DOI number: 10.5027/jnrd.v5i0.11

JOURNAL OF NATURAL RESOURCES AND DEVELOPMENT

Estimating the impact of air temperature and relative humidity change on the water quality of Lake Manzala, Egypt

Gehan A.H. Sallam[a] and E. A. Elsayed[b]

[a] Associate Professor, Drainage Research Institute (DRI), National Water Research Center, Delta Barrages, Cairo, Egypt.

[b] Associate Professor, Drainage Research Institute (DRI), National Water Research Center, Delta Barrages, Cairo, Egypt.

E-mail:ehab7878@hotmail.com

*Corresponding author: gehanhakeem@hotmail.com

Article history

Received 22/09/2014
Accepted 09/04/2015
Published 15/11/2015

Keywords

Air temperature
Climate variables change
Lake Manzala
Relative humidity

Abstract

By the late eighties the problem of climate change and its possible impacts had become an issue of global concern. Climate variables play an important role in controlling the water circulation and the water quality of lakes either as freshwater reservoirs, or as brackish lagoons. In Egypt, Lake Manzala is the largest and the most productive lake of the northern coastal lakes. In this study, continuous measurement data from the Real Time Water Quality Monitoring stations in Lake Manzala was statistically analyzed to determine the regional and seasonal variations of the selected water quality parameters in relation to changes in two climate variables: air temperature and relative humidity. Simple formulas are elaborated using the DataFit software to predict the selected water quality parameters of the Lake including Power of Hydrogen (pH), Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, and Chlorophyll as a function of air temperature and relative humidity. It was revealed that there is a measured relation between air temperature and relative humidity and the pH, DO, EC and TDS parameters and there is no significant effect on the other two parameters: turbidity and chlorophyll.

1. Introduction

Egypt is fairly unique in the distribution of its population, land-use and agriculture, and economic activity which makes it extremely vulnerable to any potential impacts on its water resources and coastal zones. According to the Human Development Report of the Initial National Communication (INC) and the United Nations Development Program **[41]**, Egypt is highly vulnerable to the impact of climate change, which may jeopardize the country's development gains.

Water pollution is a major problem in the world, especially in developing countries. It can by physical, chemical or biological **[35]**. Lakes are a vital component of water resources. Egypt has various inland water resources, all of which are part of the River Nile; these include six northern coastal lagoons opening onto the Mediterranean Sea: Mariout, Edku, Burullus, Manzala, Port Fouad, and Bardawil **[23]**. The results of efforts which included public participation, engineering and river works and strict statutory regulations by government authorities have shown only slight success in improving water resource quality **[42]**. Population growth and the expansion of urbanization in the Nile delta is an important problem affecting water resources. The northern lakes in Egypt serve as reservoirs for drainage waters, which are contaminated with anthropogenic materials **[14]**. Lake Manzala is the largest and the most productive lake of the northern Egyptian coastal lakes. It is an important and valuable natural resource area for fishing, wildlife, hydrologic and biologic regimes and table salt production **[31]**.

The lakes fisheries play an important role in the Egyptian economy. In the past they provided more than 50% of harvested fish in Egypt, though their contribution to Egyptian fish production decreased to 14.3% (2005-2012) and to only 12.5% in 2012 **[37]**. Pollution of the aquatic environment by inorganic and organic chemicals is a major factor that poses a serious threat to the survival of aquatic organisms including fish **[19]**.

Lake Manzala faces many challenges that will lead to serious changes in its water quality and fish production. A remarkable decline (34.5%) of the Manzala lagoon surface area has been estimated. These changes have been attributed mainly to the control of River Nile flooding and land use changes resulting from anthropogenic activities **[25]**. Lake Manzala is characterized by special sensitive environments. The lake is moving toward its disappearance by two opposing forces, one of them is the shrinking of the water body due to siltation of sediments coming from agricultural lands and the abundance of weeds and swamp vegetation as well as the drying practices in agriculture, while the other force involves the removal of the coastal sand bar separating the lake from the Mediterranean Sea due to erosion **[33]**.

Knowledge of the impact of sources of pollution on water resources is essential in environmental water studies as well as for resource management. The Egyptian National Environmental Action Plan of 1992 identified Lake Manzala as among the most heavily polluted water bodies in the country. The effect of pollution is noticeable along the entire lake **[6]**. Consequently, it is important to assess lake water quality based on its importance as a natural resource and at its socio-economic aspects as a significant source of inexpensive fish for human consumption in Egypt.

By the late eighties the problem of climate change and its possible impacts had become an issue of global concern. Egypt's climate is semi-arid, characterized by hot humid summers, moderate winters, and very little rainfall. The climate of Lake Manzala is also described as arid Mediterranean **[40]**. Climate variables play an important role in controlling the water circulation and the water quality of the lake. Climate variability includes changes in air temperature and relative humidity for the Egyptian coastal region of the Nile Delta which directly affects the hydraulic and biological functioning of the lakes, either as freshwater reservoirs or as brackish lagoons. The lake and lagoon ecosystems (aquatic vegetation, migrating fish and birds) would be directly affected by this change **[3]**.

Quantitative and qualitative diatom analyses of the north Nile Delta lake sediments were used to evaluate the paleo-environmental development of the lakes and climate changes during the late Holocene period. Multivariate statistical analyses distinguished 17 ecological groups that reflect changes in water salinity, lake-level and the trophic state of the lakes, which in turn are mainly related to climate changes and anthropogenic impacts **[2]**. The considerable variation in the composition and distribution of the diatom assemblages among these lakes was mainly related to differences in the water quality, salinity, nutrients concentration and climate changes **[1]**.

Not only are great efforts needed to maintain the purity and health of Lake Manzala, but additional information is also needed to provide a database for water quality status to aid proper management of the lake. There is also an imperative need for accurate, reliable lake water quality information to measure the impact of changes in climate variables on Lake Manzala's water quality.

The routine water quality monitoring program in Lake Manzala includes monthly in-situ measurements of water quality parameters in drains and canals leading into the lake. However, due to the need for information on the spatial and temporal variability of water quality in the lake, an environmental security and water resource management system using Real Time Water Quality (RTWQ) warning and communication was implemented under the Science for Peace initiative of NATO **[8]**.

The recent information and environmental security system includes Remote Sensing and Real Time Water Quality and is a suitable technique for large-scale monitoring of inland and coastal water quality with widely recognized advantages. RTWQ provides continuous measurement of different biological, chemical and physical variables. Therefore, recent years have seen increased interest and research in RTWQ for inland and coastal waters **[17]**.

Real time water monitoring involves continuous measurement of water-related parameters in-situ with results provided in real time or near real time. This new integrated water monitoring, warning and reporting system will allow water managers to protect the integrity of Egypt's vital water resources against any natural or anthropogenic threats, to implement immediate corrective and mitigation measures, and to report the suitability of water for designated beneficial water uses. Such a real time water monitoring network will lay the foundation for greater environmental security and water resource management **[30]**.

Therefore, the main objective of this study is to statistically analyze the continuous measurement data of the Real Time Water Quality Monitoring stations in Lake Manzala to measure the regional and seasonal variations of some selected water quality parameters in relation to changes in climate variables including air temperature and relative humidity and then to elaborate simple formulas using the DataFit software to predict the selected water quality parameters of the Lake including Power of Hydrogen (pH), Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Salts (TDS), Turbidity and Chlorophyll as a function of air temperature and relative humidity.

