the second largest lake in the Egyptian northern coast, (El-Adawy, 2013).A hydrodynamic and water quality model was builtfor Lake Mariout in Egyptto identify the most critical surface drainage water quality indicators, (El Naggar, 2017).Thehydrodynamic and water circulation indices were applied using numerical models to quantify hydrodynamic conditions in Lake Taihu, which is the third largest lake in east China (Sien Liu, 2013).

2. MATERIALSANDMETHODS

To investigatethe hydrodynamic conditionof Manzala Lake, data collection and numerical hydrodynamic modelingwerecarried out.Delft3D Software Package developed byDeltares, Netherlands, was employed to simulate the hydrodynamic flow condition of the lake in bothtwoand three-dimensional modeling schemes covering the whole lake area.

3. DATACOLLECTION

3.1 The Bathymetric and Topographic Data

Data included water depthsinside the lake, land boundaries and all lake islands, providedby National Authority for Remote Sensing and Space Sciences (NARSS) based on the mission in 2004 and itsupdates in 2014.

3.2 Effluent Discharges from Drains

Data measurements and records gathered from the Egyptian Drainage Authority and Drainage Research Instituteduring2012.

3.3 Salinity Measurements

Data for salinity in the sea and the lake measured by Coastal Research Institute (CORI).

3.4 Current Dredging Works

As part of the Egyptianplan to develop Lake Manzala, the dredging works and constructionof three ray channels inside the lake near the three boughazesstarted few months ago. These ray channels had a depth of 3m, which has been taken into consideration in this study.

3.5 Tidal Data

Data records provided by CORI and Shore Protection Authority (SPA).

4. ANALYSESOF DATA

4.1 Delft-3D Numerical Modeling

The hydrodynamic model was set up based on the collected data. The model computational grid has been developed to match the layout of the land boundary using a curvilinear grid technique. It extends 16 km offshore to a depth of 13 min the sea, 55 km parallel to the shoreline, and 25 km inside the lake. The grid resolution was increased in the area closed to the inlets (boughaz) which connected the lake to the sea to provide enough points of calculation tosimulate the interaction process between the sea and the lake in the right way, as shown in Figure (1). The grid orthogonality and smoothness had been checkedto satisfy the model required criteria.

