HYDRODYNAMIC IMPACTS OF EGYPTIAN COASTAL LAKES DUE TO CLIMATE CHANGE - EXAMPLE MANZALA LAKE

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ABSTRACT

Egyptian coastal lakes, which represent about 25% of the Mediterranean total wetlands, are considered vulnerable to the impacts of climate change, in particular the expected sea level rise (SLR). Manzala Lake is considered as the largest Egyptian coastal lake, it lies on the eastern north coast of Egypt. Economically, Manzala Lake is considered as one of the most valuable fish sources in Egypt. In this work, the impacts of future climatic changes on the hydrodynamic characteristics of Manzala Lake were investigated. Based on the Fifth Assessment Report (AR5) of IPCC (Intergovernmental Panel on Climate Change), downscaled (spatially and temporally) future projections of meteorological characteristics (such as surface air temperature, precipitation, evaporation…etc.) and the mean SLR for two Representative Concentration Pathways (RPCs) scenarios and two different periods in the 21st Century were used as the future projections of climatic changes. These future climate change estimates were used to modify a calibrated hydrodynamic model for the lake to study the future impacts of climate change. The calibrated hydrodynamic model was developed using a two-dimensional, vertically averaged, finite difference hydrodynamic and ecological code, MIKE21. This developed model was calibrated with measured data series for one year (2010-2011). Three hydrodynamic characteristics of the lake were chosen to present the study results, water depths, water temperature and salinity. These characteristics affect the hydrodynamic and ecological status of the lake, which in turn affect all the related activities of the lake. The results show severe impacts of future climatic changes on the studied hydrodynamic characteristics. A significant spatial distribution for the changes of studied characteristics can be noticed. In the following, the calibrated model is going to be used to simulate the impact of future climatic changes on water quality status of the lake.

Keywords: Coastal Lagoon, Manzala Lake, Climate change, MIKE21, Hydrodynamic Model, AR5

1 INTRODUCTION

Egypt covers a very arid region, it is extremely depends on the River Nile as the sole freshwater resource. In addition to the River Nile, Egypt has five coastal lakes (Mariot, Idku, Burullus, Manzala and Bardawil). Egyptian coastal lakes constitute about 25% of the total Mediterranean wet lands. Generally, the investigation of climate change impacts on the hydrodynamic and/or water quality characteristics of Egyptian water resources is seldom. In 2009, a simplified model was used to simulate two different future scenarios to study the effect of the water temperature rise (in the Rosetta branch of River Nile) on the DO concentrations (Radwan, 2009). The results indicated that Global warming might increase the stress on Rosetta branch and decline its water quality. The evaporation losses from Aswan High Dam reservoir at 2050 due to the expected climate changes have been evaluated (Badawy, 2009). The obtained results showed that the evaporation losses from AHDR will be increased by a very negligible change. The southern part of Aswan High Dam reservoir, Lake Nubia, was chosen by Elshemy and Meon (2010; 2011) and Elshemy (2013) to roughly quantify the potential influence that global climate change may have on its hydrodynamic and water quality characteristics. These impacts have been investigated using a proposed
hydrodynamic and water quality model of Lake Nubia, for the 21st Century - with two emission scenarios, including the average of eleven global climate models outputs. The results show that there will be significant impacts of the climate change on the examined hydrodynamic and water quality characteristics of Lake Nubia.

Investigation of the climate change impacts, especially sea level rise and temperature, on coastal lakes are addressed in limited publications (Anton-pardo and Armengol, 2011; Hinkel and Klein, 2009; Schallenberg et al., 2003; Simas et al., 2001; Ticehurst, 2008). Regarding Egyptian coastal zone, there are some studies are addressed to assess the impact of sea level rise on the Egyptian coastal zone and its protection works (El-Raey, 1997; Frihy, 2001; Frihy et al., 1996; Malm, 2012; SWITCH-Project, 2007). The Organization for Economic Cooperation and Development (OECD) has published a study which analyzes the climate change significant risks on Egypt (Agrawala et al., 2004). The authors stated that the northern Egyptian lakes are highly vulnerable to the impacts of climate change. Since the lakes are relatively shallow, climate change can lead to an increase in water temperature, which could result in changes in the lake ecosystems as well as changes in yield. Changes in salinity of Lake Manzala, as an example, may lead to impacts on lake ecology and fisheries. Further, given that the lake is unlikely to migrate inland, sea level rise will lead to a decline in shallow wetland areas and less abundant reed beds. They reported that So far, in-depth studies on potential impacts of climate change on lake ecosystems are not available. The study suggested some adaptation options for coastal resources such as breakwaters and Integrated Coastal Zone Management (ICZM). The second Egyptian communications report (EEAA, 2010) reported that based on IPCC Fourth Assessment Report (IPCC, 2007), which indicates that a global sea level rise of 18-59 cm is expected by the end of this century, and land subsidence rates, two models have been initiated by the Coastal Research Institute (CoRI) in 2009: the first is the business as usual one, while the second is the actual situation in progress. The results represent the actual situation that the Nile Delta could face considering the fact that the boundaries of the lakes are above zero level.

