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***Journal of Scientific and Engineering Research*, 2021, 8(8):59-67**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Assessment of Surface Water Quality of Manzala Lake, Egypt under Different Mitigations using Water Quality Indices

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Abstract Manzala lake is a model example of shallow water bodies exposed to huge amounts of drainage water containing organic and inorganic pollutants, which can be thrown in it directly or indirectly. This research aims to assess the water quality condition of Manzala Lake using the method of water quality index. The existing situation of the lake water quality is evaluated and used as a baseline for comparison with the lake water quality condition under different modeled scenarios of enhancement. To calculate the lake indices, a 3-D hydrodynamic numerical model is developed, coupled to a water quality module for the lake using the Delft-3D modeling system. The weighted arithmetic mean method is used to calculate the water quality index of the lake. The results of the model simulation imply that the improvement in the water quality of the lake is directly proportional to the increase of sea lake interaction and the reduction of the polluted effluents from drains. The optimum water quality index is achieved by reducing the water level in the lake via decreasing the effluents from the Bahr Al-Baqar drain and enhancing the density current from seawater to the lake by increasing water depth inside the lake by dredging the total area of the lake. All obstacles due to human interaction inside the lake must be removed in addition to constructing a new inlet through the Mediterranean Sea. It is concluded also that the lake is on the threshold warning of heavy metals according to the metal index method.

Keywords water quality modeling, Delft-3D, Manzala Lake, water quality index, metal index

Introduction

Manzala Lake is Egypt's most important coastal lagoon among the Egyptian northern lakes. It is located in the Northern shoreline of the Nile deltaof latitudes (31°10" to 31°40" N) and longitudes (31°50" to 32°25" E), [1]. It lies within the borders of five Egyptian governorates (Dakahliya, Damietta, Port Said, Ismailia, and Sharkiya). The surface area of the lake is about 700 km^2 with an average depth of 1 meter [2]. The lake is connected to the Mediterranean Sea through three-inlet openings called Boughaz, which are El-Soffara, El-Gamil, and the New El-Gamil [3]. Avery narrow channel called the El-Qabuty channel connects the lake to the Suez Canal. Other laterals that connect the lake with Nile freshwater originating from the Damietta branchare Al-Enania and Al-Rotma canals [4].

Manzala Lake is a dynamic aquatic system that has turned from a brackish to a more freshwater state over the past 50 years [5]. This change had greatly accelerated due to the great amounts of wastewater conducted into the lake. As shown in Figure 1, the main drains that dispose of water in the lake are Bahr El-Baqar, Hadous, Ramsis, Matarya, Serw, and Farascour. These heavily polluted drains contribute to a total discharge of about 4,000 million m^3/year [6].