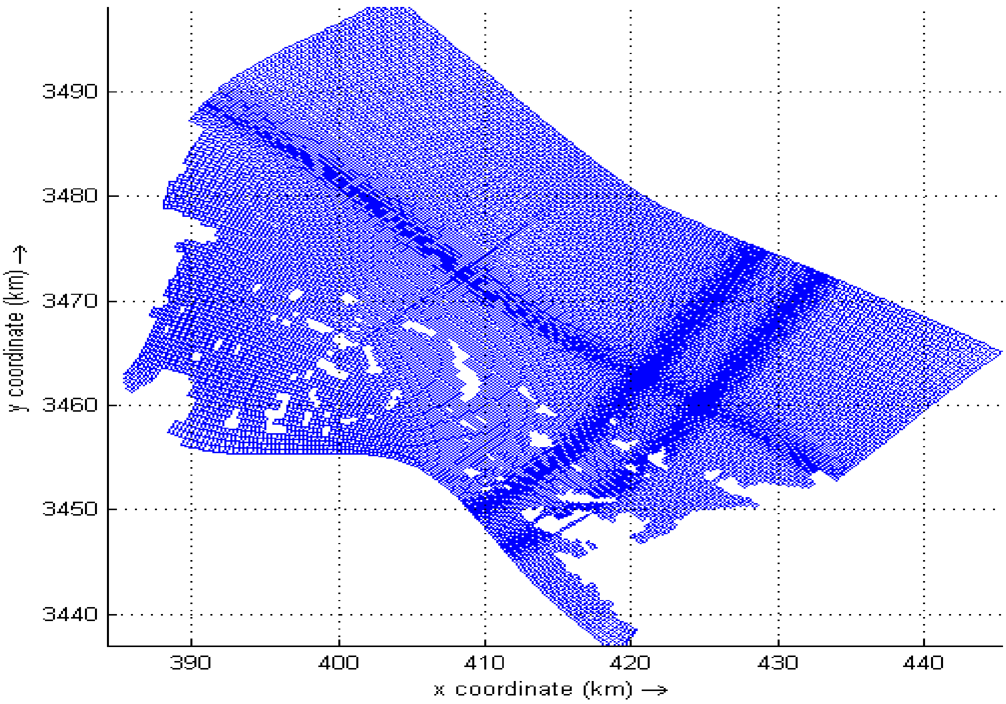

Figure (1) Computational Grid of the Flow Model of the Lake

The bathymetric data have been mapped through an interpolation procedure on the computational modelgrid to create the model bed levels, as illustrated inFigure (2).

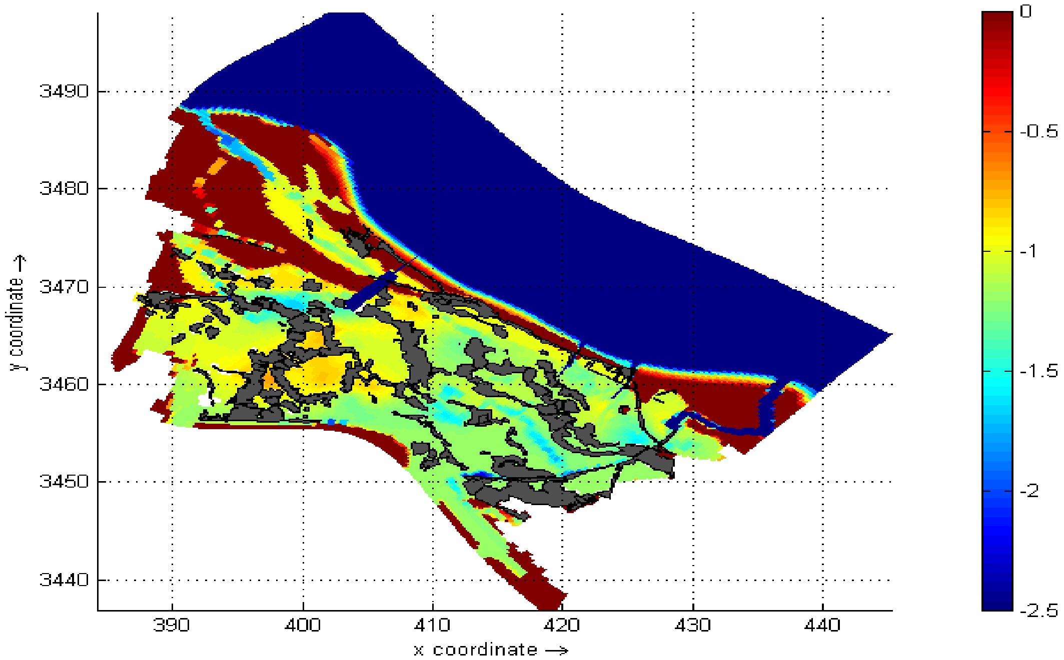

Figure (2) Water Depth inside the Lake

The tidal water level variations were incorporated into the model boundaries through the harmonic constituents (tidal amplitude and phase) that were driven by tidal analyses of the measurements of water levels.The time step selected for the model simulations based on the grid size and the Courant Number.

4.2 Drainage Effluents

Drainage effluents were modelled as discharge points with the measured drainage effluents defined for each one of them as a time series.Five discharge points were defined at the exact locations of drains outfalls of Bahr El-Baqar, Hadous,El-Matareya, El-Serw and Faraskour located in the south and west parts of the lake.Based on a statistical analysis of one-year recordsduring 2012, a boxplot was used to represent the drains effluents, as shown in Figure (3), which displays the dataset based on a five-number summary (the minimum, the maximum, the sample median, and the first and third quartiles) to each drain.

