Impacts of Climate Change on Water Balances at the Governorates Level in Egypt

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Abstract

Egypt relies on the Nile River to meet its increasing demands. Therefore, it is necessary to predict the change in water supply from Nile River due to climate change phenomenon. The impacts of climate change should be considered not only on the national level but also on the governorate level, because the water resources systems in the Egyptian governorates have different characteristics. Hence, the main objective of this study was to investigate climate change impacts on water resources systems in the Egyptian governorates and to set up necessary adaptation measures. The specific objectives were to: predict the expected releases from Aswan High Dam (AHD) due to climate change using BlueM model, study the influence of flow changes on water balances of the Egyptian governorates using a Water Balance Model (WB Model) developed by the authors, and conduct sensitivity analyses of adaptation measures to reduce the expected water shortages. Three governorates were selected namely; Qena to represent Upper Egypt, Fayoum to represent Middle Egypt and Damietta to represent Lower Egypt. The results showed that the expected release from AHD in 2050 will be reduced to 93.2 % and 84.7% of the current release based on two different emission scenarios. Consequently, the WB Model showed that Fayoum was the most affected governorate, whereas its water shortage increased in 2050 for the two scenarios. The ratio of drainage reuse to total water supply also increased for the two scenarios, and nevertheless, the drainage water did not fully cover the shortage. Moreover, no drainage was discharged to Quarun and Wadi El Rayan lakes at the system end threatening their existence. Damietta would be under high risk of severe water pollution in case of reduced release, since the ratio of drainage reuse to total supply severely increased. The sensitivity analysis proved that modern irrigation systems in the new lands, land leveling, controlling rice and sugarcane areas, and lining the reaches of irrigation canals characterized by excessive losses would lead to minimizing the future water shortage and subsequently minimizing the drainage reuse.
***Keywords**:* Climate Change, Water Balance, Egyptian Governorates, BlueM, WB Model

INTRODUCTION

It is internationally known that the earth will face increased temperatures and changes in precipitation in the coming decades. This will change the precipitation and water flow and will increase the intensity of extreme hydrological events. The Fourth Assessment Report (2007) of the Inter-governmental Panel on Climate Change (IPCC) identified Africa as one of the most vulnerable regions to climate changes. It also identified water sector as the most vulnerable. The extreme water stress and related conflict-risk are likely to affect the Nile River Basin. Current findings indicated that most of northern and southern Africa will be water stressed and the risk of water related conflict is a real one.

Several studies showed the potential for very significant changes in the flow of the Nile due to its sensitivity to temperature and precipitation changes; Sayed et al., (2004). Conway and Hulme (1996) estimated that future flow in the Blue Nile in 2025 could range between an increase of 15% and a decrease of 9%. Strzepek et al., (2001) estimated the 2020 flow into the Aswan High Dam (AHD) could decrease by 10 to 50% (Beyene et al., 2010). El-Shamy et al., (2009c) used bias-corrected statistical downscaling of 17 general circulation models (GCMs) to estimate an average reduction in flow of the Blue Nile of 15% by the end of the century and a range of change between a decrease of 60% and an increase of 45% was provided.

Riebsame et al. (1995) evaluated the global climate change on the water resources of the River Nile using four climate scenarios based on General Circulation Models (GCMs) being; baseline, the Goddard Institute of Space Sciences (GISS), USA, the Geophysical Fluid Dynamic Laboratory (GFDL), Princeton, USA, and the United Kingdom Meteorological Office (UKMO), Hadley Centre, Bracknell, UK. The authors concluded that the climatic fluctuation on the River Nile would be severe.

Being the most downstream country on the Nile, Egypt is affected by climate change impacts; not only within its borders, but also within the whole Nile basin (Stratus Consulting, 2012). Egypt is as an arid country relying on the Nile River, which provides 95% of its renewable water resources. Egypt is suffering from chronic water stress due to its limited water resources, the growing population, escalating water demands, and increased competition on water among the other Nile basin riparian. The uncertain climate change impacts on the Nile flow add another major challenge for water management in Egypt. In addition to Nile water variability, the projected increase in temperature would increase the local water demands especially for the agricultural sector (Sayed & Nour El-Din, 2004).

Many studies used generic models for simulation of the configurations, institutional conditions, and management issues of specific river basin water resource systems, and for assessment of impacts of different management alternatives. In Egypt, Omar, Moussa (2016) used the Water Evaluation and Planning (WEAP) model for assessment of different scenarios in the year 2025 by implementing different water sufficiency measures. The National Water Resources Plan in Egypt (NWRP) developed a Decision Support System (DSS) based on the RIBASIM7 model, which provided the water balance of Egypt in the base year. However, these studies were conducted on the national level. Since each governorate in Egypt has its own characteristics and challenges, the change in AHD release in Egypt will have different impacts on water resources systems of governorates. Therefore, it is mandatory to analyze the future impacts and develop adaptation strategies at both the national and local levels.

Therefore, the main objective of this study is to investigate the climate change projections and impacts on the water resources systems of Egyptian governorates and setting up adaptation measures into the local water resources planning. This main objective is divided into specific objectives being: i) to predict the AHD downstream release by applying the Blue M Model on the selected changes in flow entering Nasser Lake, ii) to study the impact of inflow change to Damietta, Fayoum, Qena governorates on the water balances of 2050 using the developed Water Balance Model, and iii) to conduct the sensitivity analyses of adaptation measures reducing the expected water shortages using the Water Balance Model. The selected three governorates represented the main three Egyptian zones, since Qena represented the Upper Egypt, Fayoum represented the Middle Egypt, and Damietta represented the Lower Egypt and Coastal areas.