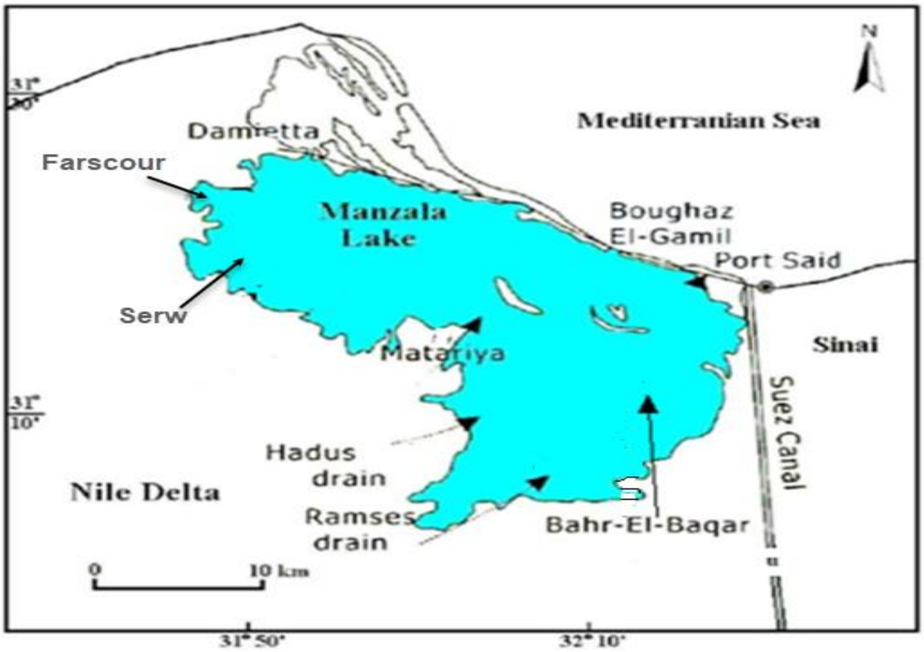

Figure 1: Main Drains that Dispose of Water in Manzala Lake

The Lake is a vital economic resource as it is considered a chief source of fish in Egypt. It contributes nearly 50% of the total country yield during the early 1970s and 35% during the 1980s [7]. Currently, it contributes about 36-50% of the total annual production of the Egyptian lakes [8]. Pollution is the most dangerous factor facing the lake specially Bahr Al-Baqar drain output, as it raised the water level of the lake due to the amount of polluted water discharged in it, which led to the lake's inability to receive seawater, consequently increased the growth and spread of plants densely and the expulsion of marine fish. The pollution of Manzala Lake has been studied by many researchers [9, 10,11,12,13, 14]. Hydrodynamic, ecological, and water quality modeling studies had been developed for Manzala Lake in some researches using different software [15, 16, 17, 18].

In this paper, the water quality index (WQI) technique using the weighted arithmetic mean method was used to calculate the water quality index for Manzala Lake. Selection of Physico-Chemical parameters used to calculate WQI were based on the important parameters for aquatic life. The evidence of pollution in Manzala Lake is a basis for selecting the water quality parameters like Biological oxygen demand (BOD), Chemical oxygen demand (COD), Amonium (NH_4), Inorganic Matter (IM), and Total Coliform Bacteria (*T. Coli*) as significant indicators parameters of surface water quality.

Materials and Methods

To investigate the water quality index (WQI) of Manzala Lake, data collection and numerical hydrodynamic and water modeling were carried out. Delft-3D Software Package developed by Deltares, Netherlands, was utilized to simulate the hydrodynamic flow and water quality conditions of the lakein three-dimensional schemes covering the whole lake area. The calibrated hydrodynamic model that was previously developed by [19] was used and extended in the current study. The hydrodynamic results were coupled to a water quality module (Delwaq) to simulate the dispersion and diffusion of substances representing the lake water quality enhancement due to the proposed scenarios. The analysis of the model results using the technique of WQI was applied to assess the effect and enhancement of each proposed scenario.

Data Collection

The bathymetric and topographic data included water depths inside the lake, land boundaries, and all lake islands were provided by National Authority for Remote Sensing and Space Sciences (NARSS) based on a mission in

2014. Tidal data records were provided by Coastal Research Institute (CORI) and Shore Protection Authority (SPA). The data for water quality modeling inside the lake and the drainage effluent of the six drains were collected from the monitoring network of the Ministry of Environment, Egyptian Environmental Affairs Agency (EEAA).

Delft-3D Numerical modeling

The 3D water quality model consists of the main water quality parameters that are foreseen to be the main pollution indicators in the lake system. The results from the hydrodynamic model were coupled to the water quality module to investigate the effect of different water quality substances discharging to the lake from the six drains, which are the main reason for the bad water quality situation in the lake. The calibration of the water quality module was carried out by comparing the values of water quality parameters (substances) of the modeled substances at specific monitoring stations inside the lake with the field measurements at the same stations.