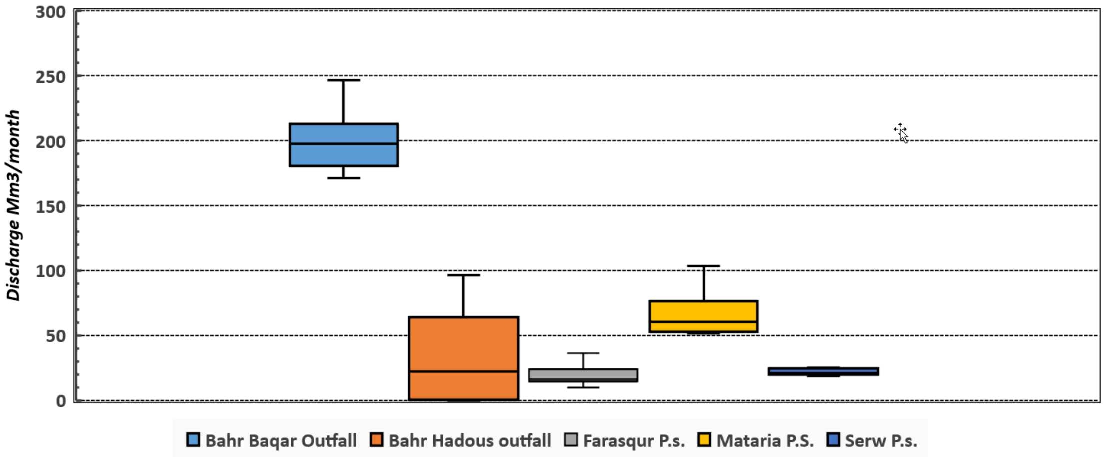

Figure (3) Drainage Water Effluents to El-Manzala Lake for the Year 2012

4.3 Model Scenarios

4.3.1 Baseline Condition

The current state of the lake has been studied hydrodynamically. Three ray channels were constructedrecently towards the lake through the three tidal inlets El-Soffara, El-Gamil, and the new El-Gamil. These ray channels had3 m depth and started from inlet with sea and extended 3 km inside the lake. Also, the narrow tidal inlet Boughdady was enlarged to 100 m width to improve the efficiency of the tidal inlets, which affect the water exchange between the Mediterranean Sea and the lake. The lake boundaries, all drains effluents, islands' locations and ray channelswere simulated in the model and the model was run with its three-dimensional scheme for a year simulation period.The current situation of the lake was used as a baseline condition for comparison between the proposed solutions to find the optimum one.

4.3.2 Model Scenarios

Different scenarios were proposed as follows:

- **Scenario 1:** Removing fish-cages and islands, this model scenario aims to assess the effect of removing the obstacles that hinder the flow circulation inside the lake and salinity impact consequently.
- **Scenario 2:** Removing fish-cages and islands and reducing the discharge of Bahr El-Baqar drain about 5 million m^3/day.
- **Scenario 3:** Removing fish-cages and islands and increasing the water depth inside the lake to be 3m. That is to investigate the effect of water depth on the advection and diffusion processes of relatively highly saline water from the sea after mixing with the lake water body.
- **Scenario 4:** It is a combination between scenario 2 and scenario 3. Where it included the removal of all fish-cages and islands, reducing Bahr El-Baqar drain discharge by 5 million m^3/day and increasing the water depth of the lake to 3 m.

5. RESULTSANDDISCUSSION

5.1 Hydrodynamic Results

The results of hydrodynamic model were represented by the variation of water level inside the lake because the increase in water level of the lake had negative impact on mixing processes between seawater and lake water,where the tidal range in the Mediterranean sea is 0.35 m (+0.17 m high water and -0.17 m low water).The model results for water level during the spring tidal cycle of the sea and the lake under different model scenariosare shown in Figure (4).