1. METHODOLOGY

The current study intended to transfer adaptation strategy of the climate change impacts on Egypt's water resources from the central national level to the governorate level. This considered the specific characteristics and relevant measures of each governorate individually. The methodology of investigating the climate change impacts on the Egyptian governorates in the current study was divided into three steps. Firstly, Global Circulation model GSM was run for investigating the impacts of climate change on surface water at Dongola Station upstream Aswan High Dam in Egypt. Then, Applying the BlueM model, the reservoir module in BlueM.Sim solves the continuity equation for multiple inflow and outflow processes. The continuity equation is solved by linearizing the process functions between user-defined nodes, thus avoiding time-consuming iterations. Processes can be defined as nonlinear functions of reservoir volume or of any other arbitrary system state and can change over time. This makes it possible to model almost any imaginable operating rule. Applying BlueM.Sim on the selected changes inflow entering Nasser Lake to predict the AHD downstream release. Finally, the WB model (simple mass balance model) was developed for assessing the impact on water balance for each of the selected three governorates (Qena, Fayoum and Damietta) and for conducting the sensitivity analyses of specific adaptation measures.

1.1. Modelled Climate Change Scenarios

Strzepek and McCluskey (2007) employed a version of a conceptual rainfall-runoff model called WatBal (Water Balance) to ascertain the possible impacts of climate change on surface water availability for Egypt. A subset of the 20 scenarios was produced by the Climate Research Unit (CRU), University of East Anglia, Norwich, UK. These data, provided on a 0.50 grid, represent the World Meteorological Organization's (WMO) standard reference 'baseline' for climate change impact studies. The available data was employed to represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961–1990 climate) with differences attributable to the different climate models used and to different emission scenarios that the world may follow. This study derived 20 scenarios using five different models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM) based on two different emission scenarios (A2 and B2), where:

CSIRO2: CSIRO Atmospheric Research, Australia.
HadCM3: Hadley Center for Climate and Prediction and Research, UK.
CGCM2: Meteorological Research Institute, Japan.
ECHAM: Max Planck Institute for Meteorology, Germany.
PCM : National Center for Atmospheric Research, USA.

A2 : describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

B2 : describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.

1.2. The Modelling Approach

Nasser Lake is modeled and its operation is simulated using the software BlueM (Lohr, 2001), developed by Darmstadt University of Technology, Germany for river basin management. **Figure 1** shows the communication between BlueM components and their external usage. The model has two interfaces: an interface, which complies with the OpenMI standard, and a .NET interface that provides direct access to the model.

The operation of Nasser Lake is described by the water balance equation under various constraints concerning storage volume, outflow from the lake and water losses, **Figure 2**. The water balance equation applied on a monthly basis has the following form:

$$\frac{dV(t)}{dt} = \sum_{i=1}^{n_{in}} Q_{in,i} + \sum_{j=1}^{n_{out}} Q_{out,j} \tag{1}$$

$$\frac{dV(t)}{dt} = I_t - Q_t - M_t - D_t - T_t - S_t - E_t \tag{2}$$

where:

I_t = Mean inflow to the storage in month t (m^3)
Q_t = Amount of water discharged from the storage in month t downstream the dam (m^3)
M_t = Amount of water released from the emergency spillway in the dam in month t (m^3)
D_t = The water demand for Toshka project (South Valley) in month t (m^3)
T_t = Amount of released water from Toshka spillway in month t (m^3)
S_t = Seepage losses from the lake in month t (m^3)
E_t = Mean evaporation from the lake in month t (m^3)
E_t = $((A_t + A_{t+1}) / 2) * C_t*1000$
A_t = Lake area at beginning of month t (km^2)
A_{t+1} = Lake area as at the end of month t (km^2)
C_t = Evaporation coefficient pertaining to month t (mm)

