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Coastal Lake Sustainability: Threats And Opportunities With Climate Change

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***Abstract**: Northern coastal lakes in the Nile Delta of Egypt have an ecosystem of distinctive nature. While customary acknowledged as environmentally rich water bodies, these lakes are alleviating the non-favorable polluting effect of development activities before reaching the Mediterranean Sea. Moreover, climate change challenges are adding more important role to coastal lakes to act as natural adaptive measure that effectively buffer potential sea level rise or any unprecedented events. Therefore, efforts are needed to maintain sustainable system for coastal lakes in face of continuously altering conditions.*

The main goal of this research study is to investigate vulnerability of coastal lake systems in facing climate changes, with reference to the water quality status. As a key indicator of healthy ecological structure, acceptable quality condition would ensure beneficial uses and, consequently, socio-economic well-being in served watershed. With the existing challenges of development processes, this research considers the hypothesis of regarding the climate change phenomenon as potentially having positive impact in improving certain water quality problems. Through a case study application in Lake Burullus, located in the northern coast of Egypt; this research study addresses one of the main water quality problems defined, which is the declining salinity level, and entailed deteriorating aquatic ecosystem and fish population. Projection for changes in salinity concentrations is based on changes in inflow/outflow salinity budget with predicted change in climate.

Results show that climate change will improve water salinity within the lake under consideration by year 2150. However, meeting target levels would still require supplementary measures. Finally, this research proposes management plan with applicable adaptation measures for Lake Burullus. This research also sets basis for future research continuation while considering factors from coastal side and served watershed side, simultaneously. This research sheds some light, through Lake Burullus case study, on management measures for coastal lakes to be considered by decision makers.

***Key words:** Lake Burullus, Water Salinity, Climate Change, Coastal Lake.*

I. Introduction

In the northern coastline of Egypt, a number of natural lakes exists; three of which are located within the Nile Delta region. These lakes have earned special environmental, economical, and social importance. As a connecting zone for saline water with fresh water, they have a unique environmental status and host a rich ecosystem. However, with increased pressure of development requirements and human activities, coastal lakes are more and more overburdened with deteriorating effects.

Furthermore, predictions in the fourth report of the Intergovernmental Panel on Climate Change (IPCC), issued in 2007, indicated that the African continent is likely to experience increased temprature compared to usual levels. Also predicted was that the annual rainfall would have greater likelihood of decreasing in much of the Mediterranean coasts of Africa. Egypt's Mediterranean coast and the Nile Delta have been identified highly vulnerable to climate change impacts. According to modeling scenarios, it is expected that temperature would change with a range between 1.8 °C to 4.0 °C and, consequently, sea level would rise with a range from 18 cm to 59 cm by the end of the current century, (IPCC, 2007).

Therefore, the Egyptian coastal lakes, while playing an important role in alleviating pollution reaching the Mediterranean Sea, would potentially have vital role for adapting to climate change in coastal region, yet considered of the most vulnerable water bodies that need to be sustained against current and potential adverse effects. Sustainability of healthy ecological system in lake ensures better beneficial uses and socio-economic well-being in served watershed. As a key indicator of healthy environment in lakes, water quality status has been the focus of this research study.

This research is investigating sustainability of coastal lakes in face of continuous alteration in conditions. Beside human activities within the framework of development processes in Egypt, climate change is expected to remarkably impact the coastal lakes' ecological structure. Earlier studies of coastal lakes in Egypt mainly focused on deteriorating bio-physical status of the lake as a result of increasing development activities, (El-Kolfat, 2002 and Elshinnawy, 2005). This research, however, investigates the effect of climate change on aspects of coastal lake environment through a case study application in Lake Burullus. With reference to water salinity level, the research study addresses changes in salinity concentrations on the basis of predicted changes in climate. Initial hypothesis suggests a possible positive side to consider in following climate change impact. Projected improvement in Burullus lake water conditions and considered management measures are, accordingly, concluded.

II. Research Objectives

Through a case study application in Lake Burullus, this research tries to investigate the hypothesis of having a positive impact of the climate change phenomenon that would improve quality state in coastal lake (e.g. in terms of salinity level). This research aims at establishing the concept of possible beneficial use of climate change by means of following the impact of hydro-meteorological changes on water salinity budget within the Nile Delta coastal zone. Findings are to be considered in management planning for sustainability of coastal lake system. Results of this research are expected to shed some light, through Lake Burullus case study, on management measures for coastal lakes to be considered by decision makers.

