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Water Quality Modeling for Lake Burullus, Egypt, Part I: Model Calibration.

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Water Quality Modeling for Lake Burullus, Egypt, Part I: Model Calibration.

نمذجة جودة المياه لبحيرة البرلس, مصر

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الملخص العربي

تعد بحيرة البرلس واحدة من خمسة بحيرات ساحلية , وهى ثانى أكبر البحيرات الساحلية في مصر والتي تقع على الساحل الشمالي المصرى للبحر الابيض المتوسط علي طول ساحل دلتا النيل. وتقع البحيرة داخل دلتا النيل. وتم اعتبار البحيرة كمحمية طبيعية بموجب اتفاقية رامسار الدولية لعام 1988، وأعلنت كمحمية طبيعية في مصر منذ عام 1998 نظرا لأهميتها الاقتصادية الكبيرة فى صيد الاسماك وكمنطقة راحة للطيور المهاجرة. وتعتبر بحيرة ضحلة وتتصل بالبحر الأبيض المتوسط من خلال بوغاز واحد. وبسبب موقعها المركزي، تستقبل البحيرة معظم مياه الصرف من منطقة دلتا النيل من خلال ثمانية مصارف. ونتيجة لذلك, فإن النظام الايكولوجى للبحيرة قد تدهور بيئيا. ولذلك يجب تطبيق استراتيجية لادارة جودة المياة بالبحيرة. ولهذا، تم تطوير نموذج ثنائي الابعاد للبحيرة للتطبيق وباستخدام البيانات المقاسة والخاصة بهيدرولوجية وجودة المياه لعام 2010 عند محطات مختلفة لمعايرة النموذج المقترح. وقد تم نمذجة مجموعة من العناصر مثل منسوب المياه, درجة حرارة المياه, الملوحة والأكسجين المذاب وغيره. وأظهرت نتائج المحاكاة اتفاق جيد بين البيانات المقاسة والنتائج.

Abstract

Burullus Lake is one of five coastal lagoons were exhibited by the northern Egyptian Mediterranean coast along the Nile Delta coast. It is the only one which lies inside the Nile Delta and is considered as the second largest coastal lagoon in Egypt. The lake has a great economic importance as a wetland, fishery and a resting area for migrating birds, so it is designated as a wetland nature reserve under the International Ramsar convention of 1988 and it is declared as a nature reserve in Egypt since 1998. It is a shallow brackish lake which is connected to the Mediterranean by a small outlet (Boughaz) and connected to the western branch of the Nile by a small canal (Brimbal Canal). Because of its central location, the lake receives most of the drainage water of the Nile Delta region through eight drains. As a result, the lake ecosystem has been environmentally deteriorated. A water quality management strategy is urgently required. For this, a 2-D hydro-ecological model for the lake was applied by developing the modeling system of MIKE21. Hydrodynamic and water quality records for about one year (starting from August 2010) at different stations were used to calibrate the proposed model. Different hydrodynamic and water quality characteristics were simulated by the developed model such as water level, water temperature, salinity and dissolved oxygen. The calibration results show a good agreement between the measured records and simulated results. The calibrated model will be used to assess the effect of applying some water quality enhancing scenarios.

Key words:

Lagoon, Wetland, Lake Burullus, Nile Delta, Water Quality, Modeling, MIKE 21.

Introduction

Lake Burullus is one of the most important coastal lagoons in the Mediterranean basin. It is the second largest lake of the Egyptian northern lakes along the Mediterranean coast. It lies totally inside the Nile Delta, in the center between the two main Nile River branches: Rosetta and Damietta, between Longitude 30° 30-E and 31° 10-E and latitude 31° 21-N and 31° 35-N, as can be seen in Figure 1. The present area of Lake Burullus is about 420 km^2 of which 370 km^2 is open water (Younes 2012). The author reported that the lake area was 588 km^2 in 1956 and 462 km^2 in 1974. The author gives some reasons for that area reduction such as land reclamation projects along the southern and eastern shores of the lake and fish farming processes.