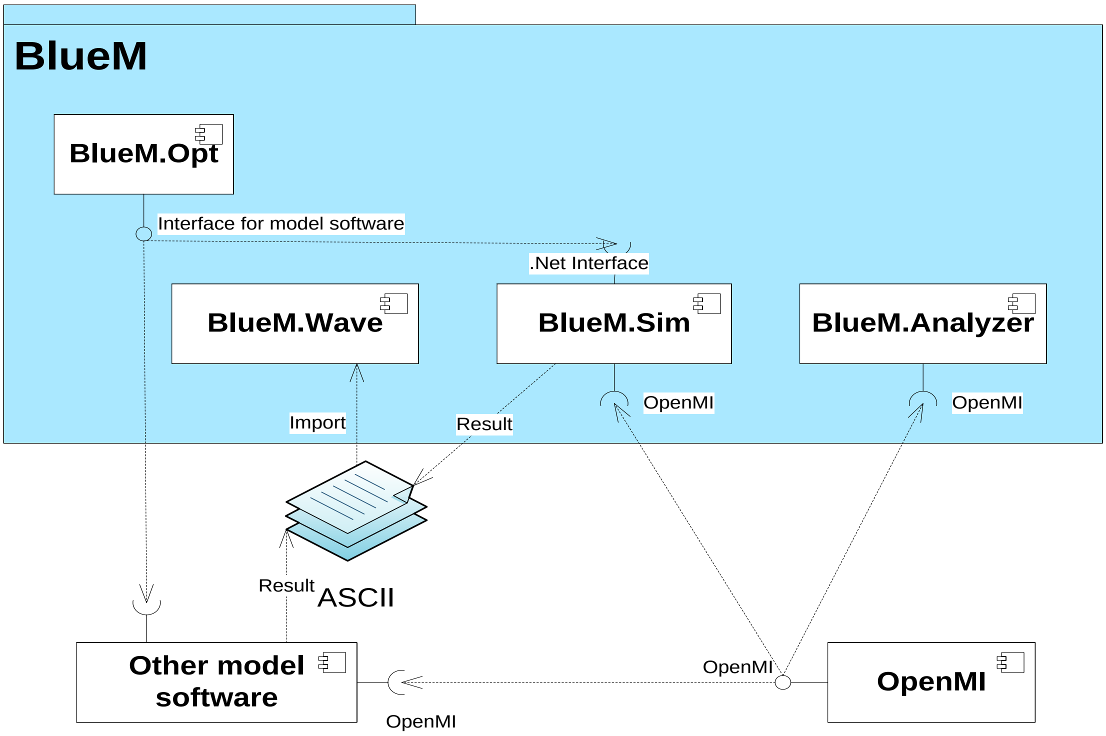

Figure 1: Interfaces of the BlueM Components and Outer Interfaces

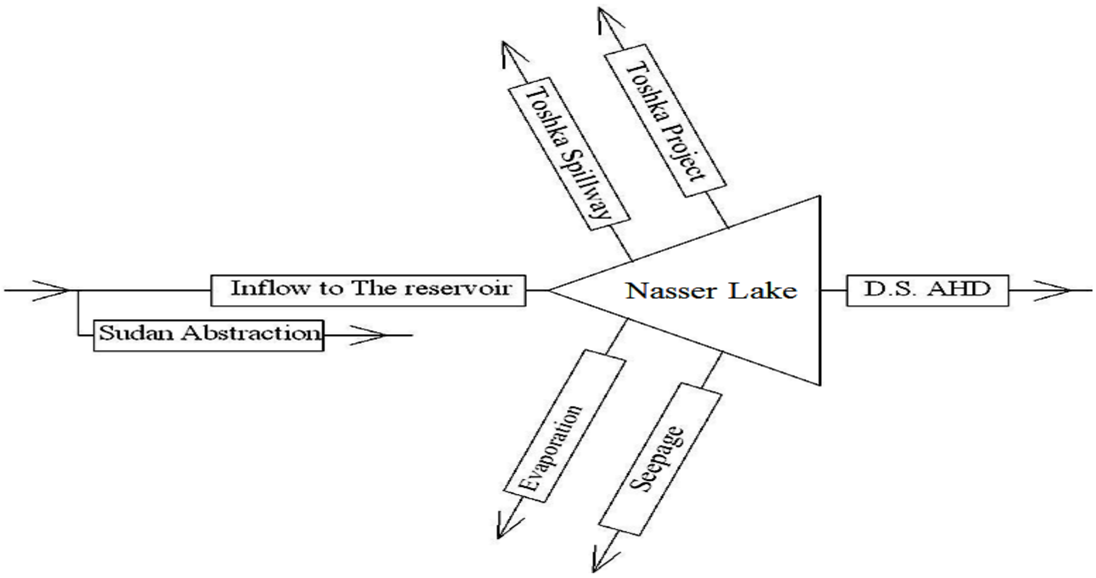

Figure 2: Scheme of Nasser Lake with its Inflow and Outflows

1.3. WB Model Description

The WB Model was developed using Microsoft Excel to estimate different components of the future water balance for several Egyptian governorates (**Figures 3 and 4**). The authors developed the WB Model as a mass balance model for estimation of different water balance components by the set of formulas from (3) to (11). The model was calibrated by comparing the resultant drainage reuse covering the water shortage with the actual current reuse in five governorates. Then, the model was applied for the Egyptian governorates through the National Water Resources Plan Project to provide the water balance in the base year 2016 and the target year 2037. The simplicity was the main goal of this model in order to be usable on the local level.

The WB Model was applied in this study for predicting the influence of the change of HAD releases on the water balance of Egyptian governorates in the year 2050 according to climate change. The simulated water balance components for the base year (2016) were estimated by the set of formulas from (3) to (11), and compared with the data collected from the stakeholders. In the future scenarios, estimation of the water balance components was based on altering the rates and factors of formulas. The main formulas of the WB Model were as following:

$$Q_{in} = Q_{\mathrm{bas}} \times f_1 \tag{3}$$

$$A_{cult} = A_{\mathrm{bas}} + (R_{\mathrm{expansion}} - R_{urban}) \times N \tag{4}$$

$$Irr_{total} = A_{\mathrm{cult}} \times Irr_{fedan} \tag{5}$$

$$Irr_{crop} = Irr_{total} \times e \tag{6}$$

$$Dom_{total} = PN \times C_{person} \tag{7}$$

$$Dom_{loss} = Dom_{total} \times f_2 \tag{8}$$

$$WW_{treated} = PN \times CWW_{person} \times f_3 \tag{9}$$

$$WW_{untreated} = (PN \times CWW_{person}) - WW_{treated} \tag{10}$$

$$\mathrm{Re}\,use = Irr_{total} + Dom_{total} + E + Aquaculture - Q_{in} - Desalination - R - GW \tag{11}$$

