

ASSESSMENT OF CLIMATE CHANGE IMPACTS ON EL-BURULLUS LAKE, EGYPT, BASED ON HYDRODYNAMIC MODELING

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ABSTRACT

According to the Intergovernmental Panel on Climate Change (IPCC) in 2007, Nile delta region is one of the most extremely affected river deltas in the world by climate change impacts. This paper presents the application of hydrodynamic modeling in Lake El-Burullus to assess the impacts of climate change on evaporation rates and the spatial distribution of salinity. The hydrodynamic model (Delft-3D) was utilized to simulate the distributed change in salinity gradient inside the lake. Once the hydrodynamic model of the lake was validated using evaporation rates, heat fluxes were possible to simulate. The carbon emission scenarios A1FI and B1 Carbon were included to represent the potential impacts under extremely high and low carbon emissions scenarios for the next 90 years. In Addition, using past three decades observations, a statistical projection scenario was generated by the Coastal Research Institute (CoRI). The study reveals that under A1FI scenario, the evaporation rates might increase by about 0.16 % a year. Similarly, according to B1 scenario, the evaporation rates might increase by about 0.11 % a year till the year 2100 while with CoRI scenario the average increase might reach 0.068 % yearly till the year 2100. The results show different rates of increase of salinity among all study sites under different carbon emission scenarios. Due to sea level rise, the lake might be subjected to an increase of sea water intrusion into the lake through a single northern inlet connecting the lake with the Mediterranean Sea. The highest increase of salinity was found around the area near Boughaz (inlet). This increase might be 17 % above the current value while the mid part was affected by an increase of salinity around 4.5 %.

Keywords: Climate Change Impact, Delft3D-Flow, Shallow Lake, Evaporation Rates, Salinity, hydrodynamic modeling

1. INTRODUCTION

Due to glacial melting and thermal expansion of the oceans, mean sea level, MSL, on a global scale, has been increasing over the past century and is expected to keep increasing in the future. Based on (IPCC, 2007) an increase between 0.18 and 0.79 in the MSL was estimated (including an allowance of 0.2m for the uncertainty related to ice sheet flow) by the end of 21st century [1]. Climate change from global warming is evident from observations in global average air and ocean temperatures, widespread melting of snow and ice and rising of sea levels. The earth surface temperature has been

increasing from 0.1 to 0.16 °C per decade during the last 50 years, arctic sea ice extent has shrunk by 2.7 % per decade with larger decreases in summer of 7.4 %; sea levels rose at an average of 1.8 mm.yr⁻¹ (1961-2003) to 3.1 (1993-2003) [2]. Oceans have been taking up over 80 % of the heat being added to the climate system, which could be associated with an increase in intense tropical cyclone activity in the North Atlantic since 1970. In some recent events the unprecedented and devastating tornado activity in 7 southern states in US (2011), Pakistan floods (2010), China floods (2011) and the 50 mile wide dust storm that engulfed Arizona state in US (2011) among others [3].

According to the Intergovernmental Panel on Climate Change report (IPCC) in 2007, Nile delta region is one of the most extremely affected river deltas in the world by climate change impacts. There are many studies utilizing hydrodynamic modeling to simulate the potential impacts of climate change on lakes. Through the research entitled "Climate change impacts on mixing and circulation at Songkhla lagoon, Thailand", the lagoon was modeled with Delft 3D, a model developed by Deltares [4]. After the verification with the available data for the region, different scenarios were created to represent the possible changes in mean sea level and river flow due to global warming. Then, these results were compared to the current conditions to determine the main changes in mixing and circulation in this coastal lagoon. Among the available literature, a 3D hydrodynamic model was also applied to investigate the implications of a change in climatic conditions for the hydrophysical behavior of deep Upper Lake Constance [5]. In another literature example, authors established a coupled hydrodynamic and ecosystem models taking into account simulated data of climate model. They used the one-dimensional hydrodynamic model DYRESM and the regional climate model REMO and applied them to the pre-Alpine, 83-m deep, currently dimictic Lake Ammersee [6]. The study concluded that the hydrodynamic model can be used to identify potential drawbacks of climate change on the lake ecosystem by higher water temperatures. In addition, this modeling provides the basis for coupled aquatic ecological models. In [7], the coastal lagoon of Mar Menor has been chosen in order to investigate the response of a transitional environment to A2 IPCC scenario using a numerical tool. A model to reproduce the hydrodynamic processes, the salinity and temperature distribution in the Mar Menor (Spain) was developed. The climate change simulation was carried out applying the A2 anomalies for 2100 to the 1997 input data set, in order to evaluate the response of the basin in terms of water exchange temperature and salinity variations. The results of the climate change simulation show an increase of the annual mean temperature of 3.28 °C and a decrease of the salinity value of 1.53 PPT. Recently, another research work goal was to quantify the potential impact of the GCC on hydrodynamic and water quality characteristics of Lake Nubia [8]. In this study, the impacts of climate change on hydrodynamic and water quality characteristics of Lake Nubia were investigated using a proposed hydrodynamic and water quality model, which simulates three periods: I [2010–2039], II [2040–2069], and III [2070–2099] – with two emission scenarios, A2 and B1, for each period. The studied hydrodynamic characteristics are water levels, evaporation water losses, and reservoir thermal structure.