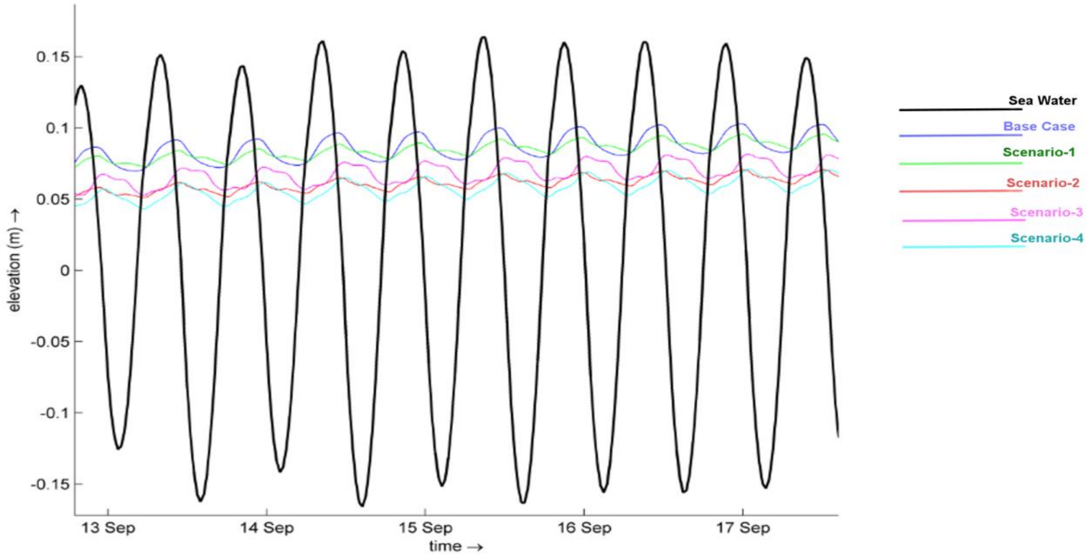

Figure (4) Comparison between Lake Water LevelsforDifferent Scenarios and the Seawater LevelsDuring Spring Tide

Also, Figure (5) shows the water level results all over the total simulated period (1 year) for all studied scenarios compared with the current situation in the lake.The results of all model scenarios showed that the water level inside the lake was above the mean sea level (0.00) due to the huge amount of discharge entering the lake through drains.

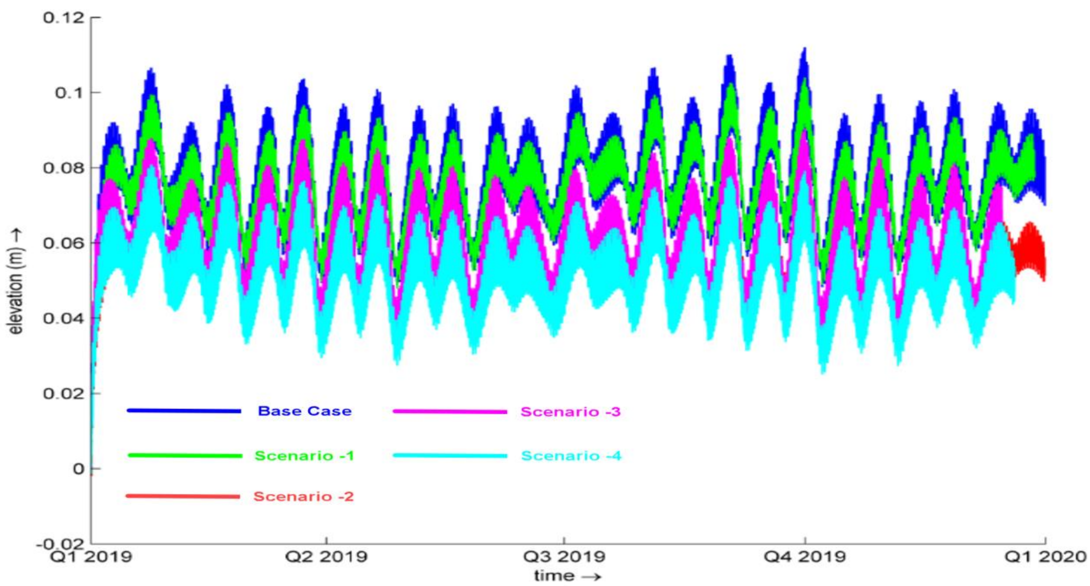

Figure (5) the Lake Water LevelsAllOver the Total Simulated Period (1Year)

However, water level variations inside the lake were relatively affected in scenario 4 compared with the results of other scenarios. The results of the water levels inside the lake in scenario 4 were decreased by about 40% than the value of the water levels in the current situation.This means that more seawater will enter the lake in high tide, consequently the water circulation inside the lake will be enhanced.