Objectives of the research study can be summarized as:

- To highlight expected changes in hydro-meteorological behavior within coastal region
- To investigate positive potentials of climate change phenomenon, with possible ability to overcome the adverse effects of development processes
- To set an alternate plan for coastal lake ecosystem sustainability and restoration , with special reference to water salinity levels

III. Methodology

As beneficial use is directly related to lake sustainability in face of inevitable changes, this research attempt to formulate a restoration plan for coastal lakes while investigating vulnerability potentials of climate changes. Among the major northern lakes that rose concerns lately in Egypt is Lake Burullus.

The research first sets basic information for present and historical periods of Lake Burullus; through literature review, data collection and survey for recent conditions in this selected case study coastal lake. Collected data covered environmental features, physical characteristics, water quality as well as meteorological data, water level measurements and discharges' records.

Vulnerability analysis and potential effects of climate change have been investigated in terms of the impact of changing evaporation and rainfall rates on water budget and quality variation within the lake of interest. The predictions of future status with climate change are then concluded by using balance functions and quality relationships. Amongst the reviewed Global Climate Models, simulation results of two climate change models have been considered in predicting future alteration in precipitation and temperature in the case study region; namely, the Community Climate System Model version3.0, of the National Center for Atmospheric Research (CCSM3-NCAR) and the atmospheric general circulation model of Max-Planck Institute for Meteorology (ECHAM5- MPI-OM) (details on models can be found in Vertenstein et al, 2004, Collins et al, 2006 and Roeckner et al, 2003).

As salinity concentration in water bodies is considered largely controlling the ecosystem well-being in general, and living organisms in particular, this research is focusing on prediction of changes in lake water salinity with climate change. Projection of changes in salinity concentrations are concluded based on changes in inflow/outflow salinity budget with predicted climate changes. Adaptive capacity of Lake Burullus and strategy for improving salinity levels are then presented in terms of combining the concluded positive impact of climate change to other supplementary measures, such as; benefiting from groundwater salinity intrusion, and decreasing drainage water inflows into the lake.

Finally, this research paves the road for future research continuation and application with more comprehensive coverage of activities to include served watershed features, wider water quality concerns (e.g. nutrients, sediments) as well as usage of advanced modelling techniques. Results of this research are expected to shed some light, through Lake Burullus case study, on management measures for coastal lakes to be considered by decision makers.

IV. Case Study Application: Lake Burullus

1.1. Main Features and Problem Definition

Lake Burullus is located in a dynamic region between Damietta and Rosetta branches of the River Nile, more precisely in the North-Western region of the Nile Delta between 30˚ 33´ to 31˚ 07´ E and 31˚ 22´ to 31˚ 26´ N, (Elshinnawy, 2003) as shown in figure (1), and is connected with the Mediterranean Sea with one opening (Boghaz Al-Burullus) in the eastern side of the lake. The lake length is about seventy (70) kilometers, with width ranges from six to fourteen (6-14) kilometers, and water depth ranges from 0.42 to 2.07 meters. The lake is separated from the Mediterranean Sea with a sand bar of 2 - 6 km width that gets narrower from west to east. The lake is the ending point for seven drains of the agricultural drainage system in Middle Nile Delta region.

The Burullus Lake has a historic reputation of having a rich aquatic ecosystem and active socio-economic status. Its environmental importance comes from hosting waterfowl and rare plants. While being the habitat for about one hundred and thirty five (135) different kinds of land and water plants (MSEA, 2010/2011), Lake Burullus is an important stop-over point for migrating birds. Furthermore, the lake has a socio-economic importance for the wide fishing activities. Therefore, to ensure its preserved status, Lake Burullus has been declared nature reserve for its content of rare plants, animals and aquatic life as well as its special geographical nature used by migratory bird. Unfortunately, maintaining the lake environmental status is facing serious challenges.

Lake Burullus, as do other northern lakes at the Egyptian coast, is the receiving pool for considerable amounts of drainage waters with various characteristics coming from development activities; urban sewage, industrial facilities, Waste Water Treatment Plants (WWTP), fish farms, as well as drainage waters rich with chemicals fertilizers and pesticides from agricultural lands in sectors of the Delta region. While working as a buffer decreasing the nutrients reaching the Mediterranean Sea, in turn, that has caused severe deterioration in the lake original environmental state and flow pattern.