As can be noticed from the previous sections, the impact of climate change on the Egyptian coastal lakes characteristics (hydrodynamic and/or water quality) was never investigated previously, although these coastal lakes are very vital to Egypt. Adaptation works to sea level rise impact, which are suggest by the addressed publications, do not include any approach to enhance the expected impacts of sea level rise, such as salinity increase, on coastal lakes characteristics. So, investigating of the impacts of climate change on the Egyptian coastal lakes characteristics (hydrodynamic and/or water quality) is essential. Moreover, the existing and suggested adaptation works should be assessed. This presented study is a part of a project titled: “Assessment of vulnerability and adaptation to sea level rise for the Egyptian coastal lakes”, and funded by the Alexandria Research Center for Adaptation (ARCA), Alexandria University, Egypt.

2 STUDY AREA

Manzala lake is the largest Egyptian coastal lake, it lies on the eastern north coast of Egypt. Figure 1 shows the layout of the lake, its dimensions are about 47 Km long and 30 Km wide. This lake serves five provinces of Nile Delta (Damietta, Dakahliya, Sharqiya, Ismailia and Port Said). Economically, Manzala Lake is considered as one of the most valuable fish sources in Egypt, it contributed about 35% of the total country yield during 1980’s (Khalil, 1990). In the present, it is considered as the most productive lake in Egypt and contributed by about 30% from the total annual production of the Egyptian lakes, which contribute by about 12.5% of Egypt total fish production (Mehanna et al., 2014). The northern boundary of the lake is the Mediterranean Sea (there are some narrow outlets, the main outlets are El-Gamil outlet and the New El-Gamil Outlet), while the eastern boundary is Suez Canal (there is a very narrow connected canal called El- Qabuty Canal). Damietta Branch of River
Nile is considered its western boundary (the lake is connected to Damietta Branch by Enanya Canal). The lake receives the discharges of a lot of drains, such as Fareskour, Elserw, Mataria, Hadous, Ramsis and Bahr Elbaqar which are considered the main drains (according to their discharges). The drained waters can be classified as an agricultural, industrial and domestic waste. Water fluctuated from low salinity in the south and west to brackish water over the most of its area to saline water in the extreme northwest. The lake hydrological and water quality status have been degraded due to the progressive increasing of industrial and agricultural waste water discharge.

![Image of study area layout](image_url)

**Figure 1.** Study area layout (modified after MWRI, 2005) and field records stations.

### 3 METHODOLOGY

In order to investigate the impact of future climate change scenarios on the hydrodynamic characteristics of Manzala Lake, projected changes in climate conditions and a developed hydrodynamic model for Manzala Lake are required. The projected climate conditions are available from CORDEX Project (Cordex Project), see section 3.2. A hydrodynamic model of Manzala Lake was developed by Elshemy et al. (2015), see section 3.1.

#### 3.1 Manzala Lake Hydrodynamic Model

Elshemy et al. (2015) have developed a two-dimensional (Vertically averaged) hydrodynamic and ecological model for Manzala Lake. The developed model was based on a two-dimensional hydrodynamic and ecological modeling system (code), MIKE21/ECOLab. This code contains three modules, hydrodynamic, advection-dispersion and ECO Lab (MIKE 21 by DHI). The basic input data for the model include: lake topography (bathymetry), drains and outlets stream flow, water quality records (physical, chemical and biological) as well as meteorological information. Five main drains were considered as the freshwater source of the lake, according to their discharges, namely: Bahr Elbaqar, Hadous, Mataria, Elserw and Fareskour. While three outlets were taken into consideration, namely: Elgamil 1, Elgamil 2 and Qabuti Canal. Due to the severe lack of field data of Manzala Lake, which are essential for hydro-ecological model developing, field measurements were recorded by the authors, Figure 6 shows the field records of salinity as an example. Some other physical, chemical and biological records could be obtained from one of the interested associations (EEAA). Hydrological records, bathymetry and drain discharges, were collected by National Research Center (NRC). Figure 2 shows the generated sea water levels for the lake outlets during the simulation period (generated by MIKE21), while figure 3 presents the developed model bathymetry. Other essential required characteristics were collected from the international publications of the previous projects on the lake (Ayache et al., 2009; Thompson...
et al., 2009). Meteorological conditions of Manzala Lake during measuring days were obtained from the internet (Infospace Website) at Port Said Airport station. According to the collected data, the lake was modeled for a typical simulation year (August 2010 to July 2011). Five stations were considered for water depth (Figure 4), while 11 stations were considered for water quality records (Figure 1). A GIS database system was developed to arrange, manage and present the collected data (historical and measured) for the model. A lot of model coefficients were calibrated to have the minimum errors; two statistical parameters were used to compare simulated and in-lake observations, the absolute mean error (AME) and the root mean square error (RMSE) (Cole and Tillman, 2001). For this study, water depth, water temperature and salinity were simulated and presented.