2. Study Area Description

Manzala Lake is located on the northeastern edge of the Nile Delta, separated from the Mediterranean Sea by a sandy beach ridge. It is the largest of the delta lakes and it is bordered by the Mediterranean Sea to the north and the north-east, the Suez Canal to the east, Dakahlia and Sharkia Provinces to the south and the Damietta branch of the Nile to the west, as shown in **Figure 1**. The lake lies within three governorates and the two macroeconomic regions of the Suez Canal and the Delta **[40]**. Lake Manzala is located between latitudes (31º 00′ 51″) and (31º 31′ 25″) north and longitudes (31º 46′ 10″) and (32º 19′ 17″) east. It extends 64.5 km in its maximum length and 49 km in its maximum width and 239 km in it total perimeter. It is shrinking in size; the rate of shrinking of the total area from 1922 to 1995 was estimated at 5.22km^2/yr. The greater losses of the lake areas were detectable along the western and southern borders of the lake **[21]**. In 1900 its area was 1907 km^2, while its area as measured by land sat imagery in 1981 was about 909.85km^2. As a result of the presence of a large number of islets in the lake, its area of open water measures only about 700km^2 **[34]**.

2.1 Hydrological Characteristics

Freshwater inflows are central to the functioning of Lake Manzala. Large discharges of relatively fresh water are provided by major drains which cross the Nile Delta. These influence lake water levels and are responsible for the freshwater conditions within large parts of the lake. The small tidal range of the eastern Mediterranean, coupled with constricted connections with the sea, reduces the influence of lake–sea exchanges and tidally induced water level oscillations within Lake Manzala **[28]**.

The lake is connected to the Mediterranean Sea via three outlets as shown in **Figure 1**, these open connections allow an exchange of water between the lake and the Sea. They are El-Gamil, El-Boughdady and the new El- Gamil **[13]**. The lake is also connected to the Suez Canal at El-Qabouti and connected with the Damietta branch of the Nile through the El Inaniya Canal. Therefore, the southwestern corner of the lake receives the majority of its freshwater input from the Serw and Faraskur pumping stations, and the Inaniya Canal. The lake is shallow, with an average depth of about 1.25 m **[11]**.

Several main agricultural drains flow into Lake Manzala and affect its water quality. Drainage water contributes about 98% of the total annual inflow to Lake Manzala. The lake once received about 7500 million cubic meters of untreated industrial, domestic and agricultural drainage water, this amount was reduced to about 4000 million cubic meters after the construction of El-Salam Canal. This water is discharged annually into the lake through several drains: Bahr El-Baqar Drains (domestic and industrial sewage), Hadous, Ramsis, El-Serw and Faraskur Drains (agricultural effluents) **[7]**.

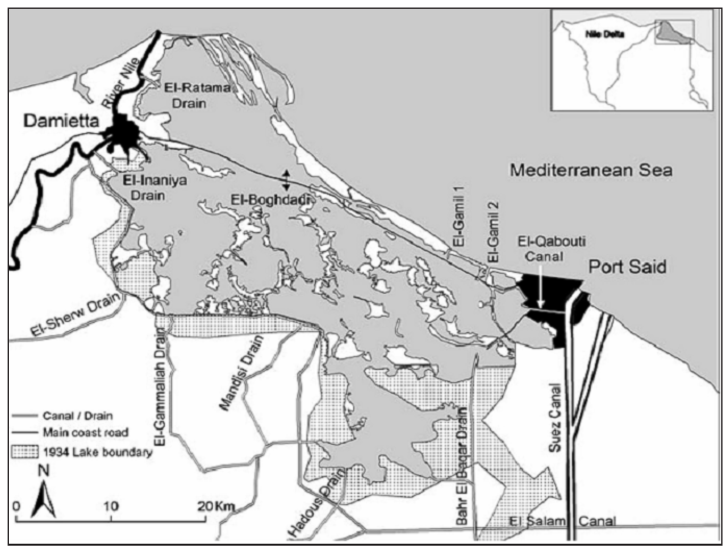


Figure 1: Layout Map of Lake Manzala

2.2 Climate and Meteorological Information

The climate of Manzala Lake is described as arid Mediterranean. The mean annual rainfall over the area is less than 100 mm. Air temperatures do not exceed 35^{o}C in the summer months. Air pressure does not vary significantly during the different seasons of the year. Wind direction mainly takes the direction of north and northwest **[3]**.

The temperature of the water in the lake is highly affected by the air temperature due to the water's shallowness. The lake is located in an arid and semiarid area, where the temperature varies greatly from summer to winter and from day to night. Air temperature is affected by the geographical location close to the Mediterranean Sea. According to records for the last century from the Egyptian Metrological Organization, the mean air temperature usually attains its minimum value of about 12.5^{o}C during the winter season. It increases gradually through spring, reaching its average maximum values of 30^{o}C in summer **[7]**.

The mean monthly relative humidity ranges between 65% and 75% throughout the year. The maximum relative humidity (75.6%) is observed in January and it decreases to 60% during April-June. These trends may reflect the origin of the air masses over the region. The low spring values appear to be caused by the dry winds associated with the Khamasin depressions. The winter peak is due to the predominance of winds coming from the sea during this time **[3]**.

2.3 Water Quality

El-Wakeel and Wahby **[15]** divided the lake into three zones from the perspective of water quality. The regions are:

- The south eastern region which receives mainly drainage water,
- The north eastern region affected by both seawater and drainage water, and
- The western region affected by drainage water, sea water and freshwater (during flood time only).

Manzala Lake is a eutrophic coastal lake that has been flooded by excess agriculture drainage over the last 30 years, changing its ecological status **[22]**. It has undergone substantial changes recently due to regulation of freshwater inflows, land reclamation and increasing discharges of pollutants. This is particularly associated with polluted drains flowing into the lake. Increases in pollutant concentrations can be attributed to increased use of fertilizer combined with an expanding population served by sewers, improved living standards and increased industrial production. Pollutant enrichment has resulted in declining water quality and eutrophication, especially in the southern parts of Lake **[12]**. Flower *et al*. **[36]** mentioned that sediment quality and quantity have strong influences on lagoon ecosystem functions and sedimentation is relevant to hydromorphology and to concepts of ecological quality. Pesticides and polychlorinates were determined in surface and core sediment samples collected from Manzala Lake from a site heavily impacted by sewage discharge. The high assessment of contamination risk indicated that sediments in two sites were likely to pose potentially adverse biological impacts **[9]**.

2.3.1 Water Salinity

The lake is brackish and the northern portion of the Lake has high salinities ranging from 3000 mg/L to 35,000 mg/L due to the influence of the Mediterranean Sea. Historically the salinity of the lake was higher **[40]**. Fishar **[20]** recorded the highest values of salinity at a section opposite to the Bughaz El-Gamil. The implementation of the El Salam Canal project will require the diversion of water from the delta. This is expected to significantly increase salinity in the lake to 8000 mg/L from the present 3000 mg/L.

Mohamed **[34]** also recorded that both electrical conductivity and salinity values are distributed in Lake Manzala in a similar trend. Their values increase in the north eastern area near Boughaz El-Gamil recording the maximal values of 43.8 mS/cm and 22.5% respectively. He mentioned that these results are in agreement with those obtained by Khalil and Bayoumi **[29]** and Abdel-Satar **[5]**. Abdel Samei *et al*. **[4]** mention that variations in the water conductivity were relatively limited, and levels characteristic of brackish water are observed at most locations, except the area that is related to the Sea-Lake connection through El-Gamil outlet which has high EC values.