Earlier surveys in Lake Burullus proved that water moving from south to north most of the time, with overwhelming discharges from served watershed side (Elshinnawy, 2005). Meanwhile, input through Boghaz Al-Burullus opening from the Mediterranean sea is not standing to balance fairly which result in poor water exchange between the Mediterranean Sea and the Lake. Records of water budget for Lake Burullus indicated that effluents from the agricultural draingae network are responsible for 95.9% of inflows into the lake, while domestic/industrial point source effluents and groundwater are responsible for 0.25% and 0.8% respectively. In addition, rainfalls contribution is about 2.2%, and flows from the sea is less than 1% (hardly 0.85%) of the total inflows into the lake. Meanwhile, water loss by evaporation is about 15.85% and outflow into the Mediterranean Sea is 84.15% of the total outflows from the lake.

Decreased rate of saline water inflow from the sea, along with the increased fresh water effluents discharged from development activities within the watershed have resulted in reducing normal salinity level in the lake. Meanwhile, the high level of nutrients input into the lake from domestic, agricultural and industrial wastewaters have caused excessive growth of unwanted aquatic plants and, consequently, slow water circulation, destruction of spawning and nursery grounds, and deterioration in fish productivity.

Deficiency in water exchange between the Mediterranean Sea and Lake Burullus has been addressed in recent studies (El-Kolfat, 2002 and Elshinnawy, 2007) with suggestion of creating a second opening. However, certain features hindered applying such a suggestion for reasons related to surrounding activities, existing infrastructure as well as a naturally found sand bar that is important to maintain shore stability.

Figure 1: Burullus Lake in Northern Coast of the Nile Delta

1.2. Data Sources

Required Hydrological, Meteorological And Geophysical Data For This Research Study Have Been Collected From Various Sources And Publications. Data Covering Main Hydro-Physical Information Are Found In Publications Of Previous Studies On Burullus Lake (El-Kolfat, 2002, Elshinnawy, 2003, Elshinnawy, 2007 And MSEA, 2010/2011).

Records of water quality measurements and salinity concentrations at the ending points of the drains have been attained from the Drainage Research Institute (DRI), while salinity in Lake Burullus and the Mediteranean Sea are retrieved from recorded measurements in Coastal Research Institute (CoRI) of the National Water Research Center (NWRC) of Egypt. More survey results and data have been collected through record reviews and cooperation with the DRI, as well as the Egyptian Shore Protection Authority (SPA), the National Authority of Drainage Network of the Ministry of Water Resources and Irrigation (MWRI), and the Egyptian Environmental Affairs Agency (EEAA). However, certain limitation in detailed measurements and frequency in sampling have been overcome with simple Artificial Neural Network (ANN) model application to fill unavailable data in simulated pattern.

Climatological data are found in browsing data centers via internet web sites; e.g. weather underground http://www.wunderground.com/ and climate explorer http://climexp.knmi.nl/. However historical meteorological data have also been consulted from early weather reports by the Egyptian Meteorological Authority (1979), within the framework of the environmental data rescue program of the National Oceanic and Atmospheric Administration (NOAA).

1.3. Rationales & Calculation Bases

This research study follow the impact of climate change in terms of variability in temperature and precipitation in current and future water budget and quality levels in Lake Burullus. The research argue how would that affect in/out freshwater balance within the lake , and consequently change in salinity levels, potentially with positive effect. Simulation results for a number of well-known global climate models have been reviewed before considering certain model predictions of temperature and precipitation. Two of these global climate models; namely (CCSM3.0)-NCAR and (ECHAM5)- MPI-OM models, have been concluded best to consider. Selection was based on models with least needed corrections when comparing actual records for recent times with model predictions for the same period of time.

Calculation started with mass balance for water budget in Lake Burullus. Then, water loss by evaporation and water gain by rainfalls in years 2050, 2100, and 2150 have been predicted, followed by computing potential changes in salinity concentrations within the lake according to changes in losses and gain in freshwater budget of lake Burullus. Data records have been dealt with on average monthly basis and likewise are the results presented.