Where:

Q_{in} = Surface water discharge entering the governorate (BCM).
$Qbas$ = Basic surface water discharge entering the governorate (BCM) = 100% of the current discharge.
f_1 = Reduction factor of surface water according to climate change.
A_{cult} = Cultivated agricultural area (m^2)
A_{bas} = Cultivated agricultural area in the base year (m^2)
$R_{expansion}$ = Horizontal expansion rate per year (m^2)
R_{urban} = Lost agricultural area per year by urbanization (m^2)
N = Number of years from base year to the target year
Irr_{total} = Total irrigation withdrawals (BCM)
Irr_{feddan} = Feddan consumption rate (m^3/feddan), (1 feddan = 4200 m^2)
Irr_{crop} = Actual irrigation withdrawal by crops (BCM)
e = Use efficiency of agricultural sector (%)
Dom_{total} = Total domestic demand (BCM)
PN = Population number
C_{person} = consumption rate per person (l/c/d)
Dom_{loss} = Domestic loss (BCM)
f_2 = Domestic losses factor
$WW_{treated}$ = Treated wastewater discharge (BCM)
CWW_{person} = Per capita wastewater discharge (l/c/d)
f_3 = Actual ratio of treated wastewater discharge to total discharge of wastewater (%)
$WW_{untreated}$ = Untreated wastewater discharge (BCM)
$Reuse$ = Drainage reuse to cover the water shortage (BCM)
E = Evaporation (BCM)
R = Rainfall (BCM)
GW = Deep Groundwater (BCM)

Input Data	2016	Units
Surface Water	0.95	BCM/year
Deep Ground Water	0.0	BCM/year
Surface Water Reduction Factor	1	Number
Deep Ground Water Factor	1.0	Number
Domestic Consumption Rate	250.0	L/capita/day
Population Number	1.311598	Million capita
Aquaculture	0.0	BCM/year
Wastewater Discharge	62.0	m3/capita/year
Treated Wastewater Discharge / Total Wastewater	0.74	Number
Domestic Water Loss/Domestic Demand	0.23	Number
Agricultural Land Area	122401.0	Feddan
Horizontal Expansion Rate	0.0	Feddan/year
Urbanization Rate	0.0	Feddan/year
Number of Years from Current Year	0.0	
Feddan Consumption Rate	6750.0	m3/feddan/year
Water Use Efficiency of Agricultural Sector	0.56	Number

Figure 3: The Input Data Collected from Water Resources Unit at Each Governorate

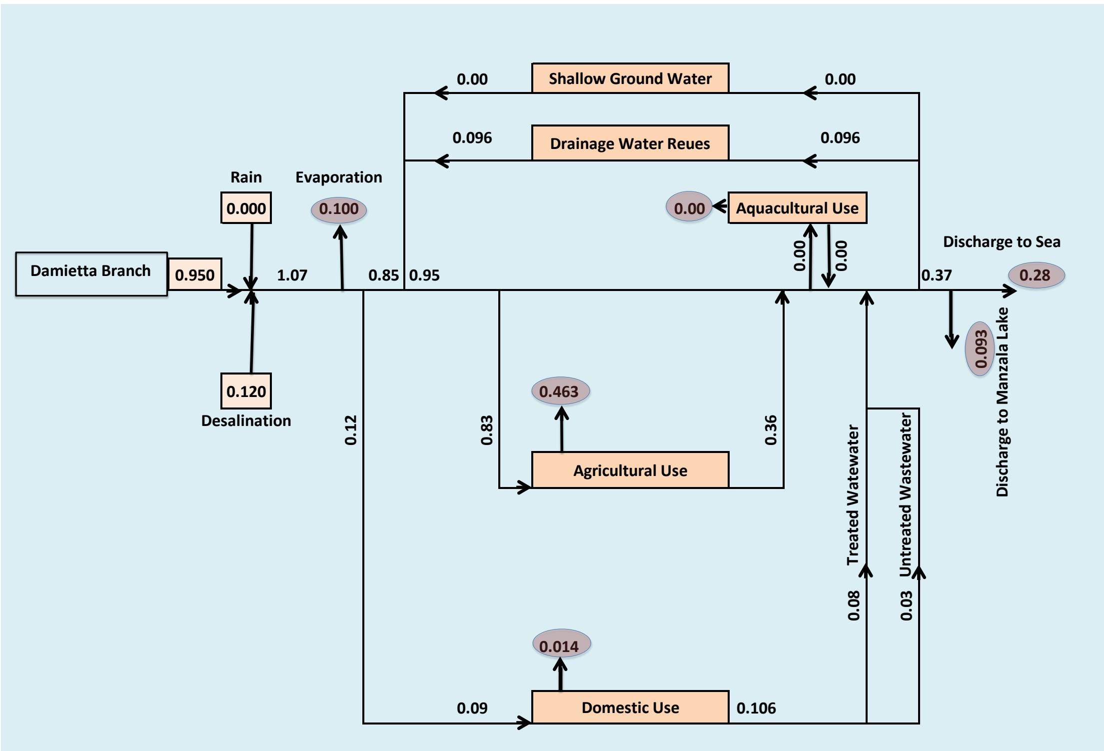

Figure 4: The Output Water Balance Components for Damietta

2. RESULTS AND DISCUSSION

Three scenarios were selected from the climate change scenarios in the year 2050 to estimate the effect of low water release on Water balances in Egyptian Governorates.