Figure 2 represents the overview of the modules and data flow diagram in D-Water Quality. The model was calibrated showing acceptable patterns compared to the field measurements, as shown in Figures 3, 4, and 5, representing samples of the calibrated water quality parameters.

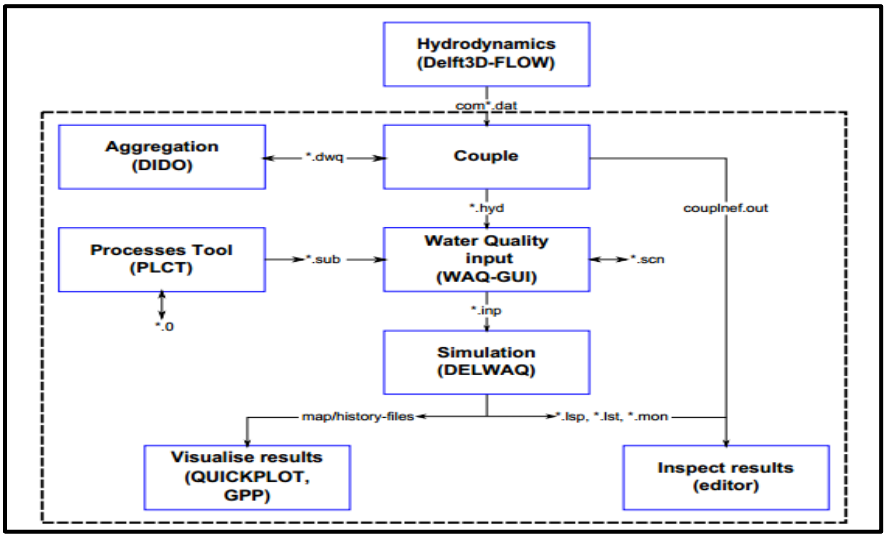

Figure 2: Overview of the Modules and Data Flow Diagram in D-Water Quality

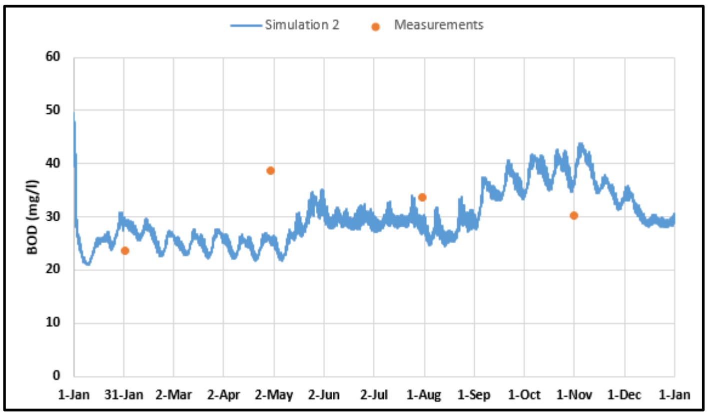

Figure 3: BOD (mg/l) Comparison at WQ-Station 2

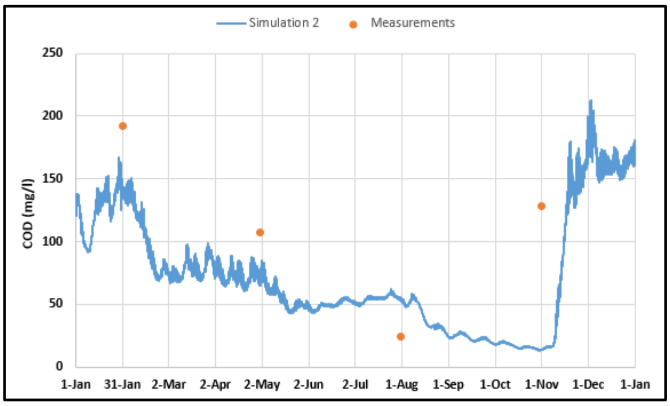

Figure 4: COD (mg/l) Comparison at WQ-Station 2

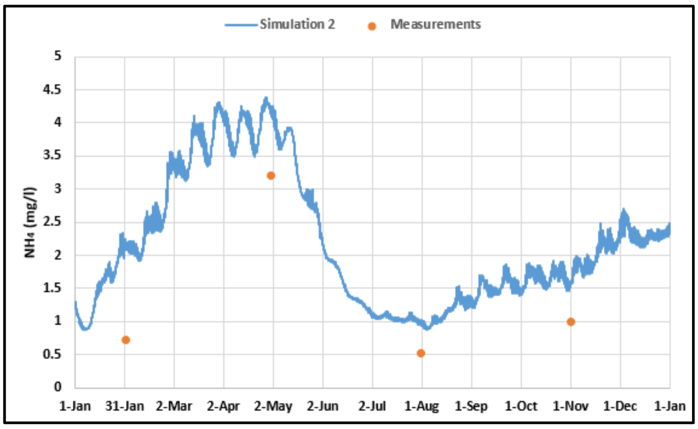

Figure 5: NH_4 (mg/l) Comparison at WQ-Station 2

Numerical model simulation of proposed scenarios

The current situation of the lake was simulated and called Baseline Condition. That is to be a reference for judging different enhancement scenarios including different proposed alternatives and also a combination between them. The current condition of the lake has been simulated in water quality modeling, three ray channels were constructed towards the lake through the three tidal inlets El-Soffara, El-Gamil, and the New El-Gmail. The existing depth of these ray channels was about 2.5 m started from the inlet with the sea (Boughaz) from the north and extended about 3 km inside the lake toward the south. Also, the narrow tidal inlet Boughdady was enlarged to 100 m width removing floating plants to improve the efficiency of the tidal inlets, which affect the water exchange between the Mediterranean Sea and the lake. Different remedy actions were proposed through the proposed scenarios. The description of model scenarios is summarized in Table 1.