In this paper, the impact of climate change on the Lake based on the inputs of globally and locally developed scenarios is investigated. Also, the change in the spatial distribution of salinity over the lake due to climate change variability is modeled.

2. STUDY AREA

One of the most vulnerable areas along the delta's coastline is Burullus Lake. This is the second largest of the Egyptian northern lakes along the Mediterranean coast as shown in Figure 1. It is located in the central part of the northern shoreline of the Nile Delta between longitudes 30°30'–31°10' E and latitudes 31°35'–31°21' N. The lake is shallow, with a maximum depth of 175 cm in the middle and western parts. The lake surface area is 410 km². The brackish lake salinity levels range from 2.1‰ in the west to 17.2‰ in the north [9]. The flushing rate is 61 days, i.e. lake water is renewed 6 times a year [10]. In 1998, the Lake was declared as a protected area by Prime ministerial decree no. 1444. Also, in 1998 Burullus Lake was approved as a RAMSAR site in Egypt.

regions (Abayazid & Al-shinnawy, 2012). These results are summarized in Table 1. These data will enable the author to take into consideration the combined effect of sea level rise (SLR) and land subsidence in the delta coast [12].

Table 1. SLR Model inputs over the last three decades based on CoRI [12]

Region	Alexandria	Al-Burullus	Port Said
Tidal Trend (mm/y)	1.6	2.3	5.3
Subsidence (mm/y)	0.4	1.1	3.35
SLR (mm/y)	1.2	1.2	1.95

According to the report published by Intergovernmental panel for climate change (IPCC) in 2006 [1], two extreme scenarios were developed. The highest scenario for carbon emission (A1FI) and the lowest one was (B1). The projected values of the mean surface air temperature, 2000-2100, for the low scenario (B1) and high scenario A1FI are given in table 2.

Table.2 The projected values of the mean surface air temperature, 2025-2100 as inputs to the applied present model

Temperature Change for Years 2025, 2050, 2075 and 2100 (°C)					
2000	Scenario	2025	2050	2075	2100
0.6 (°C)	B1	0.9	1.3	1.8	1.8
0.6 (°C)	A1FI	1.2	2.2	3.2	4.0

Based on CoRI evaluation and according to temperature increase and its projection till the end of the current century, table 3 presents the expected SLR till 2100 according to the low scenario (B1 scenario).

Table 3 Expected SLR (mm) till 2100 according to B1 low emission scenario based on CoRI estimation for the present applied model inputs

Region	SLR 2025	SLR 2050	SLR 2075	SLR 2100
West Delta	7.0	16.0	27.0	28.0
Middle Delta	8.75	19.5	32.5	35.0
East Delta	18.125	39.5	64.3	72.5

Similarly, table 4 illustrated the expected values of sea level rise in mm based of A1FI scenario.

Table 4 Expected SLR (mm) till 2100 according to A1FI high emission scenario for the present applied model inputs. (Abstracted from [12])

City	Scenario	2025	2050	2075	2100
Port Said (Eastern Region)	A1FI	27.9	68.8	109.6	144.0
Al-Burullus (Middle Region)	A1FI	14.75	37.5	60.3	79.0
Alexandria (Western Region)	A1FI	13.0	34.0	55.0	72.0

3. RESULTS AND DISCUSSIONS

3.1 Change in the Evaporation Rates

The Evaporation is an exchange process that takes place at the interface between water and air and depends on the conditions both in the water near the surface and the air above it. So any increase in the ambient air temperature will directly causes an increase in the evaporation rates. Evaporation in El-Burullus Lake is very important in any water balance study because of the shallowness of the Lake. It consumes about 15-16 % of the total water discharging into the lake yearly.