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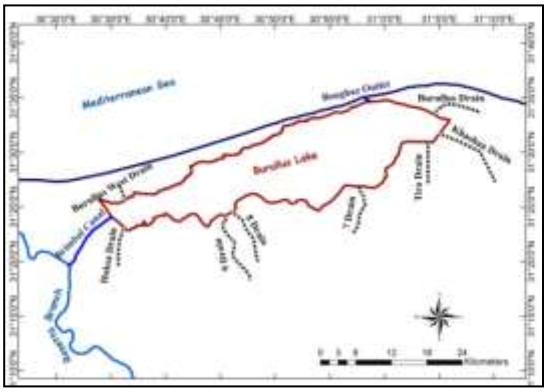

Figure 1.Layout of Lake Burullus showing its drains.

Because of its central location, the lake receives most of the drainage water of the Nile Delta region through eight drains, Figure 1. As a result, the marine ecosystem in the lake has been environmentally deteriorated (Soliman and Ushijima, (2013). Within the framework of this study, a two-dimensional, finite difference, hydrodynamic and water quality model, MIKE 21 (code), is applied to build up a hydrodynamic and water quality model for Lake Burullus. In this study, the proposed model is calibrated by the existing available observational data of Lake Burullus.

State-of-the-art

Through the literature, several studies have recently discussed the ecosystem of El Burullus Lake. Farag and El-Gamal (2011), used remote sensing approach to establish the eutrophication profile of Lake Burullus. Three Landsat Enhanced Thematic Mappers have been processed for estimation and mapping the reflectance response of chlorophyll-a and transparency, which are considered as Trophic Response Variables (TRV). The developed TRV regression model was defined, using in-situ nutrients measurements with correlation coefficients that ranged from 0.6 to 0.8 in two different seasons. Hereher, et al. (2011), applied remote sensing and a geographic information system (GIS) for mapping surface conditions of the Burullus Lagoon, Egypt as a proxy to water pollution. A spatial distribution of suspended matter, nitrogen, phosphorous, chlorophyll, dissolved oxygen, water temperature, salinity, depth, lead, copper, cadmium, clay, and sediment organic carbon has been applied. Results showed that the eastern and southern sections of the lagoon, which receive drainage wastewater, are more polluted than the northern and western sections of the lagoon. El-Adawy, et al. (2013, 2014), applied a hydrodynamic model for Lake Burullus to check a potential mitigation alternative by decreasing the pollutant loads that enter Burullus Lake i.e. diversion of existing drains, and evaluate the feasibility of adding a new artificial inlet or diversion of some drains.

Regarding MIKE 21 modeling system, it has been widely used to model different shallow water bodies, as can be noted in the literature. In 2009, Freeman, et al. used coupled hydrodynamic models MIKE 21 and MIKE 3 to provide a framework and fundamental understanding of the characteristics of Caillou Lake in the southern Lafourche marshlands and investigating the impacts of storm-related physical processes on erosion and deposition. In 2011, MIKE 21 model was developed to analyze the impact of wastewater load of industrial units in Haldia, West Bengal, on the water quality of the Hoogly estuary (Paliwal, et al, 2011). Goyal, et al. (2011), used MIKE 21 model for modelling the flow patterns prevailed off Dwarka Region, Gujarat, where the flow determines the expected variations in water quality. Water quality can be impacted by the magnitude of flow, which dilutes loadings; the travel time, which affects the amount of material that can be produced or degraded; and the degree of mixing, which affects chemical gradients. Thus, the flow, the velocity, and the degree of mixing affect the assimilative capacity of streams and rivers. Zhang, et al. (2014), examined long-term datasets of catchment inflow and lake outflow, and employs a physically-based hydrodynamic model to explore catchment and Yangtze River controls on the Poyang Lake's hydrology, China. Model simulations demonstrated that the drainage effect of the Yangtze River was the primary causal factor. Elshemy and Khadr (2015) used MIKE 21 modeling system to develop a hydrodynamic and water quality model to investigate future climate change impacts on Manzala Lake, Egypt. Three hydrodynamic characteristics of the lake were chosen to the study, water depths, water temperature and salinity. The results show significant spatially changes of water temperature of the lake. Such change will affect physical, chemical and biological processes in water bodies and, therefore, the concentration of many characteristics. The authors concluded that the increase in water levels and water salinity of the lake will severely affect the surrounding agricultural land by inundation and the quality of these agricultural lands.