2.3.2 Power of Hydrogen (pH)

The pH value is a very important factor in the study of water chemistry **[39]**. The pH test is one of the most common analyses in water testing. An indication of the sample's acidity, pH is actually a measurement of the activity of hydrogen ions in the sample. The pH measurements run on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids; those between 7.0 and 14.0 are designated as bases. A range of 6.5 to 8.2 is optimal for most organisms **[10]**.

The pH measurements taken by El-Wakeel and Wahby **[15]** in Lake Manzala showed regional and seasonal variation. In the south-eastern region the pH values vary from 7.86 in May to 8.48 in October. They attribute this to increased phytoplankton production and photosynthetic activity in the summer months. They also noted that the north eastern region has pH values slighter higher than those of the South eastern region and due to the shallow depth of the lake there is a slight difference between bottom and surface values. They also mention that the pH values near the drains are lower than in other areas of the lake. Fishar **[20]** reported that pH values in the lake were alkaline and varied from 8.1 to 9 while the lower in pH values recorded during summer could be explained by organic matter decomposition.

Mohamed **[34]** reported that the pH values of Lake Manzala fluctuated from 7.45 to 8.90 with slight regional and seasonal variations. The lowest pH values were mostly recorded in the southern region near the Bahr El-Baqr Drain due to the fermentation of the organic matter and the release of hydrogen sulfide and methane gases which lead to lower pH values. However, in the western region of the lake, the pH values lie in the alkaline side and are mostly above 8.0. These results are in agreement with those obtained by Fathi and Abdelzahar **[18]** who reported that the change in pH value was always in the alkaline side and ranged between 7.7 and 9.0.

2.3.3 Dissolved Oxygen (DO)

Dissolved oxygen is a measure of the amount of oxygen freely available in the water. The concentration of dissolved oxygen (DO) gives information on the possibilities for flora and fauna living in the water system. The DO for surface water ranges from 0 in extremely poor water conditions to a high of 15 mg/l in very healthy water. The oxygen content of natural water varies with temperature, salinity, turbulence, and the photosynthetic activity of algae and plants. In freshwater, concentrations range from 15 mg/l at 0ºC to 8 mg/l at

25°C **[16]**.

El-Wakeel and Wahby **[15]** observed that the waters of Lake Manzalah were generally well oxygenated and showed no signs of oxygen depletion. Dissolved oxygen shows wide variation on a spatial basis. The fluctuation is particularly in regions of the lake with water plants. In these regions, the dissolved oxygen values are lowest in the winter months due to the consumption of oxygen from the fermentation of water plants and reduced sunshine in winter months. In other regions of the lake that are devoid of plants, the dissolved oxygen values in winter are on an average higher than summer values. Fishar **[20]** also noted that dissolved oxygen values were high in winter.

Abdel Samei *et al*. **[4]** found that the values of DO fluctuated between 3.0-8.4 mg/1 with limited seasonal and regional variation. The highest values were recorded during the cold period (autumn and winter), while the lowest values were observed during the hot period (spring and summer) as a result of temperature elevation. Generally, the values of DO at most areas of the lake were relatively low, especially in the south-eastern region which is strongly affected by drain effluents.

Mohamed **[34]** also mentions that the water of Lake Manzala is well oxygenated during different time intervals except the inlet of the Bahr El-Baqr region which suffers from complete depletion of dissolved oxygen throughout the year and especially during hot months as a result of the decomposition of organic matter and materials consuming the dissolved oxygen. However, the maximum value of DO (10.2 mg/l) was recorded during December due to decreasing temperature and to prevailing winds which increase the solubility of atmospheric oxygen.

3. Materials and Methods

The methods used to perform Water Quality Monitoring (WQM) have changed dramatically over the last 10 years resulting in improved knowledge and understanding of the relationships between water quality and changes in hydrology, geology and climate. Technological advances in water-quality sampling and recording instruments allow for an almost continuous record of the concentrations of water-quality variables in streams and rivers. A device that measures water quality in this way is called a Real Time Water Quality (RTWQ) monitor. These monitors have sensors and recording systems to measure physical and chemical water-quality field parameters at discrete time intervals at specific locations **[24]**.

However, the data collected are only as good as the quality assurance and quality control procedures, and the quality assessment measures incorporated into the sampling program. In-stream water-quality sensors provide continuous measurements (typically, every 5-60 minutes) of water-quality conditions that may vary widely over short periods of time due to any natural or anthropogenic threats. When this data is available in real time, water management officials can be notified of these changes and are able to respond by altering treatment **[30]**.

3.1 Data Collection

The National Water Research Center of Egypt recently initiated application of the new Water Quality Monitoring technique using RTWQ instruments for some strategic points in the water resources system of Egypt, including Lake Manzala. This advanced technique for water quality sampling allows real-time (continuous) records of water-quality variables in water streams.

The water monitoring system implemented in Lake Manzala is comprised of three real-time water monitoring stations and the installation of a data collection and reporting command center. The station locations were selected to cover different regional zones in the lake. As shown in **Figure 2**, Station 1 is located in the west side of the lake, Station 2 is located at the north east side and finally Station 3 is located at the south east side. The meteorological data was collected from the nearest weather station to the study area which is Port Said Airport station **[26]**. The location of this station is also shown in **Figure 2** (Longitude: 32° 14.4′ E and Latitude: 31° 16.764′ N).

As the main objective of this study is to assess the impact of changes in two climate variables, air temperature and relative humidity, during the day and night of the summer and winter seasons on water quality parameters of Lake Manzala, the continuous measurement data of the Real Time Water Quality stations in the Lake were used. The water quality parameters are measured in real time using a HACH Hydro-lab multi-parameter probe. The real-time network in the monitoring sites was provided with sensors to measure pH, DO, EC, TDS, Turbidity and Chlorophyll. The data were recorded in a data-logger at the data collection platform every 15 minutes and adjusted to take an average, through which an average is calculated in order to obtain an hourly record. The study period started on 27 July 2009 until 20 May 2010 to include water quality measurements and meteorological data during different seasons in order to achieve the main objective of the study.

3.2 Statistical Analysis

To achieve the purpose of this study, the data was statistically analyzed by using a box-and-whisker plot to measure the regional and seasonal variations of the selected water quality parameters. Box and whisker plots are uniform in their use of the box **[27]**. In descriptive statistics, a box-and-whisker plot is a convenient way of graphically depicting groups of numerical data through their five-number summaries: the smallest observation (sample minimum), the bottom of the box is always the 25th percentile or lower quartile (the lower quartile value is the median of the lower half of the data), the median, the top of the box is the 75th percentile or upper quartile (upper quartile value is the median of the upper half of the data), and largest observation (sample maximum).

Secondly, Data-Fit software was used to elaborate simple formulae that can help predict the water quality parameters of Lake Manzala as a function of air temperature and relative humidity. Data-Fit is a science and engineering tool that simplifies the tasks of data plotting, regression analysis (curve-fitting) and statistical analysis. Oakdale Engineering Data-Fit curve fitting (nonlinear regression) and data plotting software was used. Curve fitting refers to fitting curved lines to data. These curved lines come from regression techniques or interpolation. The main objective of curve fitting is to gain insight into the data set. This will lead to improved data acquisition techniques for future experiments, extracting physical meaning from fitted coefficients, and drawing conclusions about the data's parent population **[38]**.