The evaporation rates were calculated based on the three scenarios mentioned before A1FI, B1 and CoRI. Figure.3 shows the current evaporation rates calculated in the same period of hydrodynamic model for about 6 months and the results indicates that the accumulative evaporation calculated all over the Lake in this period is 162,750,000 m³. As demonstrated, the curve is steeper in the period between 23/6 and 1/9 than during the period of the winter season.

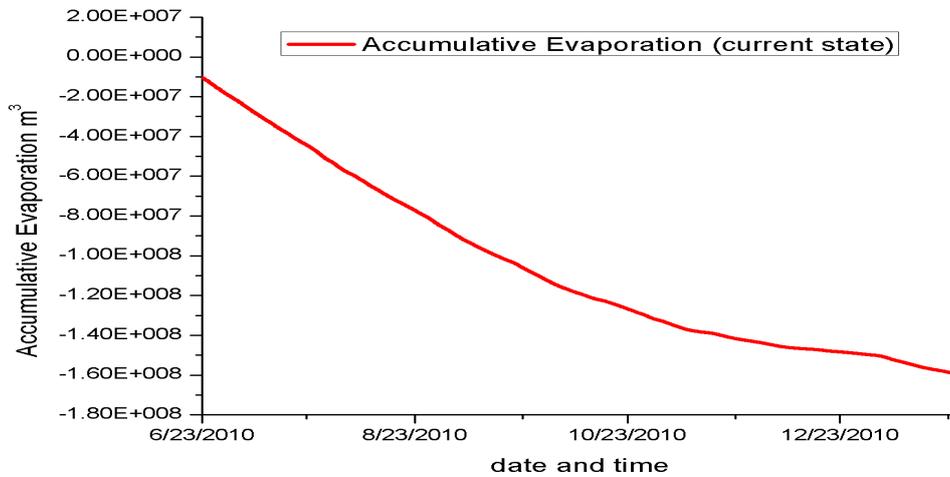


Fig.3 The simulated accumulative Evaporation (current State)

Figure 4 displays the change in evaporation rates according to CoRI climate change scenarios. Evaporation rates will increase by 2.8, 5.8 and 5.97% in 2025, 2075, and 2100 respectively.

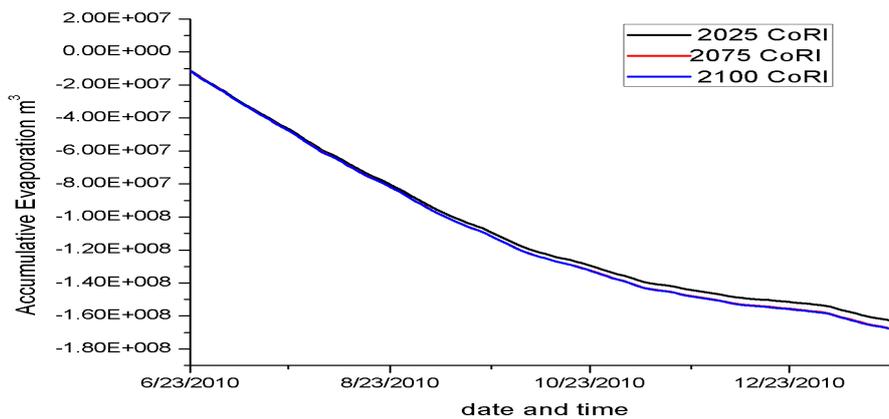


Fig.4 The simulated accumulative Evaporation based on the results of CoRI Scenario as model Inputs

Based on the most optimistic carbon emission scenario B1, the evaporation rates will increase by 2.9, 6.2, and 10.1 % in 2025, 2075 and 2100 respectively. On the other hand, based on the highest carbon emission scenario, the study revealed that the evaporation rates might be increased by 4.0, 7.6, 11.2

and 14.2 % in 2025, 2050, 2075, and 2100 respectively. Figure.5 presented the accumulative evaporation for B1 Scenario and accumulative evaporation for A1FI Scenario model inputs.