5.2 Salinity ConcentrationsInside the Lake

The studied scenarios were evaluated based on the salinity inside the lake whose values ranged from weak to noticeable through the area of the lake. The increase in salinity concentration and its distribution inside the lakewas mainly related to increase the salt intrusion from the sea to the lake. This salt intrusion was clear by decreasing the water levels of the lake to allow more saltwater to flow through tidal inlets to the lake. The salt intrusion also positively affected by decreasing the bed level of the lake which enhanced the interaction between the lake and the seawater due to density current.

From the salinity point of view,the lake was classified into two main parts. The southern part of the lake which had lower values of salinity due to the existence of drains andthe second part at the northern side of the lake which had relatively high values of salinity due to seawater interaction through the lake inlet. Due to the existence of islands and a lot of other obstacles (fish cages, weeds...etc.), theinteraction between the seawater and the lake was very poor. In case of current situation (base case),the salinity values inside the lake after one year of simulation period ranged between 5 ppt in the southern side (area near drains effluents) and 10 ppt in the middle part of the lake,while the values of salinitywas increased to15 pptnear the lake inlets (connecting lake with sea)in the northern areas. Figure (6) shows the salinity distribution values in the layernear to bottomafter one year of model simulation.

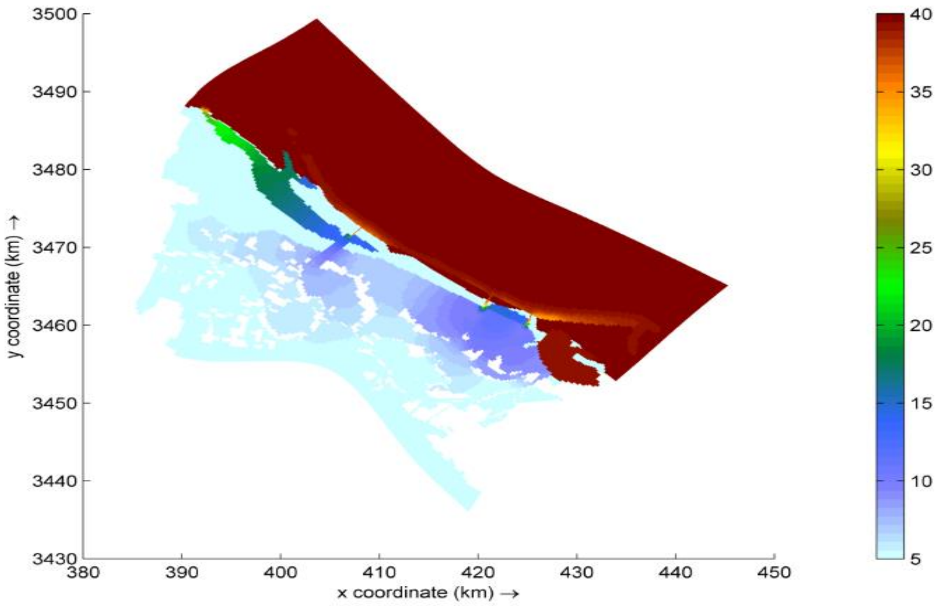

Figure (6) Salinity Concentration (ppt) Inside the Lake for the Current Situation (Base-Case)

In case of removing all obstacles (islands, fish cages, weeds…etc.) in the lake (first scenario), the water circulation inside the lake was enhanced but had an insignificant impact on the salinity values due to the continuous discharged effluents from drainsto the lake.The salinity still had values ranged from 5 ppt in the southern partsto 15 ppt near the tidal inlets in the northern areas.Figure (7) shows the salinity distribution in the layernear to bottom for scenario 1.