2.1. Variations of Nile Flows Entering Lake Nasser According to Climate Change

The results for decadal average changes for 2050 and 2100 in annual values for stream flow are presented in **Table (1)**. To estimate the effect of low water release, three scenarios were selected from the climate change scenarios generated by Strzepek and McCluskey and presented in **Table (2)**. The selected climate change scenarios will be used as a multiplier to the historical natural series (1968-2000) for simulating future inflows to the lake.

Table 1: The Results for Percentages of Decadal Average Changes for 2050 and 2100 in Annual Values

		CGCM2		CSIRO2		ECHAM		HadCM3		PCM	
Year	**Baseline**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**	**2050**	**2100**
Percentage of changes in A2-Scenario	100	75	50	92	87	107	124	97	99	100	114
Percentage of changes in B2-Scenario	100	81	70	88	82	111	124	96	96	114	193

(Strzepek & McCluskey, 2007)

Table 2: Selected Scenarios for Percentages of Changes in the Stream Flow at the Entrance of Nasser Lake

Scenarios	Percentage of change in stream flow
1	100 % “Baseline”
2	92
3	81

2.2. Sensitivity of High Aswan Dam Release to Climate Change

Applying the BlueM model on the selected changes in flow entering Nasser Lake (as shown in Table 3) showed that under drying climate scenarios, the mean annual withdrawal from Nasser Lake for the three scenarios (1, 2 and 3) will be 55.50, 51.80 and 47.10 x 10^9 m^3, respectively. This means that Egypt will fall short of its target demand in the future. **Figure 5** and **Table 3** present the average monthly releases downstream AHD for the three scenarios (1, 2 and 3).

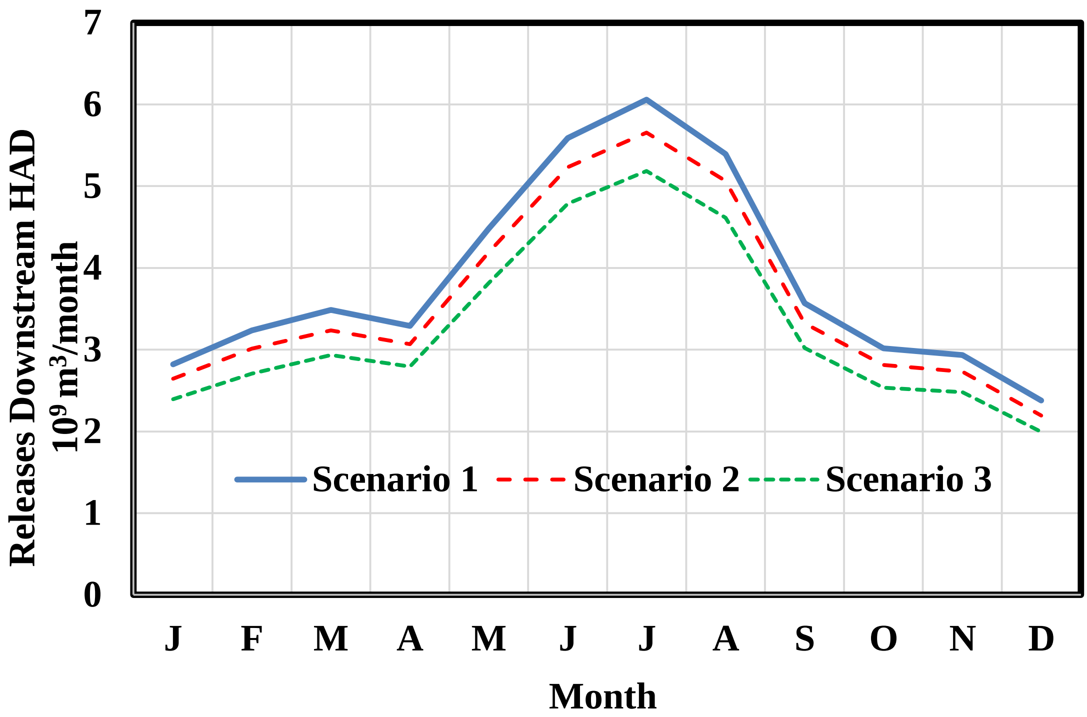

Figure 5: Average Monthly Releases from Nasser Lake (10^9 m^3/month) for the Modelled Scenarios

Table 3: Average Monthly Releases from Nasser Lake (10^6 m^3/day) for the First Reach

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Ratio 2:1 (%)	93.6	92.6	93.1	92.7	94.0	93.5	93.5	93.9	93.2	93.0	92.8	92.4	93.2
Ratio 3:1 (%)	85.1	83.3	84.4	84.5	85.2	86.0	85.6	85.5	84.8	84.1	84.6	83.5	84.7

2.3. Future Water Balances in Egyptian Governorates According to Climate Change

For the base year (2016), all data of water balance components of three governorates were collected from the stakeholders, being the Water Resources Unit, the Information Centre and Department of Environment under the secretary general of the governorate, the Irrigation District, Agricultural District, and the Company affiliated to the Holding Company for Water and Wastewater. The water balance components were also estimated from the WB Model by the equations from (3) to (11). After assuming the consumption efficiencies of different sectors, the model estimated the water shortages, which were compensated by drainage water reuse. The simulated volumes of drainage water reuse in the three governorates were compared with the actual measured data as the calibration step (**Figure 6**).