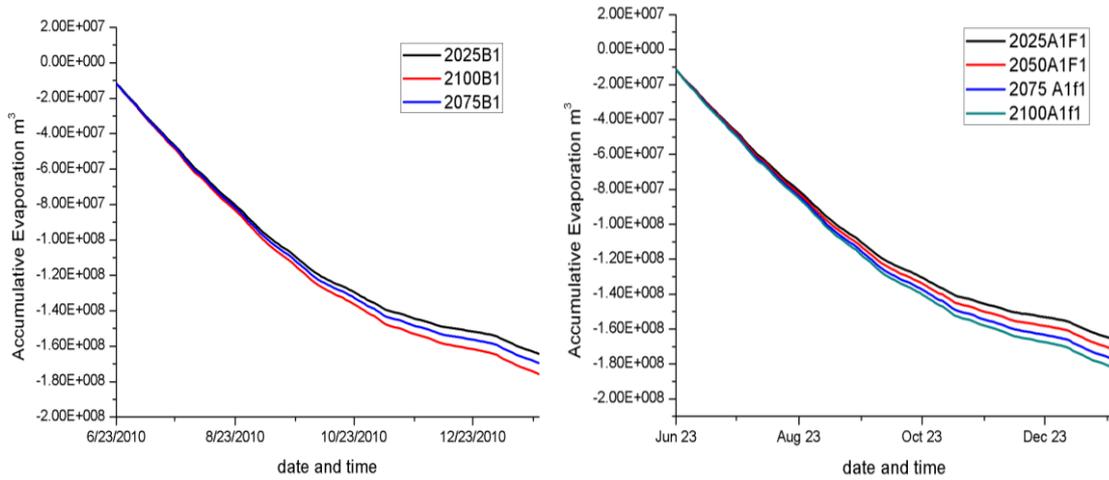


Figure.5 Left: Accumulative evaporation (B1 Scenario), Right: Accumulative evaporation (A1FI Scenario)

3.2 Change in the Spatial Distribution of Salinity

Combined effect of Sea Level rise (SLR) and increase in the evaporation rates might lead to an increase in the salinity inside the lake. The SLR might directly cause more saline water intrusion to Lake El-Burullus. Different scenarios of SLR were modeled using the developed hydrodynamic model. The results showed that the area in the east near the inlet (locally called Boughaz) might have more significant effect than the area in the west and in the middle. The modeled salinity during 2010-2011 in two monitoring stations based on the calibrated/validated hydrodynamic-water quality model is shown in Figure.6. The figure illustrated that salinity in the middle portion of the lake is between 4-2 ppt while the salinity near Boughaz station is between 3-18 ppt. These high values in the second station are due to the intrusion of saline water into the lake through the inlet.

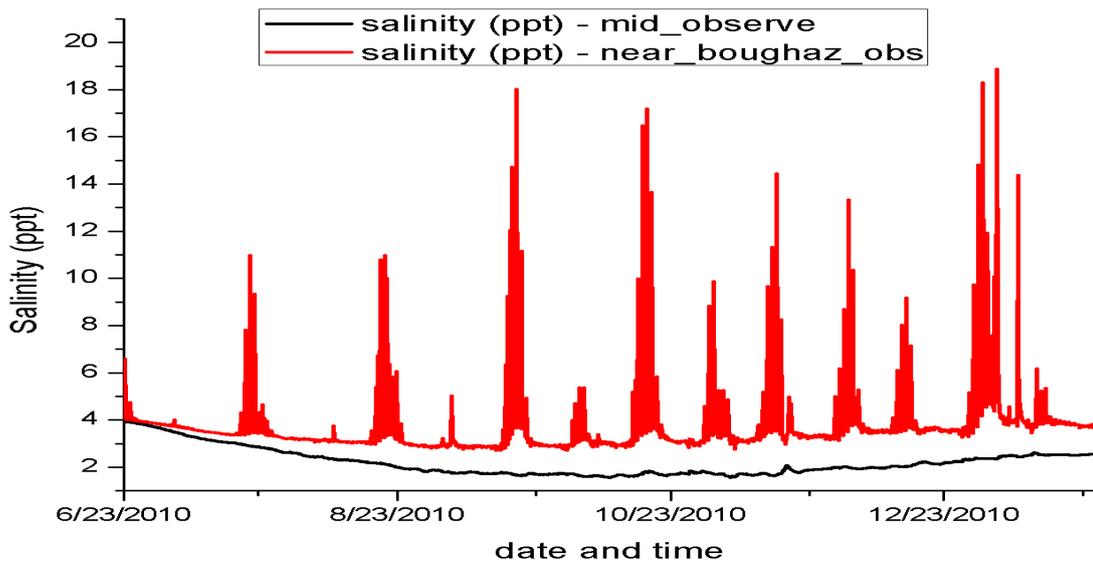


Fig.6 The simulated results of salinity in two stations (Current State)

Applying the three different scenarios, we can predict the change in the salinity levels in the mid station. Based on CoRI scenario, the increase will be around 0.2 ppt while it will increase to 0.5 ppt under B1 scenario till the year 2100. On the other hand, A1FI scenario might lead to the highest increase in the salinity and can reach 20% of the original salinity. Figure.7 shows the predicted values of salinity increase under the three scenarios.