Water balance of Burullus coastal lake is governed by inputs; including inflow from point sources, such as WWTP and industrial facilities, tributaries of the agricultural drainage network, precipitation onto the lake surface, subsurface and groundwater inflow, as well as sea water input, and on the other hand governed by outputs; namely outflow into sea, and evaporation from the lake surface. In hydrological equilibrium of Lake Burullus, mass balance for water budget is presented as follows (Thomann and Mueller, 1987):

$$Q_e + Q_d + Q_{gw} + Q_{in} + PA_s = E\,A_s + Q_{out}$$

Where; (Q_e) is effluent flow of point source from activities, (Q_d) is flow from drainage network discharging into the lake, (Q_{gw}) is flow from groundwater contribution, (Q_{in}) is inflow from sea, (P) is precipitation, (A_s) is surface area of the lake, (E) is losses by evaporation, and (Q_{out}) is loss of water outflow from estuary.

Evaporation loss of water basically governed by solar radiation, vapor pressure, surface water and air temperature, humidity level, thermal convection and wind speed (Thomann and Mueller, 1987 and Linsley R. et al., 1992). In calculating temperature-related changes in water budget, attention has also been drawn to potential changes in vapor pressure. Since molecules activities are closely connected to temprature and molecular kinetic energy is greater at higher temperature, more molecules is expected to escape the surface . consequently, the saturated vapor pressure would be assuming higher values, (consulted tables in literature; Linsley R. et al., 1992 and Wilson, 1990).

Reviewed references presented various approaches for calculating evaporation. Wilson (1990) states empirical equation for estimating evaporation, principally relative to vapour pressure and wind speed, as follows:

$$E = C\,(e_s - e)\,f(u)$$

Where; (E) is open water evaporation per unit time (e.g. mm/day), (C) is an empirical constant, (e_s) is saturation vapour pressure of the air at t ˚C (mm mercury), (e) is actual vapour pressure in the air above (mm mercury), and (u) is wind speed at some standard hieght (m).

Based on that, the following equation has been empirically concluded, while conditioned with the assmption of having the same temperature of water surface and air:

$$E = 0.35\,(e_s - e)\,(0.5+0.54u_2)$$

Where; (u_2) is wind speed in m/s at a hieght of 2m above the surface, and (E) is evaporation in mm/day. Other approaches of estimating evaporation in term of heat loss rate (H_e) has also been consulted. Edinger et al (1974) have examined a number of formulations, and suggested the following conservative expression of Brady, Graves and Geyer (1969), as mentined in Thomann and Mueller (1987).

$$H_e = (19 + 0.95\,U^2{}_w)\,(e_s - e_a)$$

Where; (U_w) is wind speed in m/s measured at a height of 7 meters above water surface, (T_a) is air temperature ˚C, (e_{sat}) is saturated vapour pressure of water (mm Hg) at T_a, (e_a) is air vapour pressure (mm Hg) that is concluded as a function of relative humedity and e_{sat} at T_a.

Based on the reviewed approaches, estimations of water loss by evaporation have been calculated from the following function:

$$E_v = \frac{H_e}{\rho\,L_h} \qquad \text{cm/day}$$

Where; (ρ) is water density in g/cm^3, (L_h) is latent heat of vaporization (585 cal/g), and (H_e) is heat loss in cal/cm^2.day.

Based on predicted changes in lake Burullus water budget, corresponding changes in salinity content have been deduced by balancing mass and concentration of substances in water bodies, with the assumptiom of completely mixed sytem (Thomann and Mueller, 1987). Salinity concentration in the Lake Burullus is a function of inflow and outflow salinity concentrations. following is the relationship used in calculating potential changes in lake water salinity:

$$Q_e S_e + Q_d S_d + Q_{gw} S_{gw} + Q_{in} S_{in} + PA_s S_p = E A_s S_E + Q_{out} S_{out}$$

Where;

(S_e) is Salinity of effluent flow of point source from development activities, (S_d) is Salinity of flow from drainage network discharging into the lake, (S_{gw}) is Salinity of flow from groundwater contribution, (S_{in}) is Salinity of inflow from sea, (S_p) is Salinity of gained flow by Precipitation, (S_E) is Salinity of lost flow by evaporation and evapotranspiration, and (S_{out}) is Salinity of outflow from estuary. Other parameters are as defined before in previous paragraphs.