The curve-fitting process was carried out using the data collected from 27 July 2009 until 20 May 2010. The regression models were developed for each water quality parameter in relation to air temperature and relative humidity, and then sorted according to the goodness of fit criteria (Residual Sum of Squares and Relative Mean Error). In all cases, the formula that has higher coefficient of determination (R^2) and less Relative Mean Error (RME) was selected as a best fit formula. Fortunately, the square of the correlation coefficient provides exactly the value of coefficient of determination.

Figure 2: Locations of the RTWQ and Weather Stations in Lake Manzala

4. Results and Discussion

The continuous measurement data from the Real Time Water Quality Monitoring stations in Lake Manzala, from 27 July 2009 until 20 May 2010, was statistically analyzed using the box-and-whisker plot method to measure the regional and seasonal variations of the selected water quality parameters in relation to air temperature and relative humidity. Simple formulas were elaborated using the Data-Fit software to predict the selected water quality parameters of the Lake including pH, DO, EC, TDS, Turbidity and Chlorophyll as a function of air temperature and relative humidity.

4.1 Regional Variations in the Selected Water Quality Parameters

Figure 3 shows the results of the statistical analysis of the collected data from the three RTWQ stations using box-and-whisker analysis to measure the regional variations in the selected water quality parameters in Lake Manzala.

The pH measurements in Lake Manzala show that pH values in the lake were alkaline and have a slight regional variation. The pH values fluctuated from 7.52 to 9.48. As shown in **Figure 3**a, the fluctuation of pH values is decreased from the east to the west and the fluctuation of measurements in station 3 is more than in the other two stations. It is clear that in the western region of the lake (station 1) the pH values are alkaline and mostly above 8.0. Moreover, the pH values in the north eastern region (station 2) are slighter higher than those in the south eastern region (station 3). Therefore it is clear that the pH values near the drains (El-Gammaliah drain, El-Serw drain and Inaniya drain in front of Station 1 & Bahr El-Baqr drain in front of Station 3) are lower than the other areas of the lake. This could be explained on the basis of the fermentation of the organic matter and the release of hydrogen sulfide and methane gases which lead to lower pH values. These results are in agreement with the previous results obtained by El-Wakeel and Wahby **[15]**, Fishar **[20]**, Fathi and Abdelzahar **[18]** and Mohamed **[34]**.

Due to the strong relationship between Electrical Conductivity, EC, and salt concentration, the salt content is commonly expressed using EC. The unit used for electrical conductivity is mmhoS/cm (mS/cm). The recorded measurements clearly show that the lake is brackish. **Figure 3**b shows that the northern region of the Lake near boughaz El-Gamil at station 2 has high salinities ranging from 5.47 mS/cm to 59.7 mS/cm with a median equal to 22 mS/cm, due to the influence of the Mediterranean Sea. However, the values of EC in the other two stations which are near drains and strongly affected by drain effluents are slighter lower and varied and distributed in an almost similar trend. Station 1 records vary from 4.06 mS/cm to 43.4 mS/cm with a median value equal to 16.7 mS/cm, while the records in station 3 vary from 3.73 mS/cm to 54.6 mS/cm with a median value equal to 15.5 mS/cm. The total dissolved salts values have the same trend as the salinity measurements. The highest values are found in station 2 records which is impacted by salt water due to its location in the North eastern region near the Boughaz El-Gamil outlet that connects the lake to the Mediterranean Sea. **Figure 3**c shows that there is a large fluctuation in the measurements from the three stations.

The water in Lake Manzala is moderately oxygenated and shows no signs of oxygen depletion in the different regions except at station 3 in front of Bahr El-Baqr drain. There is a limited regional variation in the measurements as shown in **Figure 3**d. **Figure 3**e and **Figure 3**f show the statistical analysis of the turbidity and chlorophyll measurements. The results indicate that at station 1, there is a high concentration of chlorophyll affected by agricultural runoff. However, at station 2 there is high turbidity and low chlorophyll because it is impacted by seawater. For station 3, it was found that there is high chlorophyll

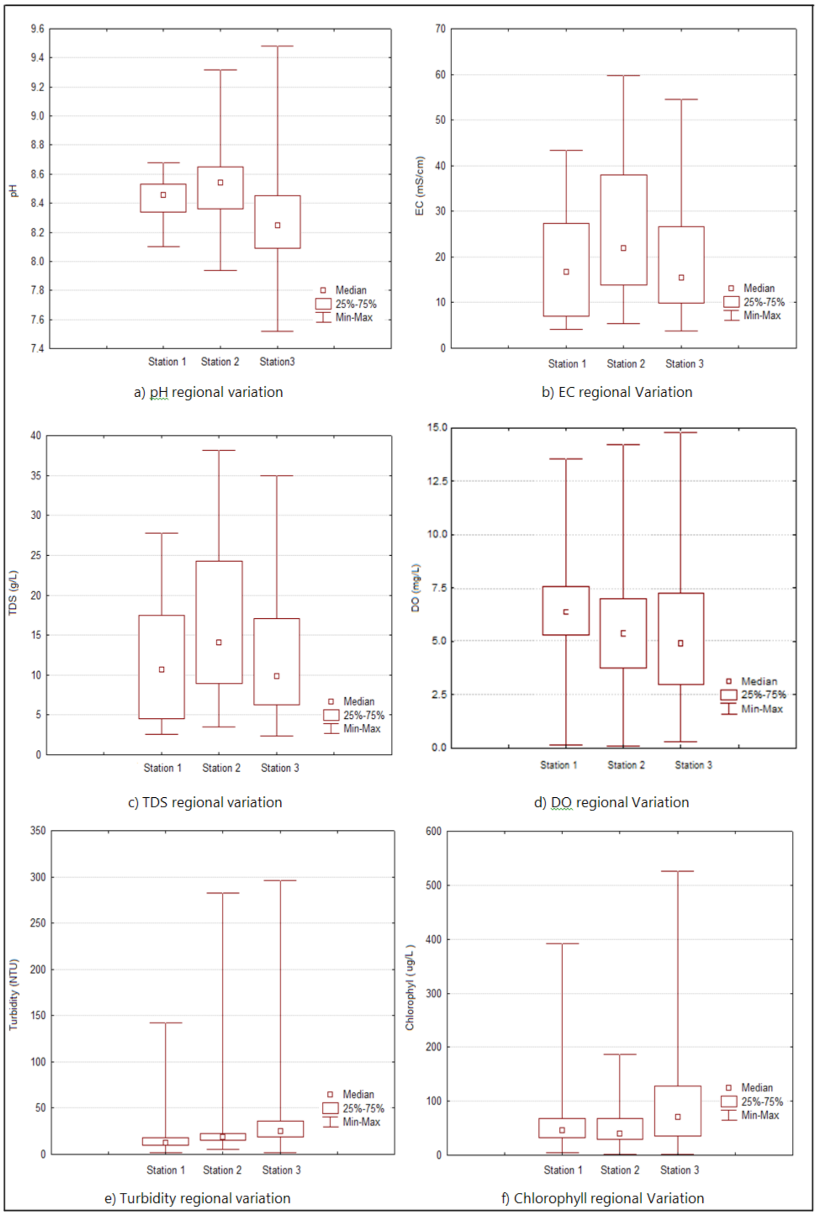


Figure 3: Regional Variations in Water Quality Parameters in Lake Manzala

concentration and high turbidity because it is less impacted by salt water and impacted by the discharge from the Bahr El-Baqar Drain.