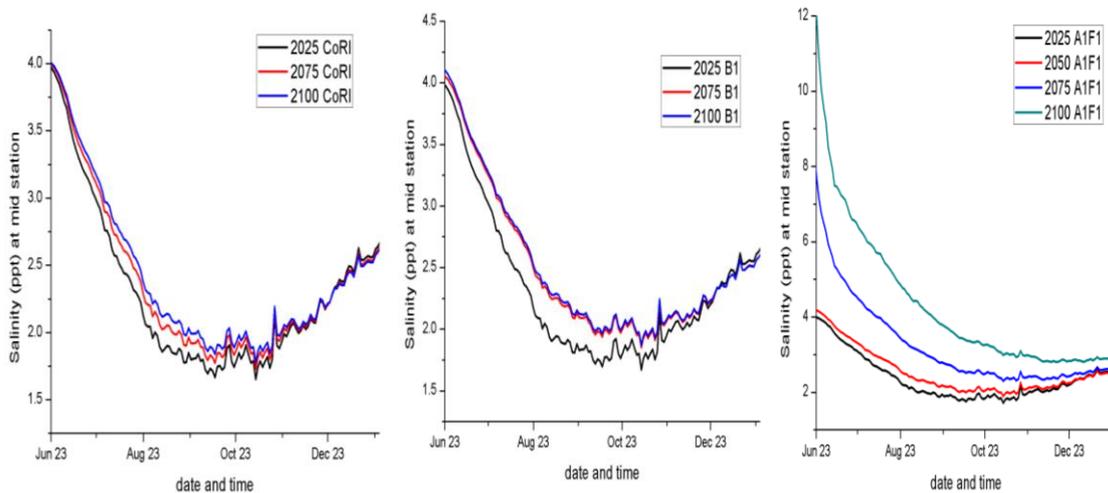


Fig.7 The simulated results of salinity at Mid station under different scenarios

Similarly, the change in salinity in the station near El-Boughaz is computed under different scenarios. Figure 8 shows the change in salinity under different scenarios. It is obvious that A1FI will cause 20-30 % increase in salinity where B1 and CoRI scenarios might cause an increase of less than 15 %.

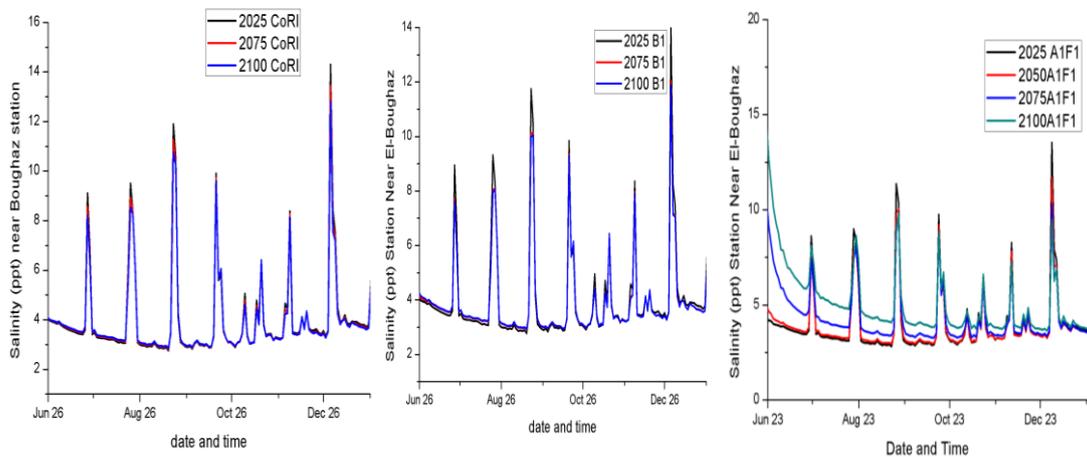


Fig.8 The simulated results of salinity Near Boughaz station under different scenarios

Figure 9 presented the predicted spatial distribution of salinity in 2025, 2050, and 2100 under different scenarios. It can be concluded that the east part is the most part affected by the increase of SLR and the increase in the evaporation rates. This combined effect will lead to an increase in the exchange rates between the sea and the Lake.