Study area

Lake Burullus is a shallow brackish lake which is connected to the Mediterranean by a small outlet (Boughaz), about 44 m width near El Burg village. The length of the lake is about 65 km, with width varies between 6 and 16 km, with an average of about 11km (El-Adawy, 2013). The depth of the lake ranges between 0.42 and 2.07 m. The eastern sector of the lake is the shallowest, showing an average depth of 0.8m (El-Shinnawy, 2003). The Lake receives most of the drainage waters from agricultural areas through eight drains in addition to fresh water from Brimbal Canal which situated in the western part of the lake, Figure 1. The main basin of Burullus Lake is classified to three sectors: eastern, middle and western, each of them has some sort of homogeneity in the geomorphological, hydrological and biological characteristics (Younes, 2012).

El- Shinnawy, (2004) reported that the hydrological situation of Lake Burullus, which collects agricultural drainage water from about 4000 km² of cultivated land in the catchment. Drainage water is discharged into the lake through a group of pumping stations at the ends of the drains, except for Khashaa drain, which discharges its water freely without pumping. The author stated that the drainage system provides the lake with about four billion cubic meter annually of agricultural drainage water. The maximum rate of water discharged to the lake takes place in July during rice cultivation season, in the range discharge 2.19 to 31.74 m3/sec, while the minimum rate takes place in February, in the range discharge 1.88 to 25 m3/sec. Shakhloba drain discharges the maximum amount, which is about 20% of the total volume, while Burullus drain discharges the minimum amount, which is about 1.68% of the total volume. Figure 2. shows the typical monthly discharges of some selected drains (as examples) to the lake (El Shinnawy, 2004).

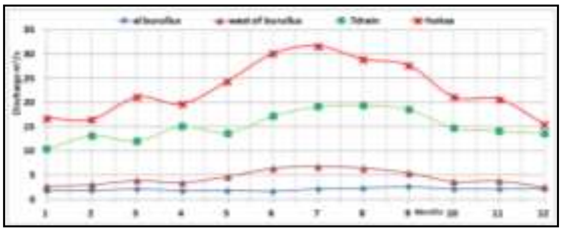

Figure 2.Typical monthly discharges of the drainage system to the lake (El Shinnawy, 2004).

Methodology

1) Mike 21 Model Description

MIKE 21 is a two-dimensional, hydrodynamic and water quality model. This model has been applied to simulate flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas (DHI, 2012). The various modules of the system simulate hydrodynamics, advection-dispersion, short waves, sediment transport, and water quality. This model computes water surface elevation, horizontal and vertical velocities, water temperature and other water quality parameters such as dissolved oxygen and nutrients. The system has a wide range of engineering and environmental applications in coastal hydraulics, oceanography, wave dynamics, harbors, rivers, lakes, environmental hydraulics and sediment processes (Warren, 2003).

2) Model Performance

The basic input data for MIKE 21 includes: lake topography (bathymetry), water levels of the lake, outlet and drains' discharges, temperature and water quality records as well as meteorological information. The bathymetry of Lake

Burullus was modeled by establishing a finite difference grid with about 48000 cells, Figure 3. A specific width, 150 m, was assigned to all cells of the model grid.