By reducing the discharge amount coming from the largest drain in addition to removing all obstacles (scenario 2), the salinity value was significantly affected. Where decreasing drain water discharges reduced the water levels inside the lake allowing

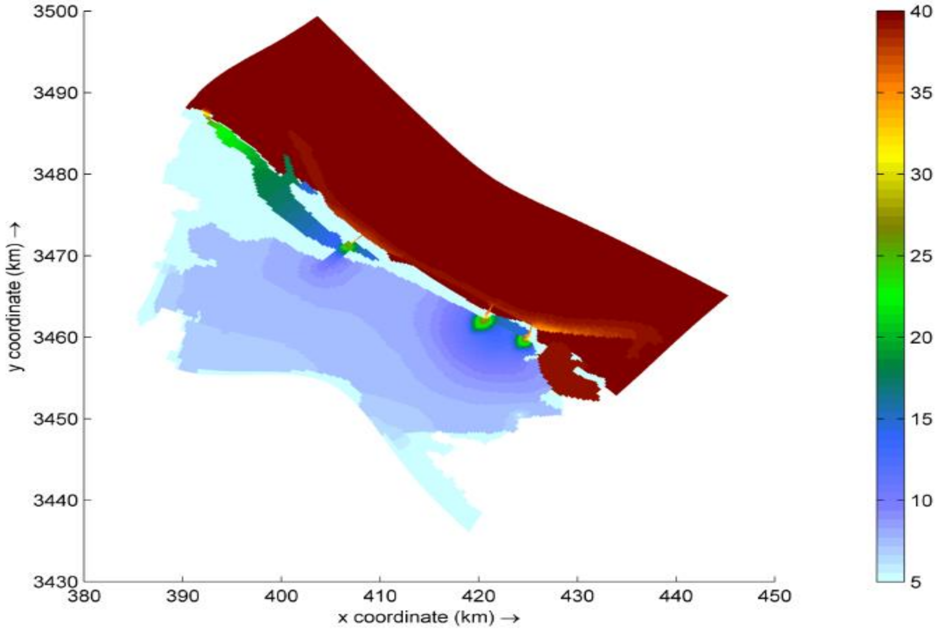

Figure (7) Salinity Concentration (ppt) Inside the Lake for Scenario 1

More seawater quantities to flow through the lake in high tide. In this scenario (scenario 2) the model results showed thatthe salinity values were about 10 ppt in the southern side and gradually increased tobe about 15 ppt inside the lake. The maximum values of salinity were obtained in the area near the tidal inlets in the northern parts of the lake which was about 20 ppt.Figure (8) shows the salinity distribution in the layernear to bottom according to scenario 2.

The effect of increasing water depth by removing all obstacles had been studied in scenario 3. The model results showed an increase of salinity concentration in the lake at the layer near to the bottom. The increase of water depth in the lake had a positive effect on density current and salt intrusion from sea to lake. The salinityvaluesof the lake were about 15 ppt in the southern parts of the lake and 17 ppt inside the lake. While the salinity values in the northern areas were about 25 ppt. Figure (9) shows the salinity distribution in the layernear to bottomin scenario 3.