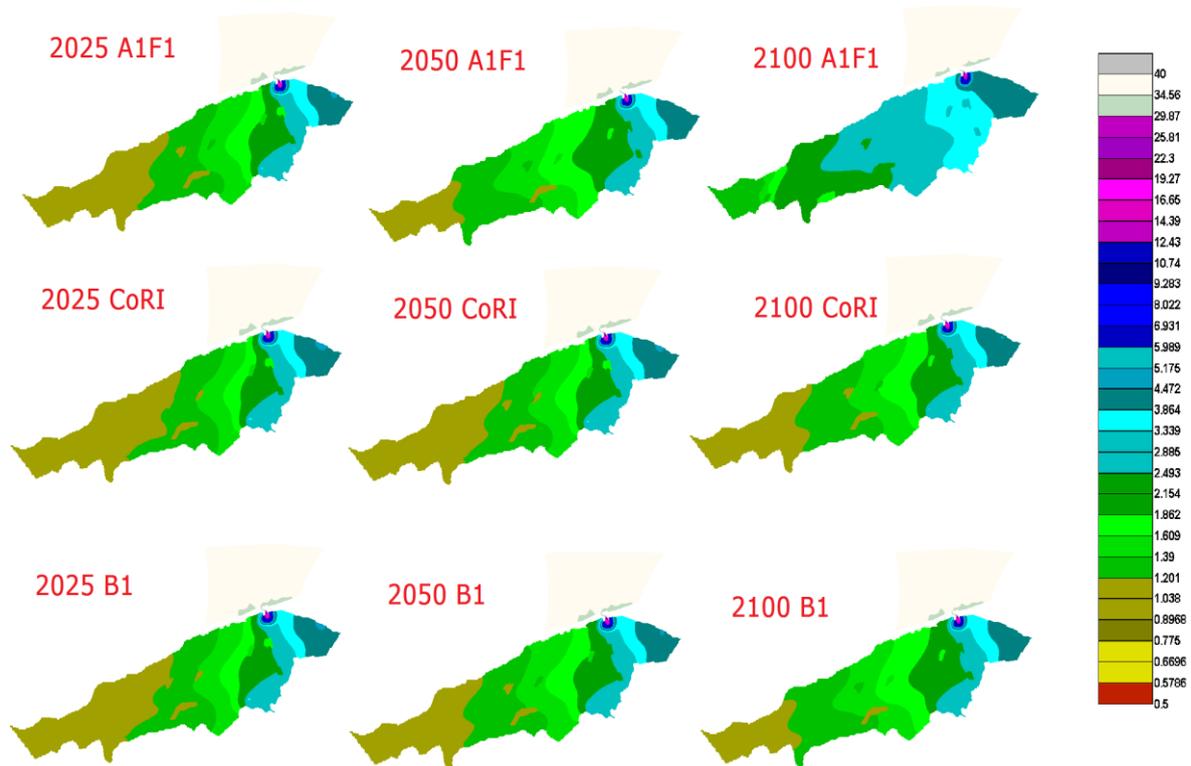


Fig.9 The simulated results of spatial distribution of salinity under different scenarios

4. CONCLUSIONS

Delft 3D model was used to simulate the hydrodynamic conditions of Burullus lagoon in Egypt and proved to be an efficient model for this purpose. It can serve to gain further knowledge on the future climatic impact upon lake ecosystems. A model to reproduce the hydrodynamic processes and the salinity and evaporation rates in El-Burullus Lake (Egypt) was developed together with the heat flux model. The hydrodynamic model was forced with real wind and water level data (2004-2005) then the model was calibrated and validated. The climate change simulation was carried out applying the A1FI, B1, and CoRI scenarios for the years 2025, 2050, 2075, and 2100 in order to evaluate the response of the Lake in terms of rate of evaporation rates and salinity variations. The results of the climate change simulation indicated an increase of the accumulative evaporation annual mean temperature of about 0.16 % a year under A1FI scenario and an increase of the salinity by 17 % in the year 2100.

5. RECOMMENDATIONS

For future modeling efforts, there is an urgent need for high quality simultaneous measurements of Lake relevant parameters such as water level, velocity, and salinity and so on at several points spread across the lagoon over a duration of at least 30 days during different seasons of the years. Drains' discharge data and atmospheric data, such as: wind, evaporation, rainfall, solar incidence should also be measured. Preferable these measurements should be repeated over few years to take into account annual variations. Sufficient model validation and accurate, reliable long term predictions may be impossible without high quality consistent data of the Lake relevant parameters.

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