4.2 The Seasonal Variations of the Selected Water Quality Parameters

To define the quantitative impacts of the seasonal changes in air temperature and relative humidity on the catchment areas of the lake, the water balance of the lake should be determined. The water balance of any hydrological system is the relationship between gains and losses. The major inflows and losses from Lake Manzala are drainage inflow, rainfall, evaporation and tidal effects.

It should be emphasized that the drainage inflow to the Lake represents the continuous inflow either by free discharge or by pumping to the lake. The drainage system provided the lake with about 2898 million cubic meters in 2009-2010 from five main sources (Bahar El-Baqar drain, Hadus drain, El-Serw pump station, Farasqur pump station and Mataria pump station). The monthly inflows of the drainage system to the lake are presented in **Table 1**. The maximum rate of water discharged to the lake takes place in the summer months. The Bahr El-Baqar drain discharges the maximum amount, which is about 38% of the total volume while the Bahr Hadus drain discharges about 30% of the total volume and the Mataria pump station discharges about 20%. The rainfall data recorded at Port Said station indicates that the mean annual rainfall over the area is about 78.35 mm. This depth of water provides the lake with mean annual volume of about 58.76 million cubic meters. Analysis also demonstrates that most rainfall takes place during the winter season (October- March). The area does not receive any rainfall in the summer months. The maximum amount of rainfall is received in December and January. The evaporation measurements at the Port Said Airport station were also collected. The monthly values of evaporation have been transformed to volumes of water losses from the lake by considering the surface area of the lake. The annual evaporation losses consume about 1277 million cubic meters. Peak evaporation occurs in late spring and early summer. However, climate changes may lead to tidal effects and seawater would enter the lake in the winter season. This behavior is related to the fact that the agricultural drainage system discharges lower quantities of water in winter than in summer as presented in **Table 1**.

The data collected at station 1 was used to measure the seasonal variations in the water quality parameters. **Figure 4** shows the results of the box-and-whisker plot statistical analysis for the collected data from 27 July 2009 until 20 May 2010. The data was divided into four categories to measure the seasonal and climate variations of the selected water quality parameters in Lake Manzala. The measurements of the summer season was divided into two categories including the measurements of the hours from sunrise to sunset and the measurements of the night hours from sunset to sunrise. The measurements of the winter season were also divided into two categories including day hours and night hours.

The seasonal analysis of the station 1 data revealed that the lake water has a slight seasonal variation in pH values. The pH values fluctuated from 8.36 to 8.68 in the summer season and fluctuated from 8.1 to 8.41 in the winter season. It is clear that the pH values in summer are slightly higher than in winter and this may be attributed to photosynthesis as mentioned by Abdel Samei *et al.* **[4]**. There is no variation between day and night observations in both summer and winter seasons as shown in **Figure 4**a.

Figure 4b shows that Electrical Conductivity (EC) values in summer are higher than in winter. This is attributed to the increased drainage water inflow and high evaporation losses in summer. Moreover, the EC values of drainage water in summer are higher than in winter. It was also observed that the variations in water conductivity during day and night hours for the two seasons are relatively limited. **Figure 4**c shows that the total dissolved salts values in summer are higher than in winter. This is attributed to the fact that the primary sources of TDS in the received waters are agricultural runoff drainage and the inflow to the lake in summer is more than in winter as shown in **Table 1**.

Table 1: Monthly Drainage Inflows to Lake Manzala (August, 2009- July, 2010)

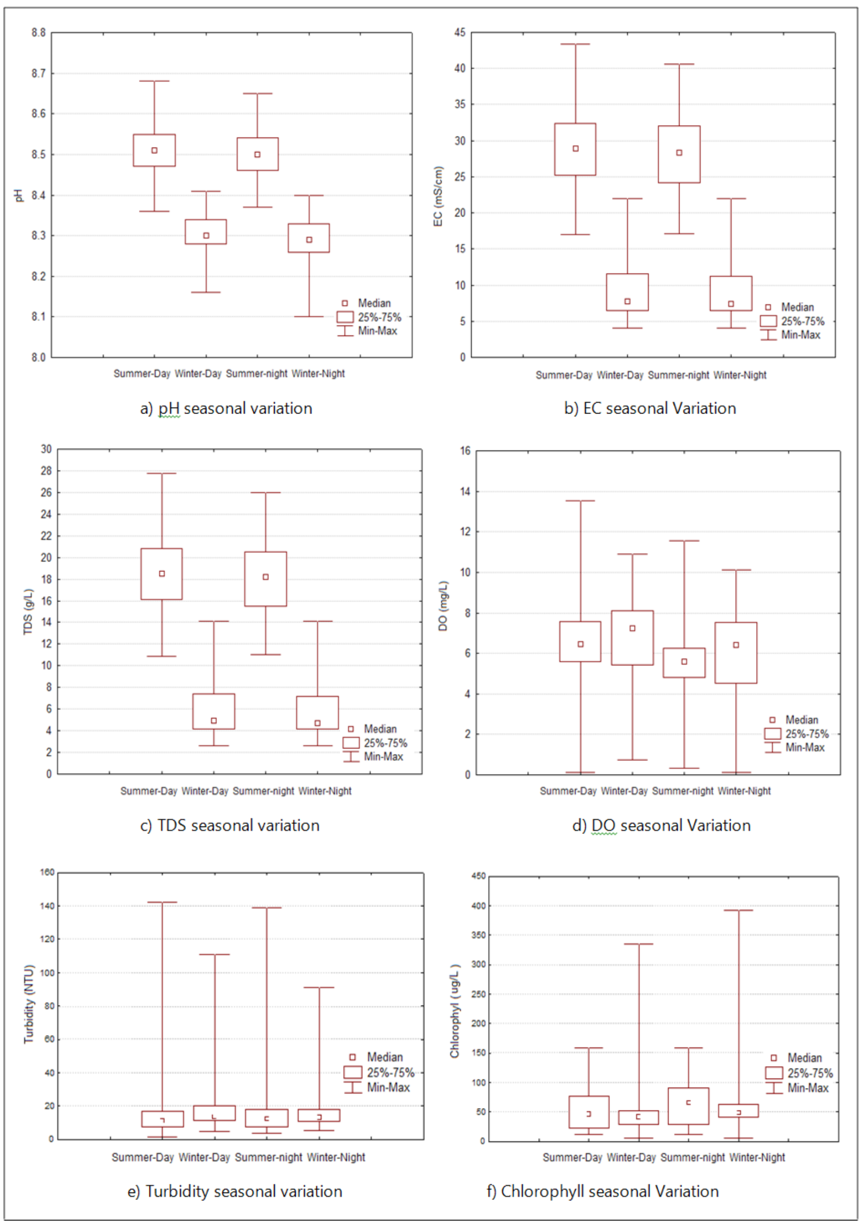
Month	Bahr El-Baqar drain	Bahr Hadus Drain	Farasqur Pump Station	Mataria Pump Station	Lower Serw Pump Station	Total
	Q (MCM/month)	Q (MCM/month)	Q (MCM/month)	Q (MCM/month)	Q (MCM/month)	Q (MCM/month)
August	101.61	95.33	49.29	122.74	0	369
September	89.05	70.86	36.41	84.49	17.4	298
October	102.65	50.15	21.58	57.58	12.08	244
November	102.69	72.75	22.3	58.51	22.26	279
December	103.48	86.27	16.16	22.1	0	228
January	99.07	59.13	19.83	56.61	0	235
February	93.74	66.05	21.67	30.52	0	212
March	103.74	61.78	27.25	23.77	0	217
April	79.33	49.42	21.87	39.69	0	190
May	76.05	45.08	27.1	30.23	0	178
June	71.8	83.05	27.37	44.48	0	227
July	84.66	87.81	18.51	30.23	0	221
Total	1107.87	827.68	309.34	600.95	51.74	2,898

As mentioned before, the water of Lake Manzala is moderately oxygenated and showed no signs of oxygen depletion. There is a limited seasonal variation in the measurements as shown in **Figure 4**d. It is clear that the values of DO in winter are higher than in summer and that they are also higher during the day than that at night in the two seasons. The lower values in summer are related to the increased flow of drainage water with low DO to the lake as shown in **Table 1**. In addition, the increased flow of drainage water increases the productivity of floating algae in the lake which consume oxygen and decrease its levels.