Figure 2. Generated tide levels for Manzala Lake outlets.

Figure 3. Developed bathymetry for Manzala Lake Model.

Figure 4. Water levels recording stations for Manzala Lake.
3.2 Climate Change Estimates

To investigate the impact of future climate change scenarios on the hydrodynamic characteristics of Manzala Lake, projected changes in climate conditions and Seal Level Rise (SLR) are required. Based on the Fifth Assessment Report of IPCC (IPCC, 2013), climatic changes estimates of two Representative Concentration Pathways (RCP2.6 and RCP8.5) for two future periods I and II (Period I: [2046-2065] and Period II: [2081-2100]) as examples, were used to modify the developed hydrodynamic model of Manzala Lake. Global mean SLRs of RCP2.6 were estimated as 0.24 m and 0.4 m for periods I and II, respectively, relative to the average sea level for (1986-2005). For RCP8.5, global mean SLR were estimated as 0.3 m and 0.63 m for periods I and II, respectively. Other climatic conditions, namely: near surface air temperature, evaporation, precipitation, relative humidity and surface wind speed, were obtained from CORDEX Project (CORDEX Project) for the same two RCPs (2.6 and 8.5) and future periods (I and II). The results of two Global Circulation Models (GCM), ICHEC and EC-EARTH, were spatially and temporally downscaled by the Swedish Meteorological and Hydrological Institute (SMHI) using RCA4 regional climate model. These projections were downscaled in space to 0.44° latitude–longitude resolution (about 50 km) for the Middle East – North Africa domain (MENA) and in time to daily average. Figures 6-8 present the projected changes for some climatic conditions and scenarios relative to the base records of (2010-2011). These data are used in this work to modify the input files of the proposed Manzala Lake hydrodynamic model.

Figure 6. Daily average changes for the study area in air temperature (Celsius) relative to 2010-2011 daily average for some selected scenarios and future periods.
3.3 Climate Change Impacts on the Hydrodynamic Characteristics

The global climate change effects on the hydrodynamic characteristics of Manzala Lake are presented in relation to the calibrated model results of the 2010-2011 base case. The future climate change scenarios cover the same period of the calibration process (daily and spatially downscaled). Three hydrodynamic characteristics of the lake are investigated with respect to the climate change: water depths, water temperature and salinity. A regression analysis was developed between air temperature and water temperature for the different drains and outlets to estimate future water temperature initial conditions.

4 RESULTS AND DISCUSSIONS

4.1 Manzala Lake Hydrodynamic Model

The calibrated and verified hydrodynamic model simulation shows a good agreement with the observed water depth and the measured water temperature and salinity profiles at various locations during the simulation period. Examples of calibration process results can be seen in Figure 9 for water depth, Figure 10 for water temperature, Figure 11 for salinity. In general, the presented examples can be considered as accepted (AME and RMSE values are very small) as the model is limited by several assumptions and approximations used to simulate hydrodynamics, transport and water quality processes. Beside the uncertainty of the recorded field data and the missing parameters which have been completed from different sources.
4.2 Climate Change Impacts

Figures 12 – 14 show water depth profiles of Manzala Lake at different stations, as examples, due to global climate change for some selected scenarios. ΔWD is the average water depth change (%) between the simulated base case of the year 2010-2011 and the simulated scenario case. As can be seen in the presented figures, it can be noticed that the relative water depth changes are proportional to the sea level rise change. The station of Tanees is considered as the most affected station by the sea level rise more than other stations. This is logically, as it is the nearest station to the outlets. On the other hand, station of El-Roda is considered as the least affected one because of its spatial location (refer to Figure 4). For (RCP2.6_I) scenario, as an example, a rise of sea level by 0.24 m will increase the water depth at Tanees station (the lake eastern side) by about 102% (max.) of its basic water depth (of the calibration period, 2010-2011), which is about 0.32 m. The average change in water depths, relative to the basic water depth, at Tanees station will be about 69%. While for El-Roda station (the lake western side), the maximum and average change in water depth relative to its basic water depth will be 98% and 48% respectively. For maximum expected rise of sea level, (RCP8.5_II) scenario,
average water depth changes, relative to basic water depth, for Tanees and El-Roda stations will be 189% and 162%, respectively.