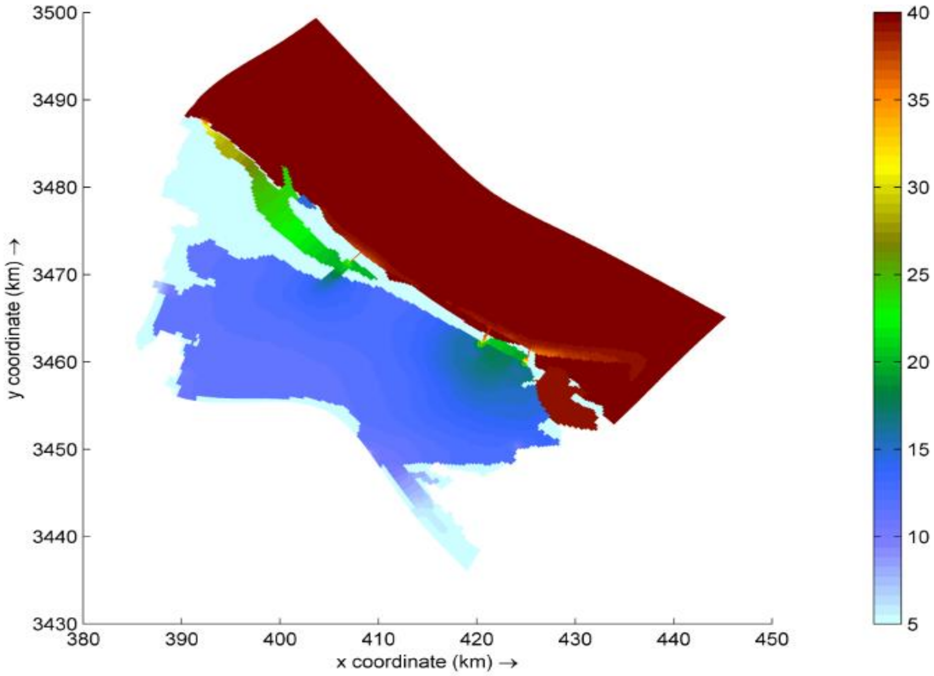

Figure (8) Salinity Concentration (ppt) Inside the Lake for Scenario 2

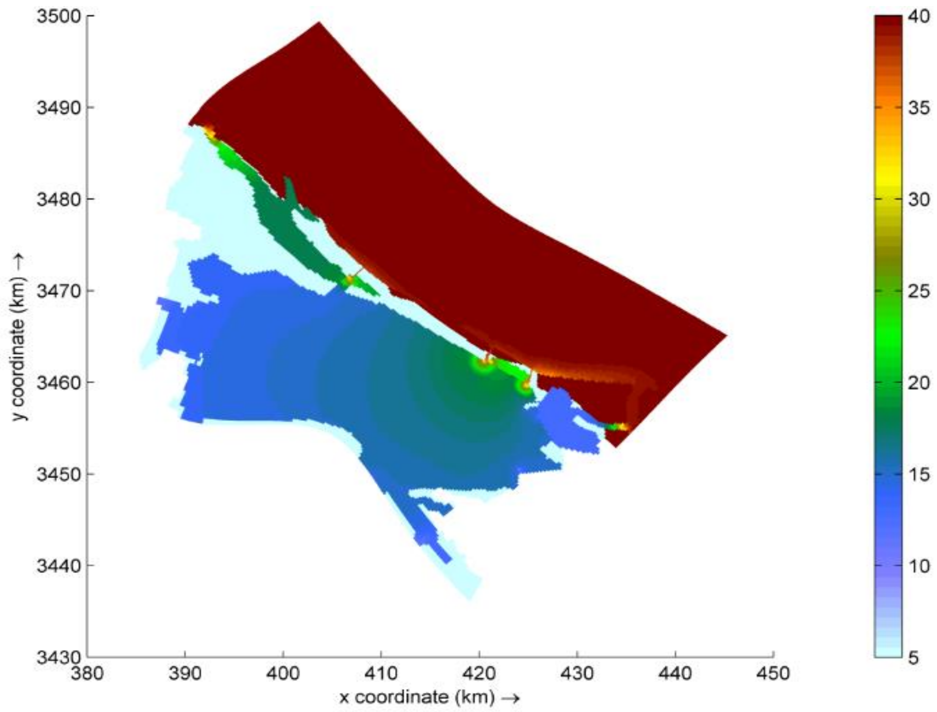

Figure (9) Salinity Concentration (ppt) Inside the Lake for Scenario 3

Scenario 4 investigated the effect of the combination of the most effective actions which were reducing water discharged from Bahr El-Baqr drain, increasing water depth and removing obstacles. The results of the model in scenario (4) showed better results for increasing of salinity values due to density current and water levels reduction in the lake. This salinity was increased to 20 ppt in the southern parts and inside the lake. These values gradually increased in the northern areas to be 25 ppt. Figure (10) shows the salinity distribution in the layernear to bottomin scenario 4, while Figure (11) represents a comparison between all scenarios concerning salinity.