Figure 4e shows that there is limited fluctuation in the turbidity measurements in both winter and summer. For chlorophyll measurements there is more fluctuation in the summer than in winter. As chlorophyll is produced by microscopic plant algae **[32]**, the amount of chlorophyll in the water is usually highest in summer and lowest in winter because it is not easy for plants to grow in winter and, as mentioned above, the increased flow of drainage water in summer increases the productivity of floating algae. As a result, the chlorophyll values in summer are slightly higher than in winter in Lake Manzala. There is some variation between day and night observations in both summer and winter as shown in **Figure 4**f. It is clear that the chlorophyll values at night are slightly higher than in the day.

4.3 Data-Fit Results

Data-Fit software as a science and engineering tool, simplifying the tasks of data plotting, regression analysis (curve fitting) and statistical analysis was used to elaborate simple formulae to help predict future water quality parameters for Lake Manzala including pH, DO, EC, TDS, Turbidity, and Chlorophyll as a function of air temperature and relative humidity and to measure the impact of changes in these climate variables on the water quality parameters. The curve-fitting process was carried out using the data collected at station 1. The regression models (formulae) were developed for each water quality parameter in relation to air temperature and relative humidity, and then sorted according to the goodness of the fit criteria. In this case, the accuracy of the model was measured in terms of the Mean Percentage Relative Error (MPRE). The formula with lowest MPRE was selected as the best fit formula. The Mean Percentage Relative Error was calculated as follows:



a) pH seasonal variation
b) EC seasonal Variation
c) TDS seasonal variation
d) DO seasonal Variation
e) Turbidity seasonal variation
f) Chlorophyll seasonal Variation

Figure 4: Seasonal Variations in Water Quality Parameters in Lake Manzala

MPRE=∑{[(Model result- Field measurement)/Field measurement]×100} / Number of results

Table 2 shows the statistical results of the data fit. The values of MPRE of the curve fitting formulae for pH, EC, TDS, DO, turbidity and chlorophyll are 0.005%, 10.31%, 10.30%, 20.237%, 58.465 and 40.295 respectively. The high values of MPRE for turbidity and chlorophyll mean that there is no measured relation and no significant effect of air temperature and relative humidity on these two parameters.

The formulae were tested using in-situ measurement data on the water quality of Lake Manzala that was carried out monthly by the Egyptian Environmental Affairs Agency (EEAA) through ten stations which covered the whole area of the lake from August 2010 to February 2013. The equations were used to predict the pH, EC and DO parameters using the measured data of the air temperature and relative humidity of the Port Said Airport weather station. The predicted data and the actual in-situ measurements as an average for the ten stations were compared as shown in **Table 3**.

The percentage of the errors between the actual measured water quality data (AWQ) and the predicted water quality (PWQ) was carried out to check the accuracy of the prediction equations as follows:

$$Diff = PWQ - AWQ$$

$$Error\% = \left(\frac{\sqrt{\Sigma(Diff.)^2}}{n}\right)/avg.AWQ$$

It was found that the error percentage for pH values is equal to 1.12 %. For EC values, it was equal to 8.34% and for DO it was 15%. However, for DO, if the measured value of February 2012 which equal to 15.7 mg/l was omitted from data, the error percentage would be reduced to 9.5%. This could be attributed to the fact that the DO for surface water ranges from 0 in extremely poor water conditions to a high of 15 mg/l in very healthy water (EPA 1999). The error percentages for the different parameters are less than 10% which could be considered as a minor error and the predicted equations could be accepted.

5. Conclusions

Lake Manzala is the largest and the most productive lake of the northern Egyptian coastal lakes. Climate variables play an important role in controlling the water circulation and the water quality of this lake due to its particularly sensitive environments. Continuous measurement data from the Real Time Water Quality monitoring stations in the Lake was used to measure the regional and seasonal variations of water quality parameters of the Lake and to elaborate simple formulae to help predict the selected water quality parameters as a function of air temperature and relative humidity.

For the regional variations, the recorded measurements clearly show that the lake is, in general, brackish. There are high salinities in the northern region of the Lake which is impacted by salt water. The salinities are slighter lower in the other regions which are strongly affected by drain effluents. It was found that the pH values in the lake are alkaline and have a slight regional variation. The water of Lake Manzala is well oxygenated and shows no signs of oxygen depletion in the different regions. In the regions affected by drain effluents there is high chlorophyll concentration and high turbidity, while in the other regions which are impacted by seawater there is also high turbidity but low chlorophyll. The salinity values in the summer are higher than in winter. The values of DO in winter are higher than in summer. There is limited fluctuation in the turbidity measurements in both winter and summer. For chlorophyll measurements there is more fluctuation in measurements in summer than in winter.

The statistical results of the data fit showed that the values of Mean Percentage Relative Error of the curve fitting formulae for pH, EC, TDS, DO, turbidity and chlorophyll are 0.005%, 10.31%, 10.30%, 20.237%, 58.465 and 40.295, respectively. The high values of MPRE for turbidity and chlorophyll mean that there is no measured relation and no significant effect of air temperature and relative humidity on these two parameters. The percentage of the errors between the actual measured water quality data (AWQ) and the predicted water quality (PWQ) using the predicted curve-fitting formulae could be considered as minor and the predicted equations may be accepted.

Table 2: Data-fit Results of Water Quality Parameters as a Function of Air temperature and Relative Humidity

Parameters	Curve Fitting Formula	Standard Error	MPRE
pH	$Y = 7.39316+0.1980786T-0.02483165T^2+0.00134705T^3-0.000032031T^4+0.000000277T^5+1.00892RH-0.67255RH^2$	0.06	-0.005
EC	$Y = -137.90064+30.91409188T-3.353723283T^2+0.16933044T^3-0.003906172T^4+0.000033531T^5+94.66885RH-59.53963RH^2$	4.38	-10.31
TDS	$Y = -88.29161+19.79180696T-2.147021433T^2+0.108398995T^3-0.002500486T^4+0.000021463T^5+60.6088RH-38.1181237RH^2$	2.81	-10.3
DO	$Y = -22.26074+2.810343005T-0.222979974T^2+0.006947245T^3-0.000074004T^4+90.81673RH-139.879RH^2+65.5938441RH^3$	1.61	-20.237
Turbidity	$Y = -594.55474+165.11058T-16.72347T^2+0.78675T^3-0.01741T^4+0.00015T^5+106.445RH-104.43171RH^2$	21.02	-58.465
Chlorophyll	$Y = 387.4939-44.57771T+2.18541T^2-0.00143T^3-0.00194T^4+0.00003T^5-446.057RH+740.91785RH^2-397.5RH^3$	32.6	-40.295

In which: Y= Value of water quality parameter, T=Air temperature in Celsius, and RH= Relative humidity (%).