Figure 12. Water depth distribution at El-Roda station, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

Figure 13. Water depth distribution at El-Nasayem station, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

Figure 14. Water depth distribution at Tanees station, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

The study of the climate change impacts on the eco-hydrodynamic characteristics of the lake (water temperature and salinity), was done for four future scenario (RCP2.6_I, RCP2.6_II, RCP8.5_I and RCP8.5_II). All expected changes in meteorological conditions (air temperature, precipitation, evaporation, relative humidity and wind speed) and sea level rise of these scenarios were taken into consideration. The RCP8.5_II scenario was difficult to be investigated due to model simulation instability, so the results of this scenario were excluded. The presented results for this study can be considered as an indication for future climate change impacts and shouldn’t be considered as accurate predictions. A focus on water temperature change can be noticed in the presented figure, as water temperature change will affect physical, chemical and biological processes in water bodies and, therefore, the concentration of many characteristics. As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances.
from the water. Increased temperature also decreases the solubility of gases in water, such as O2, CO2, N2, CH4 and others. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter. Growth rates also increase leading to increased water turbidity, macrophyte growth and algal blooms, when nutrient conditions are suitable (Elshemy, 2011). Figures 15 – 16 show water temperature profiles of Manzala Lake at different stations, as examples, due to global climate change for some selected scenarios. ∆T is the average water temperature change (%) between the simulated base case of the year 2010-2011 and the simulated scenario case. According to the simulation results, it can be noticed that the relative change in water temperature, relative to the calibrated case, is affected by the spatial location of the stations, refer to Figure 1, and the changes of air temperature and sea level. As an example, Station No. 2 lies in the eastern north side of the lake between the two northern outlets, the hydrodynamic characteristics at that station is highly affected by the future seal level rise. So the relative water temperature change at this station will be the smallest, compared to other studied stations. The average relative change will be about 7%, 8% and 12%, for RCP2.6_I, RCP2.6_II and RCP8.5_I, respectively. While station No. 6, which lies in the southern middle part of the lake away from the outlets, has the biggest relative average temperature changes which are expected to be about 10%, 12% and 16%, for RCP2.6_I, RCP2.6_II and RCP8.5_I, respectively.

Figure 15. Water temperature distribution at Station No. 2, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

Figure 16. Water temperature distribution at Station No. 6, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

Figures 17 – 18 show salinity profiles of Manzala Lake at different stations, as examples, due to global climate change for some selected scenarios. ∆S is the average salinity change (%) between the simulated base case of the year 2010-2011 and the simulated scenario case. According to the simulation results, it can be noticed that the relative change in salinity concentration, relative to the calibrated case, is affected by the spatial location of the stations, refer to Figures 1 and 5, and the changes of water temperature and sea level. As an example, Station No. 2 which lies between the two northern outlets, the salinity concentration at that station is highly affected by the future seal level rise. So the relative salinity concentration change at this station will be the biggest, compared to other studied stations. The average relative change will be about 81%, 112% and 81%, for RCP2.6_I,
RCP2.6_II and RCP8.5_I, respectively. While station No. 8, which lies in the southern west part of the lake away from the outlets, has the smallest relative average salinity concentration changes which are expected to be about -4%, -1% and -4%, for RCP2.6_I, RCP2.6_II and RCP8.5_I, respectively.

Figure 17. Water salinity distribution at Station No. 2, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

Figure 18. Water salinity distribution at Station No. 8, Manzala Lake, for some selected future climatic scenarios and periods compared to the basic water levels (of model calibration).

5 CONCLUSIONS

One of the main goals of this research work is to quantify the potential impact of the global climate change on hydrodynamic characteristics of Manzala Lake. In doing so, we recognize the limitations of this modeling approach including the uncertainty in GCMs output, the downscaling approaches and the hydrodynamic and ecological model. Thus, the results presented here are an indication of the effects of climate change on hydrodynamic characteristics of Manzala Lake, and are not intended to be exact predictions. The impacts of climate change on hydrodynamic characteristics of Manzala Lake were investigated using a proposed hydrodynamic and water quality model, to simulate two periods: I: [2046-2065] and Period II: [2081-2100] - with two Representative Concentration Pathways (RCP2.6 and RCP8.5), for each period, including the average of two downscaled (spatially and temporally) GCMs outputs. The global climate change effects are presented relative to the calibrated model results of the year 2010-2011 base case. The presented 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. Moreover, severe spatially changes in water depths and salinity concentrations will occurred, due to the sea level rise. 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. Suitable crop distribution for the expected land quality should be investigated. A sensitivity analysis should be done by using each of predicted meteorological variables and sea level change separately to check its effect on the hydrodynamic characteristics.
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