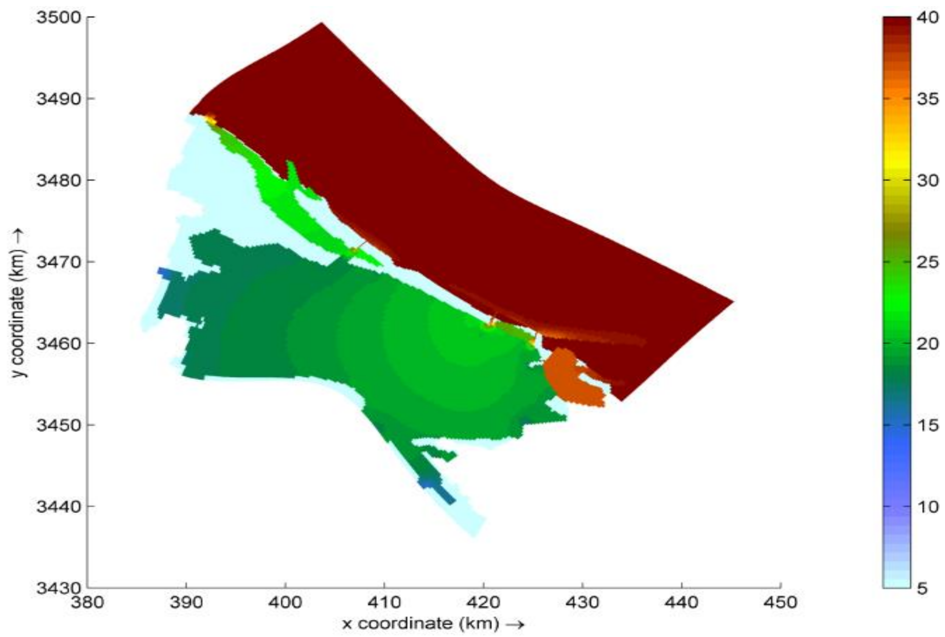

Figure (10) Salinity Concentration (ppt) Inside the Lake for Scenario 4

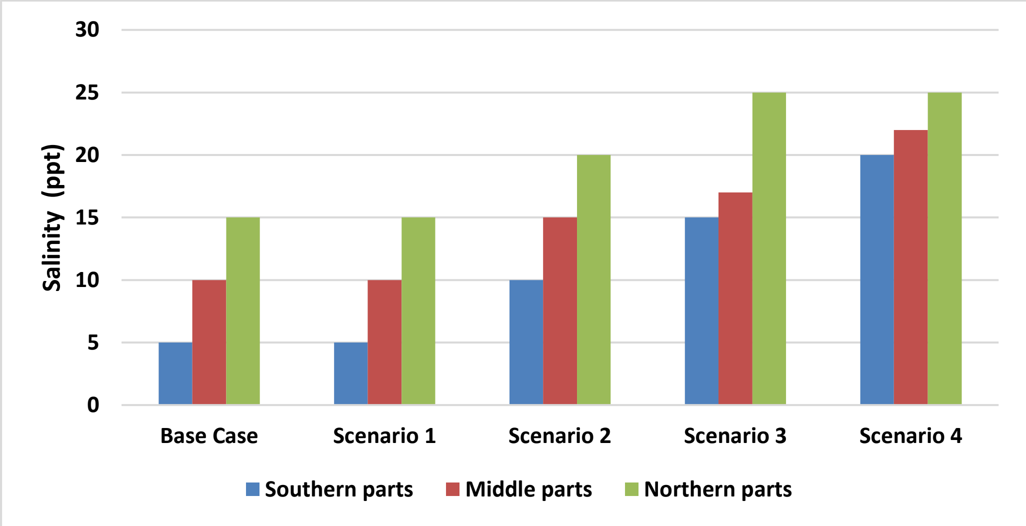

Figure (11) Comparison of Salinity Values between All Scenarios and the Current Situation.

6. CONCLUSION

It became clear that the main problems of the Manzala lake were related to the amount of discharged polluted water coming from drains which lead to low salinity values inside the lake. Increasing the quantities of water entering from the sea to the lake could overcome these problems and improve the distribution of the degree of salinity. This point was achieved by 2 main processes.The firstprocesswas reducing water discharge coming from Bahr El-Baqr drain. Decreasing drain water discharges reduced the water levels inside the lake and allowed more seawater quantities to flow through the lake in high tide (scenario 2).The second process was increasing the water depth inside the lake by dredging the total area of the lake. Increasing water depth in the lake had positive effect on density current and salt intrusion from sea to lake (scenario 3).The effect of combination of reducing water discharge from Bahr El-Baqr drain, increasing water depth and removing obstacles showedbetter results of the model increasing of salinity values due to the constructive effect on both of density current and water level reduction in the lake (scenario 4).

7. ACKNOWLEDGEMENTS

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