Table 1: Description of Proposed Scenarios

Proposed Scenario	Model Description
1	Removing only the obstacles and encroachments inside the lake.
2	Reducing the flow discharges from the Bahr Al-Baqar drain by 5 million m^3/day, and removing the obstacles and encroachments.
3	Increasing only the water depth inside the lake by dredging the lake bed to 2.5 m.
4	Reducing the flow discharges from Bahr Al-Baqar drain in combination with increasing the lake water depth.
5	Connecting the lake with the seawater by new inlet located in the northwest area of the lake.
6	Combining Scenario 4 and Scenario 5.
7	Scenario 6 in addition to stopping the flow discharged from Farascour and Serw drains into the lake.

Results and Discussion

1. **Water quality index**

Water quality index (WQI) is a simplified technique, which can represent the reliable picture of water quality conditions inside the lake. In this research, the weighted arithmetic mean method for WQI is used to calculate the water quality index for Manzala Lake. The index gives a number between 0 (best water quality) and 100 (worst water quality). Another index (MI) is used to calculate the water quality index for heavy metals inside the lake. These indices are calculated for the baseline condition of the lake and are compared with the water indices obtained for different proposed scenarios.

Water quality index by weighted arithmetic mean method can be found out by the following formula, [20].

$$WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}$$

where Wi is the unit weight of each parameter, Qi is the 0–100 subindex rating for each variable, and n is the number of subindices aggregated.