Table 3: Predicted and Measured in-situ Water Quality

Date of in-situ sampling	Air Temperture	Relative Humidity	Avg. Actual EC	Predicted EC	Avg. Actual pH	Predicted pH	Avg. Actual DO	Predicted DO
Aug. 2010	29	78	28.17	30.53	8.29	8.52	5.11	5.67
Nov. 2010	23	74.6	14.6	19.44	8.21	8.4	5.26	5.37
Feb. 2011	16.5	72	8.8	8.56	8.43	8.29	7.37	6.48
May-11	22	73	14.88	17.18	8.43	8.38	5.01	5.55
Aug 2011	28	74	26.48	29.09	8.56	8.51	2.73	5.82
Nov. 2011	19	70	9.2	11.27	8.35	8.32	6.17	6.177
Feb. 2012	14	75	5.35	7.69	7.46	8.29	15.7	6.7
May-12	22.6	73.96	21.33	18.51	8.4	8.39	8.33	5.46
Nov. 2012	22	75	7.93	17.31	8.4	8.38	5.81	5.39
Feb. 2013	16.5	74	8.48	8.72	8.07	8.3	4.37	6.31

6. References

[1] Abdelfattah Zalat and Simone Servant Vildary, "Distribution of diatom assemblages and their relationship to environmental variables in the surface sediments of three northern Egyptian lakes," *J. Paleolimnology*, vol. 34, no. 2, pp. 159-174, Aug. 2005. Doi: http://dx.doi.org/10.1007/s10933-005-1187-0

[2] Abdelfattah Zalat and Simone Servant Vildary, "Environmental change in Northern Egyptian Delta lakes during the late Holocene, based on diatom analysis," *J. Paleolimnology*, vol. 37, no. 2, pp. 273-299, Feb. 2007. Doi: http://dx.doi.org/10.1007/s10933-006-9029-2

[3] Abdel Ghaffer, E., "Impact of Climate Change on the Hydrology of Lake Manzala," in *Proc. 1st Inter. Conf. on Environmental Change of Lakes, Lagoons and Wetlands of the Southern Mediterranean Region,* Cairo, Egypt, ECOLLAW, 3-7 Jan. 2006, pp. 12-29. Available: http://www.geog.ucl.ac.uk/melmarina/ecollaw2006

[4] Abdel -Samei A. Elewa, Ebtisam A. Saad, Mohamed B. Shehata and Mohamed H. Ghallab, "Studies on the Effect of Drain Effluents on the Water Quality of Lake Manzala, Egypt," *Egypt. J. Aquat. Biol. & Fish.,* Vol. 11, no.2, pp. 65 -78, 2007. ISSN: 1110-6131. Available: http://www.esfhd.eg.net

[5] Abdel Satar, A. M., "Environmental studies on the impact of the drains effluent upon the southern sector of Lake Manzala, Egypt," *Egypt. J. Aquat. Biol. & Fish*., Vol.5, no.3, pp. 17- 30, 2001. Available: http://www.esfhd.eg.net

[6] Adel Ali A. Mageed, "Distribution and Long-Term Historical Changes of Zooplankton Assemblages in Lake Manzala (South Mediterranean Sea, Egypt)," *Egypt. J. of Aquat. Research,* Vol. 33, no 1, pp. 183-192, 2007. ISSN: 1687-4285. Available: http://www.oceandocs.org/bitstream/handle/1834/1901/Text.pdf?sequence=1

[7] Ahmed, M. H., El Leithy, B. M., Thompson, J. R., Flower, R. J., Ramdani , M., Ayache, F. and Hassan, S. M., "Application of remote sensing to site characterization and environmental change analysis of North African coastal lagoons," *J. Hydrobiol*., vol. 622, no. 1, pp. 147-171, Apr. 2009. Doi: http://dx.doi.org/10.1007/s10750-008-9682-8

[8] Akram Mohamed ElGanzori, "Satellite Monitoring of Water Quality in Lake Manzalah, Egypt," in *Proc. TIGER Workshop,* Cape Town, South Africa, 20 - 21 Nov. 2006, pp. 60-75. Available: http://www.tiger.esa.int

[9] Assem O. Barakat, Alaa Mostafa, Terry L. Wade, Stephen T. Sweet and Nadia B. El Sayed, "Assessment of persistent organochlorine pollutants in sediments from Lake Manzala, Egypt," *Marine Pollution Bulletin*, vol. 64, no. 8, pp. 1713-1720, Aug. 2012. Doi: http://dx.doi.org/10.1016/j.marpolbul.2012.03.022

[10] Campbell, G. and S. Wildberger, "*The Monitor's Handbook*," LaMotte Company, Chestertown, MD, 1992, pp. 30-32, 36-39. Available: http://www.lamotte.com

[11] Dowidar, N. M. and Abdel-Moati, A. R., "Distribution of nutrient salts in Lake Manzalah (Egypt)," *Rapp. Comm. Int. Mer. Medit,* vol. 28, no. 6, pp. 185–188, 1983.

[12] E. Kock Rasmussen, O. Svenstrup Petersen, J.R. Thompson, R.J. Flower and M. H. Ahmed, "Hydrodynamic-ecological model analyses of the water quality of Lake Manzala (Nile Delta, Northern Egypt)," *J. Hydrobiol*., vol. 622, no. 1, pp. 195-220, Apr. 2009. Doi: http://dx.doi.org/10.1007/s10750-008-9683-7

[13] Elewa, A. A.; Saad, E. A.; Shehata, M. B. and Ghallab, M. H., "Studies on the effect of drain effluents on the water quality of Lake Manzala, Egypt," *J. Aquat. Biol. & Fish.,* vol. 11, no. 2, pp. 65 – 78, 2007. Available: http://www.esfhd.eg.net

[14] El-Sammak, A. A. and El-Sabrouti, M. A., "Organic carbon distribution and preservation in sediments of Lake Burullus, S. E. Mediterranean, Egypt," *Fresenius Environmental Bull.,* vol.4, pp. 457-462, 1995.

[15] El-Wakeel, SK. and Wahby, S.D., "Hydrography and chemistry of Lake Manzalah, Egypt," *Arch. Hydrobiol,* vol. 67, no. 2, pp. 173-200, 1970.

[16] EPA., "*Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule,*" United States, Environmental Protection Agency, Office of Water (4607) publishing, 201pp. April 1999. Available: http://www.epa.gov

[17] Farag, H. A., "Using Earth Observation (EO) Technique for Monitoring Water Quality in Lake Burullus," *Nile Basin Water Sci. & Eng. J.*, vol.4, no. 2, pp. 37-46, 2011. Available: http://www.nilebasin-journal.com

[18] Fathi, A. A. and Abdelzahar, H. M. A., "Limnological studies on the wetland Lake El-Manzala, Egypt," *Bull. Fac. Sci. Assiut. Univ.,* vol. 32, no. 2, pp. 215-233, 2003. Available: http://www.aun.edu.eg/faculty_science/bulletin.htm

[19] Fatma Mohsen Shalaby and Heba Abd-El Migeed, "Impact of Environmental Contaminants on the Testes of Oreochromis niloticus with Special Reference to Ultrastructure of Spermatozoa in Lake Manzala (Egypt)," *J Environ Anal Toxicol* , vol. 2, no. 6, pp. 1-8, Jun. 2012. Doi: http://dx.doi.org/10.4172/2161-0525.1000149