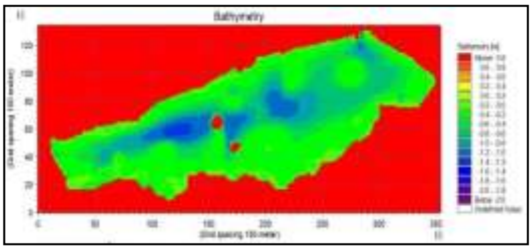

Figure 3. Bathymetric map of Lake Burullus

Discharges and water surface elevations were specified as monthly and daily average values, respectively. Water levels were collected two times a day by Coastal Research Institute (CORI) using stage boarder at different stations, Figure 4. Figure 5 shows the typical water level records for one year at different stations.

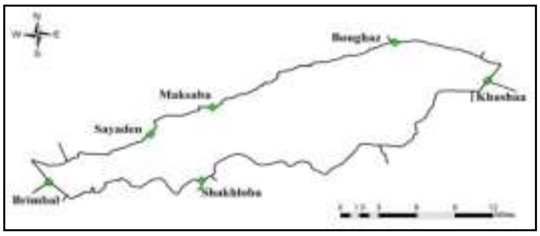

Figure 4. Locations of water levels stations of Lake Burullus.

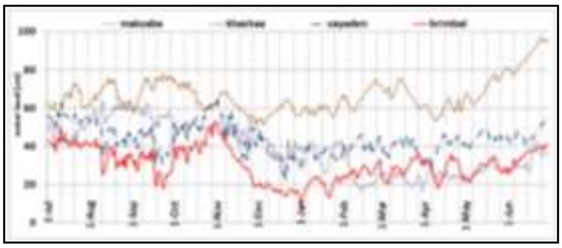

Figure 5.Measured water levels for one year at different stations of Lake Burullus.

The meteorological data as tidal variation, wind vectors, relative humidity, clearness and water temperature were obtained for the nearby local meteorological station from the internet (websites of "Weather Underground" and "Infospace"). The recorded meteorological data were given for every three hours. Figure 6. shows the 2010-2011 distribution of air temperature at Baltim station, the nearest station to Burullus Lake.

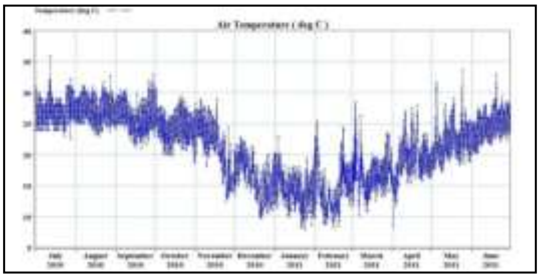

Figure 6.Air temperature records (2010 – 2011) at Baltim station, Egypt.

The observed water quality records include dissolved oxygen (DO), biochemical oxygen demand (BOD), ortho-phosphate (PO_4), nitrate-nitrite ($NO_3 - NO_2$) and ammonium (NH_4). The water quality data were obtained from the Egyptian Environmental Affairs Agency (EEAA). Unfortunately, these data were recorded four times only per year (in the four seasons) at different twelve stations as seen in figure 7.

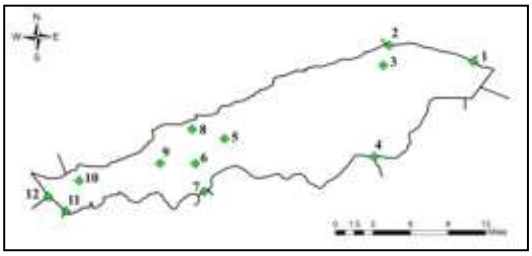

Figure 7. Locations of water quality stations of Lake Burullus.

3) An Integral Model

Geographical Information System (GIS) model is used as an integral model to obtain the missing observed data at drains boundary conditions such as, water levels and water quality parameters. An interpolated map for biochemical oxygen demand, as an example, can be seen in Figure 8.