The water quality index developed for Manzala Lake consisted of 5 steps:

1. Selection of Physico-Chemical parameters used to calculate WQI were based on the important parameters for aquatic life. The evidence of pollution in Manzala Lake is a basis of selecting the water quality parameters like biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium (NH_4), inorganic matter (IM), and total coliform (T Coli) as significant indicators parameters of surface water quality.
2. Development of a rating scale to obtain the rating (Qi).A rating scale was prepared for a range of values of each class. The rating varies from 0 to 100 and is divided into five intervals. The rating (Qi = 100) indicates that the concentration of the parameter in the water exceeded the standard permissible limits and water is highly polluted. The rating (Qi = 0) means excellent water quality as the parameter is within the permissible limits. The other ratings fall between these two values and are Qi = 75, Qi = 50, and Qi = 25 standing for excessively polluted, moderately polluted, and slightly polluted, respectively. Table 2illustrates the proposed classification with ranges of concentrations of these parameters. This scale is a modified version of the rating scale given by [21].
3. Estimating the unit weight of each indicator parameter (Wi) by considering the weightage of each parameter. The assigned weight reflected the significance of a parameter for a particular use and had a considerable impact on the index. It was calculated by a value inversely proportional to the recommended standard (Si) of the corresponding parameter. In the current case, the weight of each indicator was considered between 0.01 and 0.05, where the maximum indicator value was 0.05 and the minimum value was 0.01.

$$W_i \propto \frac{1}{S_i}\ , \qquad W_i = \frac{k}{S_i}$$

$$W_i = Max\ [Min(k/si\ ,\ 0.05)\ ;\ 0.01]$$

where K is the proportionality constant of the ''Weights'' for various water quality characteristics.

$$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}}$$

Table 2: Rating Scale for Calculating WQI

Parameters	Ranges				
BOD (mg/l)	<60	60-63	63-66	66-69	>69
COD(mg/l)	<80	80-250	250-400	400-550	>550
NH_4 (mg/l)	<1.37	1.37-4.5	4.5-6	6-7.5	>7.5
IM (mg/l)	<50	50-62.5	62.5-75	75-87.5	>87.5
Total coliform MPN/100ml	<5000	5000-($5x10^5$)	($5x10^5$)-($7.5x10^5$)	($7.5x10^5$)-($1x10^6$)	>($1x10^6$)
Q_i	0	25	50	75	100

4. Determining the sub-index value (W_i*Q_i).Aggregating the sub-indices to obtain the overall WQI. The subindices were aggregated using weighted sum aggregation functions to obtain the final WQIs. In this additive aggregation process, the subindices were combined through summation by calculating the weighted arithmetic means. This approach was used in developing the WQIs developed by [22], [23], and [24]. Table 3 illustrates the Water Quality index for Baseline and different Scenarios.
5. Rating of water quality index for all scenarios was compared with WQI of the baseline condition. WQI has been classified into 5 classes, where the water quality was rated as excellent, good, poor, very poor, and unfit. Table 4 illustrates the rating of water quality.

Figure 6 represents the rated water quality index for the baseline condition and the different proposed scenarios.

Table 3: Water Quality Indices for Baseline and Different Scenarios

		BOD	COD	NH_4	IM	T. Coli	Sum.	WQI $\sum_{i=1}^{n} W_iQ_i / \sum_{i=1}^{n} Wi$
$K = \frac{1}{\sum_{i=1}^{n} \frac{1}{S_i}}$	*Si*	60	80	1.37	50	5000		
	1/Si	0.02	0.01	0.73	0.02	0.00	0.78	
	k	1.28						
$W_i = k/S_i$	*Wi*	0.02	0.02	0.05	0.03	0.01	0.12	
Baseline	*Qi*	100.00	100.00	100.00	100.00	100.00		
	*Wi * Qi*	2.14	1.60	5.00	2.57	1.00	12.31	100.00
Scenario 1	*Qi*	0.00	100.00	75.00	100.00	100.00		
	*Wi * Qi*	0.00	1.60	3.75	2.57	1.00	8.92	72.47
Scenario 2	*Qi*	0.00	75.00	75.00	100.00	100.00		
	*Wi * Qi*	0.00	1.20	3.75	2.57	1.00	8.52	69.21
Scenario 3	*Qi*	0.00	75.00	50.00	100.00	75.00		
	*Wi * Qi*	0.00	1.20	2.50	2.57	0.75	7.02	57.03
Scenario 4	*Qi*	0.00	25.00	50.00	50.00	75.00		
	*Wi * Qi*	0.00	0.40	2.50	1.28	0.75	4.93	40.09
Scenario 5	*Qi*	0.00	50.00	50.00	100.00	75.00		
	*Wi * Qi*	0.00	0.80	2.50	2.57	0.75	6.62	53.77
Scenario 6	*Qi*	0.00	25.00	50.00	50.00	50.00		
	*Wi * Qi*	0.00	0.40	2.50	1.28	0.50	4.68	38.06
Scenario 7	*Qi*	0.00	25.00	50.00	50.00	25.00		
	*Wi * Qi*	0.00	0.40	2.50	1.28	0.25	4.43	36.02