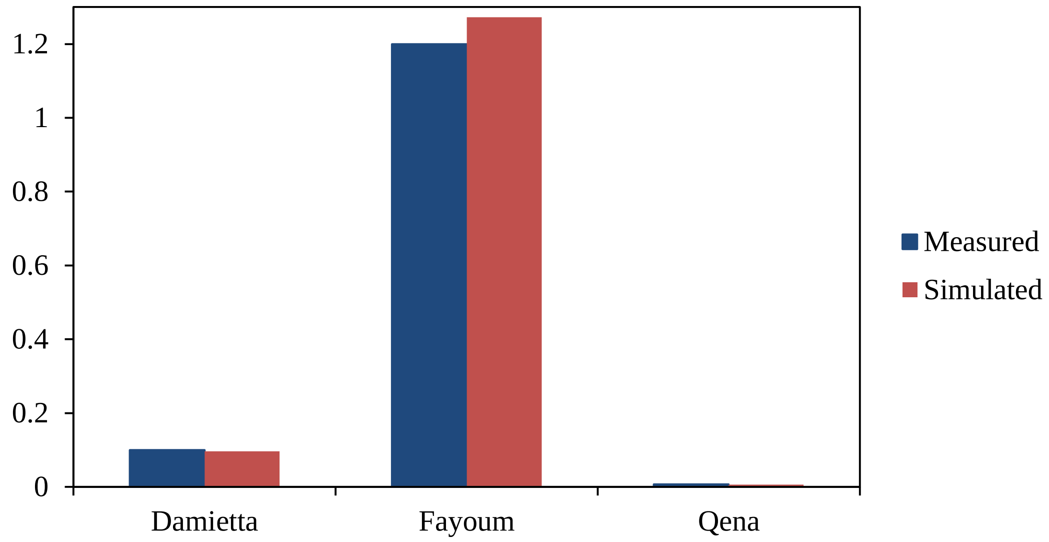

Figure 6: Measured and Simulated Drainage Reuse in the Three Governorates (BCM/year)

During the calibration process, the Mean Percentage Relative Error (MPRE) (%) for the volumes of drainage water reuse in the year 2016 was calculated as follows:

$$\boldsymbol{MPRE} = \frac{\Sigma\left[\left(\frac{\boldsymbol{Numerical\ result - Field\ measurement}}{\boldsymbol{Field\ measurement}}\right)\times \boldsymbol{100}\right]}{\boldsymbol{Number\ of\ results}} \qquad (12)$$

The MPRE value for drainage water reuse was 0.816. This indicated that the model overestimated the field measurements of the drainage reuse by 0.816 %. The resultant drainage reuse from the model was the main result to be tested and calibrated, since it covered the water shortage and was estimated as the difference between the total water supply and the total water demand. Wolters, et al., (1989) also estimated the water balance calculations for Fayoum with the aid of a computer and compared the calculated drainage outflow with measured values. The closing error of the water balance appeared to be small as it was less than 5%. Hence, it was clear that WB Model can be used in predicting the future volumes of drainage water reuse and subsequently the water shortages in the three governorates.
Based on the results of BlueM, the developed WB Model was applied to the three governorates. It is obvious from Table (3) that the yearly water release from AHD was 93.2 and 84.7% of the current release in scenarios (2) and (3) respectively. The values of surface water reduction factor (f_1), in Eq (3), were 0.932 and 0.847 in scenarios (2) and (3), respectively. Table (4) shows the main findings of WB Model simulations for both scenarios in 2050.

Table 4: Analyses of Water Balances in Damietta, Fayoum and Qena governorates for the Year 2016 and for Two Scenarios in 2050

	Damietta				Fayoum				Qena			
Scenario	**Current**	**2**	**3**	**3***	**Current**	**2**	**3**	**3***	**Current**	**2**	**3**	**3***
Water shortage (BCM)	0.095	0.349	0.453	0.323	1.4	1.91	2.22	1.62	0.014	0.366	0.55	0.34
Drainage reuse (BCM)	0.095	0.349	0.453	0.323	1.4	1.91	1.91	1.62	0.014	0.366	0.55	0.34
Shortage after reuse (BCM)	0	0	0	0	0	0	0.31	0	0	0	0	0
Ratio of reuse to total water supply (%)	9.1	39.9	58.9	36	31.5	44.4	51.3	39	0.07	19.1	28.8	21
Drainage outflow (BCM)	0.36	0.25	0.14	0.23	0.48	0.011	0	0.18	0.6	0.294	0.11	0.31

*Scenario and measures

Since adaptation is the only viable option to cope with the climate change, NWRP/MWRI, 2013 categorized the adaptation measures in Egypt under three pillars: optimal use of available resources, development of new resources, and water quality improvement. From the list of NWRP measures, the current study selected the relevant measures for each governorate and investigated their impacts on the water balance in the scenario (3&Measures).