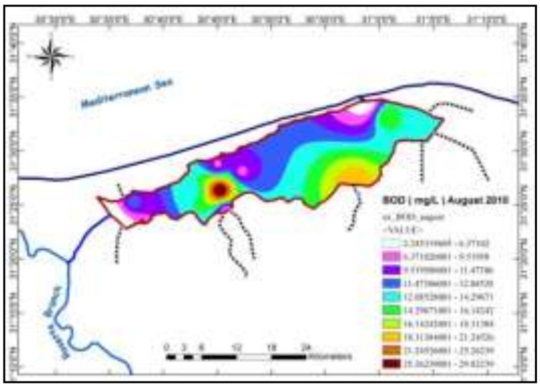

Figure 8.Biochemical oxygen demand distribution in Lake Burullus in August 2010.

4) Model Calibration

The proposed model is calibrated by modifying the model coefficients, which give the smallest error for observed and simulated records of different hydrodynamic and water quality characteristics. Some of the modified coefficients are: eddy viscosity coefficient (set as a time-varying function of the local gradients in the velocity field and smagorinsky factor is equal to 0.25), chezy number coefficient (set as 50 $m^{1/2}/s$) and wind friction coefficient (set as varying with wind speed and equal to 0.0016).

Two statistics are used to compare simulated and measured in-lakes observations, the Absolute Mean Error (AME) and the Root Mean Square (RMS) (Cole and Tillman, 2001). AME and RMS are computed according to the following equations:

$$\text{AME} = \frac{\sum|\text{Simulated value} - \text{Observed value}|}{\text{Number of Observations}} \quad (1)$$

$$\text{RMS} = \sqrt{\frac{\sum(\text{Simulated value} - \text{Observed value})^2}{\text{Number of Observations}}} \quad (2)$$

Results and Discussion

Hydrodynamic Results

Figure 9 shows the profile of water surface levels at two selected stations (Shakhloba and Maksaba), as typical examples, in Lake Burullus during the studied calibration period. A close match between the simulated and measured trend of water surface levels can be noticed. The AME and RMS values, of the calibration process, shows a good agreement of the simulated water surface levels with the observed water surface levels. The average AME and RMS values are 0.11 and 0.13 m, respectively.

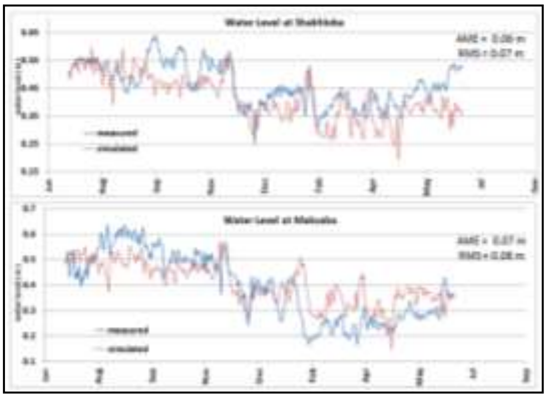

Figure 9.Simulated water levels at Shakhloba and Maksaba stations compared to the measured value.

The water temperature annual profile (2010-2011) at station No.1 and station No. 12, as examples, in Lake Burullus can be seen in Figure 10.

The AME are estimated by about 0.8 °C and 0.59 °C for stations No.1 and 12, respectively. While the corresponding RMS are 0.85 °C and 0.73 °C for stations No.1 and 12, respectively, during calibration process. The average AME and RMS values for the all stations are 1.14 °C and 1.43 °C, respectively. Although there are only four available limited records per year, the figure shows an approaching trend for the simulated records.

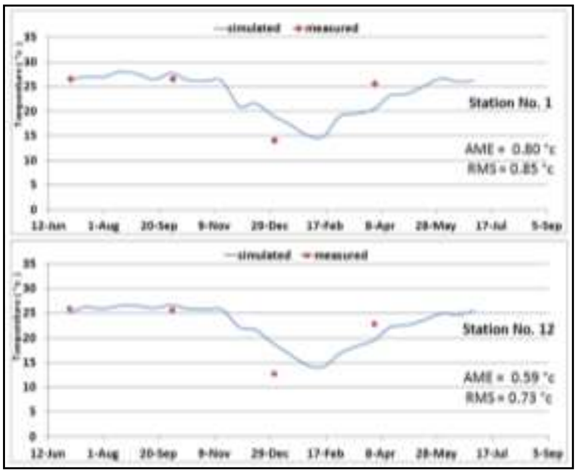

Figure 10.Simulated and Measured water temperature at stations No. 1 and No. 12 in Lake Burullus for the calibration period.