Table 4: Rating of Water Quality

WQI Value	Rating of Water Quality
(0 –25)	Excellent
(26-50)	Good
(51-75)	Poor
(76-100)	Very Poor
>100	Unfit

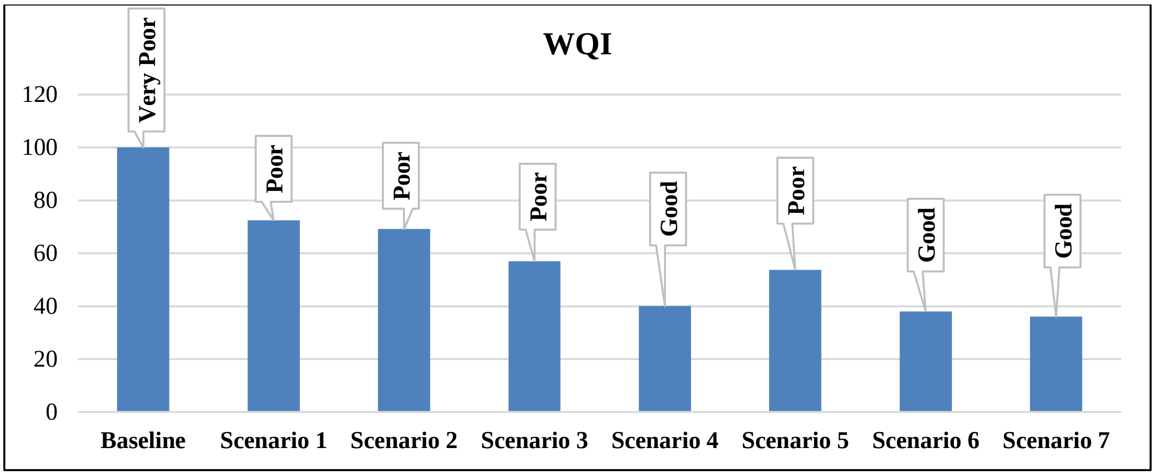

Figure 6: Rated Water Quality Index for Baseline and Different Scenarios.

From the obtained results, it was concluded that the most enhanced scenario was Scenario 7 that was developed by dredging all the area of the lake to 2.5 m depth after removing all the obstacles in the lake in addition to decreasing the discharged wastewater coming from Bahr El-Baqar drain and constructing new inlet permitting more seawater intrusion to the lake. Scenario 7 transformed the baseline case from a very poor condition to a good condition.

2. Metal contamination of manzala lake water by metal index

The metal index (MI) is based on a total trend evaluation of the present status. The higher the concentration of metal compared to its respective MAC value (the maximum allowable concentration), the worse the quality of the water. MI value >1 is a threshold of warning [25]. Heavy metals selected to calculate the metal index for the lake were Cd, Cr, Cu, Ni, Pb, and Zn as representatives for heavy metals.

The MI was calculated using the following formula, [26].

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i}$$

Where Ci is the concentration of each element, and MAC is the maximum allowable concentration.

MI calculations for heavy metals in baseline conditions and all proposed scenarios are summarized in Table 5.