Application covered predicting climate change impact on water salinity levels in Lake Burullus, on monthly basis, till year 2150. Results are demonstrated in details in the following section.

V. Result Analysis & Discussion

In setting the baseline conditions of the coastal lake Burullus, with reference to the physical and water quality status, initial vulnerability assessment to climate change showed certain potentiality of the lake to stand physically steady. Adaptive capacity of the lake is armed with natural coastal sand bar along with hard structures at the outlet or Boghaz Al-Burullus.

However, predictions of changes in water quality in relation to climate change have shown slight improvement in conditions within the lake, yet not utterly satisfactory to target quality status. Confirmed by reviewed literature and recent measurements, water budget in Lake Burullus indicated obvious minor impact of inflow from sea when compared to inflow from watershed activities (i.e. wastewaters reaching the lake). Prediction of changes in sea water inflow into the Lake Burullus with sea level rise scenario of one meter above current level by year 2100 have been examined. Results showed that one meter increase in sea level would cause minor difference in lake water salinity, 0.5% difference in about 100 years, when compared with that of the scenario of the same sea level as present. Therefore, it has been concluded that inflow from sea can be considered having insignificant effect in salinity budget within the Lake Burullus even with considerable rise in sea level.

On the other hand, evaporation is currently responsible for about 15% of freshwater loss from water budget in Lake Burullus. Predictions showed that expected climate changes and rising temperature in the region would increase the freshwater loss to 20% by year 2150. The effect of predicted diminishing quantity of freshwater in the lake, in terms of reduction in rainfall rates and increase in evaporation rates, has been found beneficial in elevating water salinity concentrations within the Lake Burullus.

1.4. Predicted Salinity Levels in Lake Burullus

Based on previously stated rationales and computing principles, predicted salinity concentrations in years 2050, 2100, and 2150 were determined. Findings of monthly mean salinity concentrations within the Lake Burullus in years 2050, 2100, and 2150 are stated in table (1). Predictions of water salinity concentrations range from 2.97 mg/L to 3.46 mg/L during year 2050, while ranging from 3.02 mg/L to 3.48 mg/L by year 2100. With remarkable boost in year 2150, salinity concentrations range from minimum value of 3.14 mg/L in December to maximum value of 3.78 mg/L in March. An illustartion of changes in salinity concentrations from current levels due to climate change impact is in figure (2). Meanwhile, figure (3) shows climate change impact in terms of accelerating trend in average annual salinity concentration within Lake Burullus.

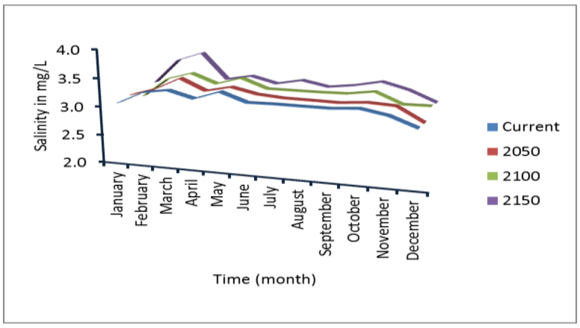

Figure 2: Predicted change in salinity levels with climate change for years 2050, 2100 and 2150

Results of predicted change in water quality as a result of climate change have shown improved status of salinity concentrations in Lake Burullus, but not to the extent that cure the lake problems. Target salinity level of 5.0 mg/L in lake waters has been recommended in early research studies as the acceptable levels of salinity that ensure regaining healthy aquatic ecosystem and fish population. This target level is also considered as an environmentally soft measure that helps eliminating unwanted aquatic plants which are excessively found in the lake as a result of high nutrient contents.

Predicted salinity concentrations reach 3.78 mg/L at its maximum value in March of year 2150 which, while indicating trend of increase in salinity levels in the lake, yet is not satisfactory to target salinity levels of 5.0 mg/L. Results also show that water salinity in the Lake Burullus would assume peak levels in March and May during the year. The high salinity levels in lake waters during spring time can be explained by increased evaporation resulting in loss of freshwaters from the lake combined with reduced discharges from the agricultural lands within the served watershed. Combined effect of these factors may cause raise in salinity concentrations in Lake Burullus at that certain time of the year.