Figure 11 shows the annual profile (2010-2011) of salinity at stations No. 7 and No. 12, as examples, in Lake Burullus during the studied calibration period. The AME are estimated by about 0.06 and 0.07 ppt for stations No. 7 and 12, respectively. While the corresponding RMS are 0.12 and 0.8 ppt for stations No. 7 and 12, respectively. The average AME and RMS values are 0.64 and 0.77 ppt, respectively. As can be seen in Figure 11, the measured records are closely lies on the simulated trend in a very good way.

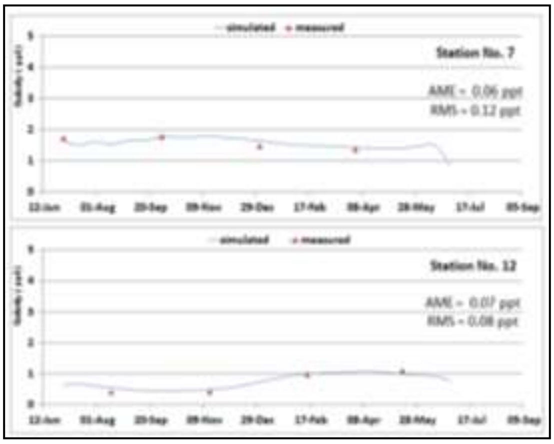

Figure 11.Simulated and Measured salinity at stations No. 7 and No. 12 in Lake Burullus for the calibration period.

Water Quality Results

The water quality model results and field measurements of the calibration process for different stations in Lake Burullus are presented as shown in Figures 12 – 16 for DO, BOD, NO_3, NH_3 and PO_4, respectively. The AME and the corresponding RMS are estimated for stations as seen in the figures. the average AME values are 1.45, 1.86, 0.70, 0.46, and 0.11 mg/l and the average RMS values are 1.86, 2.38, 0.79, 0.54 and 0.13 mg/l for DO, BOD, NO_3, NH_3 and PO_4, respectively.

As mentioned before, due to limited number of field records, comparison between field and simulated records can't be perfectly evaluated. The measured records can be seen in the figures closely lie on the simulated trend, which can be considered a good agreement.

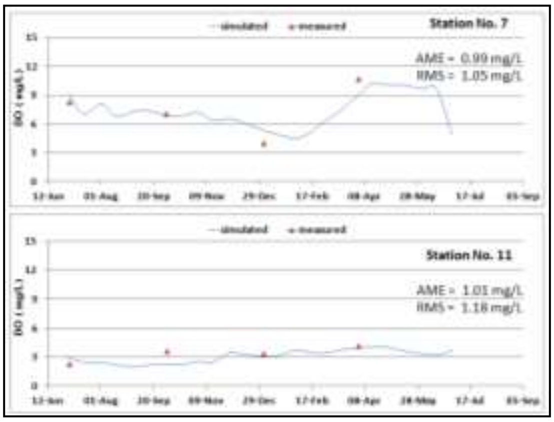

Figure 12.Simulated and Measured DO at stations No. 7 and No. 11 in Lake Burullus for the calibration period.

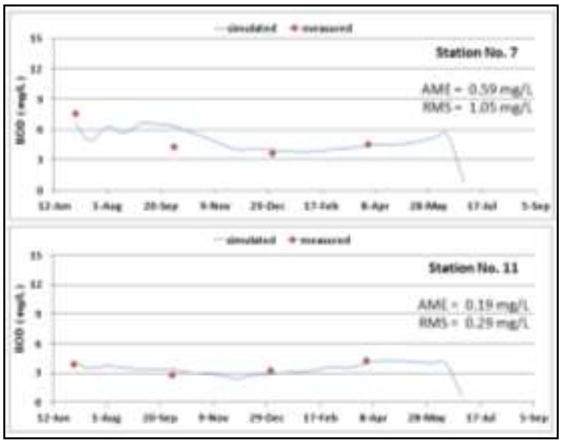

Figure 13.Simulated and Measured BOD at stations No. 7 and No. 11 in Lake Burullus for the calibration period.