Table 5: MI Calculations for Baseline Condition and Proposed Scenarios

Condition	Category	Cd	Cr	Cu	Ni	Pb	Zn
Baseline	Ci/MAC	3.330	0.60	0.24	0.12	1.00	0.100
	MI*	5.390					
Scenario 1	Ci/MAC	3.330	0.60	0.24	0.12	1.00	0.100
	MI*	5.390					
Scenario 2	Ci/MAC	3.000	0.50	0.20	0.10	0.90	0.100
	MI*	4.800					
Scenario 3	Ci/MAC	2.667	0.40	0.20	0.12	1.00	0.100
	MI*	4.487					
Scenario 4	Ci/MAC	2.667	0.30	0.18	0.09	0.80	0.090
	MI*	4.127					
Scenario 5	Ci/MAC	2.667	0.40	0.20	0.11	0.90	0.100
	MI*	4.377					
Scenario 6	Ci/MAC	2.333	0.30	0.18	0.09	0.80	0.090
	MI*	3.790					
Scenario 7	Ci/MAC	2.333	0.30	0.18	0.09	0.75	0.085
	MI*	3.738					

*MI value >1, a threshold warning

According to obtained results of all scenarios, it was concluded that the lake is on the threshold warning of heavy metals according to the metal index method (MI).

Conclusions

Reducing the flow discharged into Manzala Lake, removing all obstacles from the lake, and increasing the water depth inside the lake by dredging its bed to 2.5 m in addition to connecting the lake with the seawater by a new inlet located in the northwest area of the lake will be the optimum solution to minimize the pollution in the lake and increasing the rank of lake water quality from a very poor condition to a good condition according to water quality index.

It was concluded also that the lake is on the threshold warning of heavy metals according to the heavy metal index method (MI).

Acknowledgments

I would like to thank Hydraulic Research Institute (HRI) for data support and cooperation for this research, National Authority for Remote Sensing and Space Sciences (NARSS) for data supply.

References

[1]. El-Badry AE, Khalifa MM. (2017). "Geochemical assessment of pollution at Manzala lake, Egypt: Special mention to environmental and health effects of arsenic, selenium, tin, and antimony". JApSc., 17(2), 72-80.

[2]. Bek, M.A., Lowndes, I.S. and Hargreaves, D.M. (2010). "The application of a validated hydrodynamic model to improve the water management of an Egyptian shallow water coastal lake". 5th International Congress on Environmental Modelling and Software - Ottawa, Ontario, Canada - July 2010.

[3]. Elewa, A.A., Saad, E.A., Shehata, M.B. and Ghallab, M.H. (2007). "Studies on the effect of drain effluents on the water quality of Lake Manzala, Egypt". J. Aquat. Biol. and Fish, 11(2), 65-78.

[4]. Negm, A.M., Bek, M.A. and Abdel-Fattah, S. (2018). "Egyptian Coastal Lakes and Wetlands: Part I: Characteristics and Hydrodynamics". Vol. 71, Springer.

[5]. Bayoumi A. R. and Magdy T. Khalil. (1988). "Tilapia Fisheries in Lake Manzala, Egypt". Bull. Inst. Oceanology & Fish. ARE, 14 (3), 87 - 99.

[6]. Wael H. Hegazy, Mohamed A. Hamed, M. E. S. Toufeek, and Bazada K. A. Mabrouk (2016). "Determination of Some Heavy Metals in the water of the Southern Region of Lake Manzala, Egypt". Egypt. J. Aquat. Biol. & Fish., Vol. 20, No. 4, 69 – 81.

[7]. Khalil, M. T. (1990). "The physical and chemical environment of Lake Manzala, Egypt". Journal of Hydrobiologia, 196, pp.193 – 199.

[8]. Randa R. Elmorsi, Mohamed A. Hamed, and Khaled S. Abou-El-Sherbini (2017). "Physicochemical Properties of Manzala Lake, Egypt". Egypt. J. Chem. 60, No. 4, pp. 519-535.