[20] Fishar, M.R.A., "Distribution and abundance of benthic assemblages in El-Gamil basin (Lake Manzalah, Egypt)," *Bull. Nat. Inst. Oceanogr. & Fish., ARE.*, vol. 25, pp. 151-166, 1999. Available: http://www.nodc-egypt.org/en/2013-09-04-11-30-

51/144-volume-25-1999

[21] Frihy, O.; Dewidar K.; Nasr S. and El Raey, M., "Change detection of the northern Nile delta of Egypt: shoreline changes, Spit evolution, margin changes of Manzala lagoon and its islands," Int. J. Remote Sensing, vol. 19, no. 10, pp. 1901–1912, 1998. Doi: http://dx.doi.org/10.1080/014311698215054

[22] Gamal M. El-Shabrawy and Mousa O. A. Germoush, " Seasonal changes and abundance of rotifers in a shallow Manzalah lake (Egypt)," *J. Ecohydrology & Hydrobiology*, vol. 14, no. 3, pp. 243-252, 2014. Doi: http://dx.doi.org/10.1016/j.ecohyd.2014.06.001

[23] GEF, "GEF Country Portfolio Evaluation: Egypt (1991–2008)," Global Environment Facility Evaluation Office Editing and design: Nita Congress, Global Environment Facility Evaluation Office, 1818 H Street, NW, Washington, DC 20433 USA, Tech. Rep. No. 51, 2009, 163 p, Available: https://www.thegef.org/gef/eo_office

[24] Habash A., El-Sadek A., and Shaban M., "Using Real -Time Telemetry System for Assessing Water Quality and Improving Routine Monitoring," in *Proc. 10th Gulf Water Conference,* Doha – Qatar, 22-24 April 2012,. pp. 369-382. Available: http://www.acwua.org/node/177

[25] H. M. El-Asmar and M. E. Hereher, " Change detection of the coastal zone east of the Nile Delta using remote sensing," *J. Environmental Earth Sciences*, vol. 62, no. 4, pp. 769-777, Feb. 2011. Doi: http://dx.doi.org/10.1007/s12665-010-0564-9

[26] http://www.wunderground.com/weather-forecast/EG/Port_Said_Airport.html

[27] Jerome H. Friedman and Werner Stuetzle, "John W. Tukey's Work on Interactive Graphics, The Annals of Statistics," The Annals of Statistics, vol. 30, no. 6, pp. 1629-1639, Dec. 2002. Doi: http://dx.doi.org/10.1214/aos/1043351250

[28] J.R. Thompson, R.J. Flower, M. Ramdani, F. Ayache, M. H. Ahmed, E. K. Rasmussen and O. S. Petersen, "Hydrological characteristics of three North African coastal lagoons: insights from the MELMARINA project," *J. Hydrobiol.*, vol. 622, no. 1, pp. 45-84, Apr. 2009. Doi: http://dx.doi.org/10.1007/s10750-008-9680-x

[29] Khalil, M. T. and Bayoumi, A. R., "Fishery assessment survey of Lake Manzala, Egypt," *Bull. Nat. Inst. Oceanogr. & Fish., ARE.*, vol. 14, no. 3, pp.139-154, 1988. Available: http://www.nodc-egypt.org/en/2013-09-04-11-30-51/125-volume-14-1988-no-3

[30] Khan, H., Abdel-Gawad, S., Dawe, P. and Khan, A.A., "Environmental Security and Water Resources Management System Using Real Time Water Quality Warning and Communication," in *Water Observation and Information System for Balkan Countries (BALWOIS) Conf.,* Ohrid, Republic of Macedonia, 25-29 May, 2010, paper 573. Available: https://indico.cern.ch/event/75395/

[31] Mahmoud H. Ahmed, Noha Donia and Mamdouh A. Fahmy, "Eutrophication assessment of Lake Manzala, Egypt using geographical information systems (GIS) techniques," *Journal of Hydroinformatics*, vol. 8, no. 2, pp. 101-109, IWA publication 2006. Available: http://www.iwaponline.com/jh/008/jh0080101.htm

[32] Mitchell, P. 1990 Atlas of Alberta Lakes. *University of Alberta Press.* 675 pp. Available: http://alberta-lakes.sunsite.ualberta.ca/

[33] Mohamed E. Hereher, " The Lake Manzala of Egypt: an ambiguous future," *J. Environmental Earth Sciences*, vol. 72, no. 6, pp. 1801-1809, Feb. 2014. Doi: http://dx.doi.org/10.1007/s12665-014-3088-x

[34] Mohamed H. H. Ali, "Assessment of some water quality characteristics and determination of some heavy metals in Lake Manzala, Egypt," *Egypt. J. Aquat. Biol. & Fish.,* vol. 12, no.2, pp. 133 -154, 2008. Available: http://www.esfhd.eg.net

[35] Mona S, Zaki, Attia A. Abou Zaid, Mostafa F. Abdelzaher and S. I. Shalaby, "Clinicopathological Changes in Fish Exposed To Pollutants," *Life Sci J*, vol. 11, no. 3, pp. 271-278, 2014. Available: http://www.lifesciencesite.com

[36] R.J. Flower, P. G. Appleby, J.R. Thompson, M. H. Ahmed, M. Ramdani, L. Chouba, N. Rose, R. Rochester, F. Ayache and M. M. Kraiem, , N. Elkhiati, S. El Kafrawy, H. Yang, and E. K. Rasmussen, "Sediment distribution and accumulation in lagoons of the Southern Mediterranean Region (the MELMARINA Project) with special reference to environmental change and aquatic ecosystems," Hydrobiologia, vol. 622, no. 1, pp. 85-112, Jan. 2009. Doi: http://dx.doi.org/10.1007/s10750-008-9677-5

[37] Sahar F. Mehanna, Ibrahim M. Shaker and Alam El-Deen Farouk, " Impacts of excessive fishing effort and heavy metals pollution on the tilapia production from Lake Manzalah," *4th Conference of Central Laboratory for Aquaculture Research*, Cairo, Egypt, (2014), 57-74.

[38] Shaban, M. and Elsayed, E. A., "Regression Based Modeling and Numerical Simulations for the Assessment of Water Management Practices for El-Salam Canal Project, Egypt," *Nile Basin Water Sci. & Eng. J.,* vol.5, no. 1, pp. 1 -13, 2012. Available: http://www.nilebasin-journal.com

[39] *Standard Methods of the Examination of Water and WasteWater*, 19th ed., American Public Health Association Publishing APHA., New York, 1995, 1193 pp. Available: http://www.mwa.co.th/download/file_upload/SMWW_1000-3000.pdf

[40] UNDA, "Project Document Lake Manzala Engineered Wetland Prepared for: United Nations Development Agency," One United Nations Plaza, New York, United States 10017. Prepared by: Tennessee Valley Authority 400 W. Summit Hill Drive, 185 p. United Nations Development Agency, 1997. Available: Project Document.doc - Global Environment Facility

[41] UNDP, "Human Development Report. Report of United Nations Development Program", 2006. Available: http://hdr.undp.org/en/ (04/01/2013)

[42] Zubaidah Ismail, Rahizah Sulaiman and Ramlee Karim, "Evaluating trends of water quality index of selected Kelang River tributaries," *J. Environmental Eng. And Management*, vol. 13, no. 1, pp. 61-72, Jan. 2014. Available: http://omicron.ch.tuiasi.ro/EEMJ/issues/vol13/vol13no1.htm