Figure (7) shows the estimated water balance of Fayoum by the WB Model. Fayoum was the most affected governorate, whereas the water shortage increased from 1.4 BCM in the year 2016 to 1.91 and 2.22 in both scenarios of 2050 in case of continuation of the current policies. Although the surface water supply for Fayoum was the largest, the water shortage was the largest as well, because the agricultural horizontal expansion area in the surrounding desert area increased. The drainage water covered the water shortage in scenario (2), but it did not fully cover the scenario (3). Similar to the current water balance, Wolters, et al., (1989) reported that a large percentage of the irrigation water supplied is used by the crops and the overall efficiency is 63%. This high overall efficiency has its origin in some summer shortage and in the re-use of drainage water within the system.

Moreover, there was no drainage water outflow at the end of the system to Qarun and Wadi El Rayan lakes. This is in agreement with Wolters, et al., (1989) that confirmed that the re-use from the drainage catchment of Lake Qarun results in a lower Lake Qarun level. This would threaten the existence of lakes as confirmed by Wolters, et al., (1989) who reported that drainage to Lake Qarun comes from the two main drains, Batts and Wadi, and from the catchment of several minor drains. About 69% of The Fayoum drains discharge into Lake Qarun.

The ratio of drainage reuse to the total water supply increased from 31.5% to 44.4 and 51.3% in both scenarios. This absolutely would deteriorate the system water quality and threaten the public health and environment.

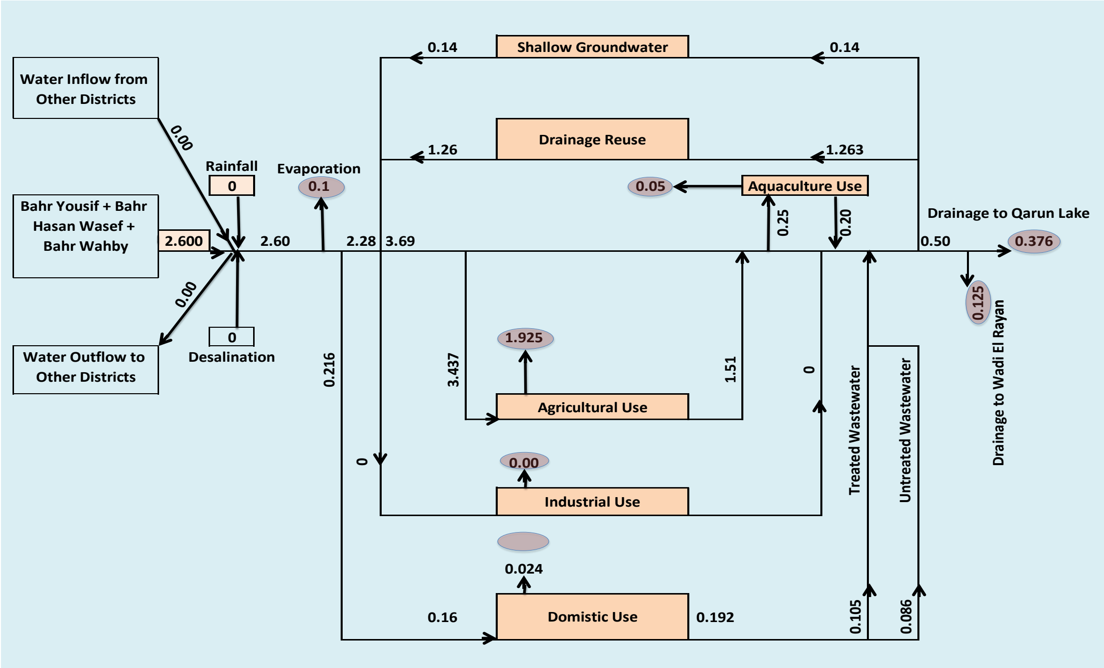

Figure 7: The Output Water Balance Components for Fayoum in the Excel Worksheet of the WB Model

Damietta water shortage increased from 0.095 BCM in the year 2016 to 0.349 and 0.453 in both scenarios of 2050 in case of continuation of the current policies. Unlike Fayoum, there was no surrounding desert available for agricultural horizontal expansion projects. The drainage water covered the water shortage in both scenarios. The ratio of drainage water reuse to the total water supply increased from 9.1 to 39.9 and 58.9% in both scenarios. It was observed that ratio of reuse to total supply was the highest between the three governorates in scenario (3), although there was no increase in the agricultural demand in Damietta. This was due to the very low supply of surface water, which was highly consumed by the increased domestic and industrial demands. The high ratio of reuse would severely deteriorate the system water quality and threatens the public health and environment.

Qena was the least affected governorate, although the agricultural horizontal expansion area in the surrounding desert area also increased. But the horizontal expansion rate was lower in Qena than in Fayoum according to the plans of both governorates. The water shortage increased from 0.003 BCM in the year 2016 to 0.366 and 0.55 in both scenarios of 2050 in case of continuation of the current policies. The drainage water covered the water shortage in both scenarios. The ratio of drainage water reuse to the total water supply increased from 0.1 to 19.1 and 28.8% in both scenarios. The drainage water reuse would become a main water supply in Qena in the year 2050 and this would deteriorate the system water quality and threatens the public health and environment.