Table 1: Predicted change in salinity levels with climate change during years 2050, 2100 and 2150

Time	**Salinity in mg/L**			
	Current	**2050**	**2100**	**2150**
January	3.05	3.11	3.02	3.19
February	3.26	3.25	3.35	3.63
March	3.33	3.46	3.48	3.78
April	3.21	3.27	3.32	3.33
May	3.36	3.36	3.45	3.41
June	3.21	3.27	3.28	3.30
July	3.21	3.23	3.28	3.39
August	3.21	3.22	3.28	3.30
September	3.20	3.21	3.28	3.35
October	3.24	3.25	3.35	3.44
November	3.15	3.22	3.16	3.32
December	2.98	2.97	3.16	3.14

It has been noticed, as presented in figure (3) and table (2), that salinity increases at a flatter rate during this century, till 2100, yet between year 2100 and 2150 it is predicted to increase with a higher rate. The rate of change for salinity concentration in Lake Burullus has accelerated from 0.08% increase rate during this century to about 0.2% from years 2100 to 2150.

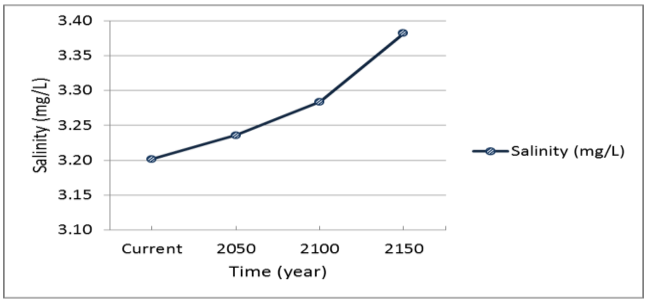

Figure 3: Climate change impact on main trend of salinity concentrations within Lake Burullus

Table 2: Potential trend of salinity concentrations in Lake Burullus

Time	Current	2050	2100	2150
Mean Annual Salinity in mg/L	3.20	3.24	3.28	3.38

In an attempt to evaluate the potential benefit gain by climate change, current conditions have been investigated while assuming hypothetical reduction of inputs from the served watershed; discharges from agricultural drainage network, WasteWater Treatment Plants and industrial facilities. Results are illustrated in figure (4) and presented in table (3). Hypothetically reduced discharges cover a range from no action taken up to 30% reduction in allowed wastewater discharges into Lake Burullus. It was concluded that to achieve the same improvement in lake Burullus salinity due to climate change, it is required to reduce about 28% of the discharged wastewaters from development activities within the served watershed.

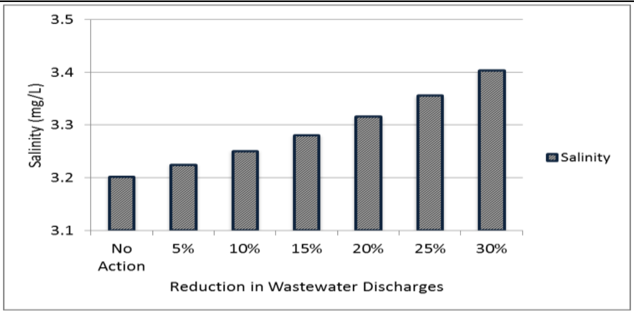

Figure 4: Salinity improvement with proposed reduction in wastewater discharges

Table 3: Predicted improve in Burullus Lake water salinity with reduced wastewater discharges from development activities in served watershed

% of Discharge Reduction	No Action	5%	10%	15%	20%	25%	30%
Salinity in mg/L	3.202	3.225	3.251	3.281	3.316	3.356	3.404

1.5. Climate Change Potential Benefit in Management Measure

It has been established that restoring original water salinity levels within Lake Burullus is directly related to aquatic ecosystem recovery, in general, and fish population regain, in particular. However, as highlighted by prediction findings, trend of salinity level increase in the lake as a result of climate change is not to the extent to compensate the adverse effects of the development processes in the region. Therefore, a management plan for sustainable ecosystem in Lake Burullus is required to face development wastes on one hand and benefit from climate change impacts on the other.