[9]. Abdel-Mouti, M.A.R. (1985). "Studies on the chemistry of Manzala lake waters, Egypt". Ph.D. Thesis, Alexandria University, Egypt.

[10]. Badawy, M. I. and Wahaab, R. A. (1997). "Environmental impact of some chemical pollutants on Lake Manzala". International Journal of Environmental Health Research 7, 161-170.

[11]. Rasmussen, E. Kock, et al. (2009). "Hydrodynamic-ecological model analyses of the water quality of Lake Manzala (Nile Delta, Northern Egypt)". Hydrobiologia 622.1: 195.

[12]. EL-Saharty, A. (2014). "Water, Nitrogen and Phosphorus Budgets of Lake Manzalah". Journal of Marine Engineering & Technology, 13.3: 57-62.

[13]. Orabi OH and Osman MF (2015). "Evaluation of some pollution at Manzala Lagoon: Special reference to medical importance of Mollusca in Egypt". Journal of Environmental & Analytical Toxicology, 5(5).

[14]. Gawad S.S. (2018). "Concentrations of heavy metals in water, sediment and mollusk gastropod, *Lanistes carinatus* from Lake Manzala, Egypt". The Egyptian Journal of Aquatic Research, 44(2):77-82.

[15]. Elshemy, M. and Khadr, M. (2015). "Hydrodynamic impacts of Egyptian Coastal Lakes due to climate change-example Manzala Lake". Int Water Technol J, 5(3), pp.235-247.

[16]. Elnaggar AA and El-Alfy MA. (2016). “Physiochemical properties of water and sediments in Manzala Lake, Egypt”. Journal of Environmental Sciences, 45(2):157-74.
[17]. El-Ghazali AM, Amer AA, and Mustafa MM. (2015). “Proposed Decision Support System for Reduction of Total Phosphorus in Lake Manzala”. Egyptian Computer Science Journal, 39(4):56-70.
[18]. Khadr, M., and Elshemy, M. (2017). “Data-driven modeling for water quality prediction case study: The drains system associated with Manzala Lake, Egypt”. Ain Shams Engineering Journal, 8(4), 549-557.
[19]. Elsaeed G, El-Hazek AN, Bahgat M, and Fathallah NF (2020). “Investigating the Improvement of Water Circulation of the Egyptian Northern Lakes, Case study Al-Manzala Lake”. International Journal of Applied Science and Research 3 (5).
[20]. Brown, R.M., McCleiland, N.J., Deininger, R.A. and O’Connor, M.F. (1972). “A Water Quality Index—Crossing the Psychological Barrier”. Proceedings of the International Conference on Water Pollution Research, Jerusalem, 787-797.
[21]. Tiwari TN and Mishra MA (1985). “A preliminary assignment of water quality index of major Indian rivers”. Indian J Environ Prot., 5(4): 276-9.
[22]. Horton, R. K. (1965). “An index number system for rating water quality”. Journal of Water Pollution Control Federation, 37(3), 300–306.
[23]. Brown, R. M., McClelland, N. I., Deininger, R. A., and Tozer, R. G. (1970). “A water quality index. Do we dare?”. Water and Sewage Works, 117, 339–343.
[24]. Otto, W. R. (1978). “Environmental indices: Theory and practice”. Ann Arbor Science Publishers Inc.
[25]. Bakan, G., Boke Ozkoc, H., Tulek, S., and Cuce, H. (2010). “Integrated environmental quality assessment of Kızılırmak River and its coastal environment”. Turk. J. Fisheries Aquat. Sci. 10, 453–462.
[26]. Tamasi, G. and Cini, R. (2004). “Heavy metals in drinking waters from Mount Amiata. Possible risks from arsenic for public health in the province of Siena”. Sci. Total Environ. 327, 41–51.