The scenario (3&Measures) for the three governorates assumed a number of measures that can reduce the feddan water consumption and increase the irrigation efficiency. Based on the results of Omar, Moussa, (2016), Fayoum Water Resources Plan/NWRP (2012), Ghanem (2008) and Wolters, et al., (1989), the following measures would reduce the water demand in the agricultural sector:

- Turning a number of illegal feddans of the rice crop consuming 7,000 m3/feddan to normal crops with an average consumption of 3,000 m3/feddan would save 4,000 m3/feddan.
- Applying lazer land leveling would save about 5% of the feddan water consumption.
- Applying modern irrigation techniques would save 4,000 m3/feddan.
- Lining and maintenance of mesqas in effective reaches would increase the use efficiency of agricultural sector by about 5%.
- Continuation of removal of aquatic weeds and reduction of the dead zones in the streams in main canals would increase the use efficiency of agricultural sector by about 3%.

Based on discussions with representatives of the Water Resources Units, Irrigation Districts, and Agricultural Districts, so as collected data at the three governorates, each measure has a potential specific implementation ratio at each governorate according to its characteristics. **Table (5)** shows the impact of each measure on the saved water quantity for every governorate.

Table 5: Saved Water Quantities from Different Measures at Each Governorate

Measures' Implementation Ratio	Saved Water Quantity (BCM/year)
	Fayoum
Turning 2,814 feddans of illegal areas of rice crop to normal crops	0.011
Expanding areas applying lazer land leveling from 10,000 feddans to 65,000 feddans	0.002
Increasing areas applying modern irrigation techniques from 40,000 feddans to 85,000 feddans	0.16
Lining and maintenance of 1,000 km of mesqas in effective reaches	0.2
Continuation of removal of aquatic weeds and reduction of the dead zones in the streams in 1,544 km of main canals	0.07
Damietta	
Desalination	0.14
Turning 1,100 feddans of the illegal areas of rice crop to normal crops	0.04
Expanding the areas applying lazer land leveling from 30,000 feddans to 100,000 feddans.	0.003
Increasing the areas applying modern irrigation techniques from 650 feddans to 1,000 feddans	0.001
Lining and maintenance of 320 km of mesqas in effective reaches	0.03
Continuation of removal of aquatic weeds and reduction of the dead zones in the streams in 471 km of main canals and 242 of main drains	0.02
Qena	
Expanding the areas applying lazer land leveling from 50,000 feddans to 150,000 feddans	0.032
Increasing the areas applying modern irrigation techniques from zero to 120,000 feddans	0.48
Lining and maintenance of 250 km of mesqas in effective reaches	0.11
Continuation of removal of aquatic weeds and reduction of the dead zones in the streams in 500 km of main canals and 200 km of main drains	0.06

Using the WB Model, sensitivity analysis for different adaptation measures was conducted to minimize the future water shortages in the three governorates. Modern irrigation techniques in new lands, land levelling in old lands, controlling rice and sugarcane areas strongly reduced the water consumption rate per feddan (Irr_{feddan}), which subsequently reduced the total irrigation withdrawal (Irr_{total}) as in eq (5). Lining the most sensitive reaches of irrigation canals reduced the use efficiency of agricultural sector (e), which subsequently increased the actual irrigation withdrawal by crops (Irr_{crop}) as in eq (6). From the sensitivity analyses, it was obvious that higher implementation rates of different measures were achieved; lower water shortages and lower drainage reuse were found in the three governorates.

3. CONCLUSION AND RECOMMENDATION

The current study predicted the influence of climate change on the AHD release in the year 2050 using the BlueM model. The authors developed the WB Model, which investigated the influence of changes in AHD releases on the water balances of three Egyptian governorates, and assessed the impacts of different adaptation measures. These three governorates represent three Egyptian zones, where Qena is of Upper Egypt, Fayoum is of middle Egypt and Damietta is of Lower Egypt. The AHD release to Egypt will decrease to 93.2 or 84.7% of the current release in 2050 according to the climate change based on two different emission scenarios. This will increase the water shortage in Fayoum governorate from 1.4 to 1.91 or 2.22 BCM, deteriorate the water quality of the system, and eliminate two natural lakes being Quarun and Wadi El Rayan lakes. Qena water shortage will increase from 0.014 to 0.366 or 0.55 BCM, and its water quality will be deteriorated. Damietta water shortage will increase from 0.095 to 0.349 or 0.453 BCM, and its water quality will also be deteriorated. Fayoym will be the most affected governorate and Qena will be the least affected governorate. However, Damietta will have the worst water quality between the three governorates with the scenario of 84.7% reduction in release.

The sensitivity analyses of WB Model recommend that modern irrigation techniques in new lands, land levelling in old lands, controlling rice and sugarcane areas, and lining the most sensitive reaches of irrigation canals are adaptation measures having a high potential of minimizing the future water shortage and subsequently minimizing the drainage reuse. The relevant measures reduced the water shortage in the scenario (3) with 84.7% reduction from 2.22 to 1.62 BCM/year in Fayoum, from 0.453 to 0.323 BCM/year in Damietta, and from 0.55 to 0.34 BCM/year in Qena.

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