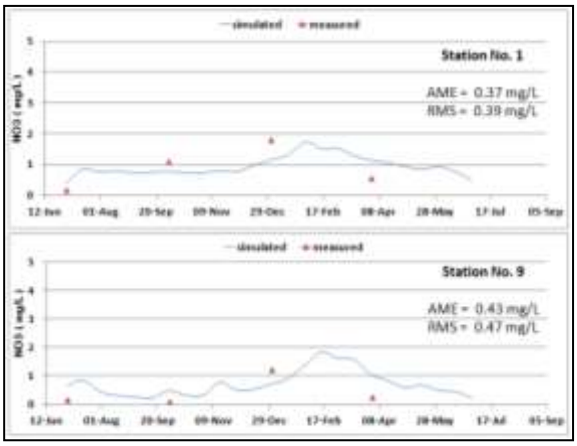

Figure 14.Simulated and Measured NO_3 at stations No. 1 and No. 9 in Lake Burullus for the calibration period.

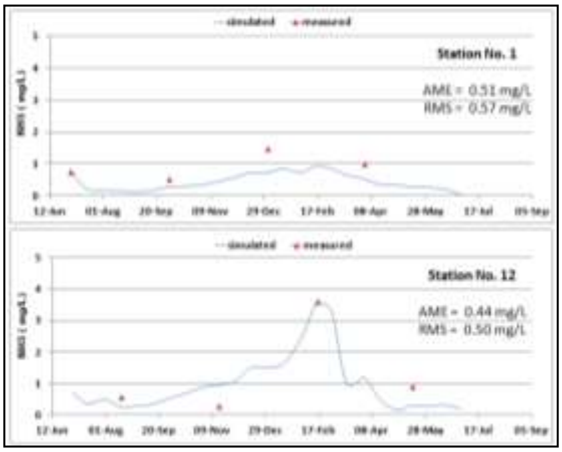

Figure 15.Simulated and Measured NH3 at stations No. 1 and No. 12 in Lake Burullus for the calibration period.

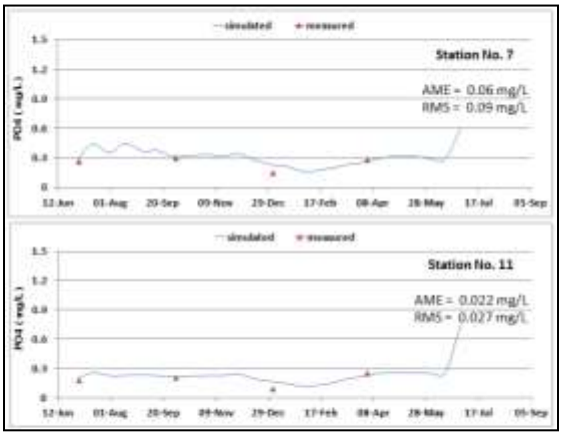

Figure 16. Simulated and Measured PO4 at stations No. 7 and No. 11 in Lake Burullus for the calibration period.

Conclusions

Lake Burullus is considered as one of the most important lagoons in Egypt, due to the related economic activities. A water quality managemnet stratigy is essential to enhance the water quality status of this lake. For that, a two dimensional hydro-ecological model is developed, based on MIKE 21 modeling system. Three hydrodynamic parameters (water levels, water temperature and salinity) and five water quality characteristics (DO, BOD, NO_3, NH_3 and PO_4) are simulated. Although the scarcity of field records, the model results are closely match the measured records. The developed model will be used to investigate some enhancement feasible scenarios for the lake water quality.

Acknowledgment

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