Proposed management measures for elevating salinity in face of increased low-saline wastewater discharges into the lake could be either by decreasing such effluent discharges and/or by providing source of saline water inputs. As presented in the above section, the gradual reduction in development process discharges into the lake is having limited improving effect in salinity levels. Therefore, the concept of providing an extra source of saline water inputs has been worth considering. Saltwater intrusion into groundwater in the Nile delta coastal region has customary been addressed as negative impact of development processes and groundwater excessive withdraw (Sakr et al., 2004). However, a recent study by Elshinnawy and Abayazid (2011) has shown that climate changes and consequent sea level rise is projected to cause additional saline water intrusion into aquifer of the Delta coastal region (figure 5). The study predicted further advance of saline water /freshwater interface landward and, as a result, considerable upward movement of saline water. That, in turn, would make more water with high salinity concentration available nearer to surface and viable to be used as a source to feed lake Burullus and increase its water salinity concentration. Therefore, a managemnt plan that establishs well network system for saline water extraction and redirection into the lake is worth considering for pilot application.

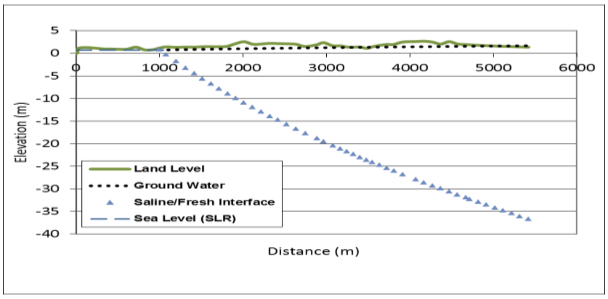

Figure 5: Predicted saltwater/freshwater interface movement and groundwater elevation in 2100 [after Elshinnawy and Abayazid, 2011]

VI. Conclusion and Recommendation

Northern coastal lakes in Nile Delta form an ecosystem of distinctive nature and are customary acknowledged as environmentally rich and worth maintaining for better coastal management in face of development processes. These lakes are alleviating the adverse non-favorite polluting effect of developments before reaching coastline. Moreover, climate change challenges are adding more important role to coastal lakes to act as natural adaptive measure that effectively buffer potential Sea Level Rise and/or unprecedented events. For their unique feature and potential uses, this research study addresses the rising concern for coastal lakes in Egypt, in context with development processes and climate change impact, through a case study application for Lake Burullus. The lake is a meeting point for different types of water properties that is affected by coastal characteristics, development processes in served watershed, meteorological fluctuations, in addition to the expected variations with climate change and sea level rise.

This research investigated the potential positive effect of climate changes on alleviating development activities adverse impacts on water quality, with special reference to salinity concentrations as a key component of life in aquatic system. Prediction results show certain improvement in lake water salinity and potential favorable rise to some extent. Salinity concentrations in Lake Burullus are predicted to raise to 3.46 mg/L by year 2050, and 3.48 mg/L in 2100, then boost up to 3.78 mg/L in year 2150. Projected findings have also shown that lake water salinity increases at a flatter rate during this century, till 2100. Yet, between year 2100 and 2150, it is predicted to increase with a higher rate. The rate of change for salinity concentration in Lake Burullus has accelerated from 0.08% during this century to about 0.2% from years 2100 to 2150.

Yet findings proved that expected salinity improvement resulting from climate change are not enough to completely encounter the effects of wastewater discharges from agricultural and industrial activities within the served watershed. Consequently, the target levels for sustained lake environment required management measures to be considered.

Therefore, in order to restore salinity degree and regain original healthy ecosystem within Lake Burullus, the study proposes supplementary management measure while making positive use of inevitable climate change impact and salinity intrusion in coastal delta aquifer. Predicted sea level rise as a result of climate change is expected to cause landward/upward advancement of saline water/fresh water interface in the aquifer of the coastal region in the Nile delta. Accordingly, sea water intrusion would result in waters with high salinity levels approaching the ground surface and easier to be used as a source to feed Lake Burullus and, hence, increase its water salinity level. The managemnt plan proposes establishing viable well system for saline water withdraw and redirection while considering a pilot application.

It is, however, recommended to pursue studying broader aspects of the role of coastal lakes in adaptation to climate changes while protecting their valuable ecosystem as well as restoring a healthy environmental status within. Advanced modeling techniques are expected to play a key role in examining alternate changes in conditions within the served watershed, different options of activities, scenarios for climate change, various management measures while considering cost-effectiveness. Therefore, it is recommended to couple watershed management approaches with climate change modeling to reach more comprehensive overview and investigate more concerns simultaneously.

VII. Acknowledgement

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