Compatibility of Water Resources System in Egypt to Future Climate Change Projections, Case Study Qena Governorate - Upper Egypt

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ABSTRACT

In this paper, the water resources system in Qena governorate was proposed by studying the natural and hydrogeological conditions of the governorate, including its location, groundwater, climate and rain. Also Studying the Social and economic conditions of the study area including its population, crops, drinking water and etc. Through the water balance model and a Water Shortage Quality Index on 3 scenarios: the base case scenario in 2018, the realistic scenario in 2050 without any adaptation measures and the optimistic scenario in 2050, which considers adaptation measures of water shortage.

Keywords: Climate Change, Water Balance Model, Water Security Quality-based Index

1.1 INTRODUCTION

Egypt is as an arid country suffering from chronic water stress due to its limited water resources, the growing population and escalating water demands. Egypt depends on the Nile River, which provides 95% of its renewable water resources. The uncertain climate change impacts on the Nile flow add another major challenge for water management in Egypt. In addition, Nile water variability and the increase in the temperature have direct adverse impacts on the total cropped area and 13 crops areas, self-sufficiencies of wheat, rice, cereal and maize, and socioeconomic indicators (Omar et al., 2018).

It is well known that the temperatures will be increased on the earth and there will be changes in precipitation in the next decades, that accordingly will change water flows and might lead to an increase the intensity of extreme hydrological events. Many studies investigated the link between climate and the Nile flow. Strzepek and McCluskey (2007) estimated 20 scenarios for variations of Nile flows entering Lake Nasser in 2050 and 2100 using five general circulation models (GCMs) based on two emission scenarios. They provided 12 reduced flows and 8 increased flows. El-Shamy and Wheater (2009) provided a range between -60% and +45% of the Blue Nile flow by the century end using bias-corrected statistical downscaling of 17 GCMs. Conway and Hulme (1996) estimated that the future flow in the Blue Nile in 2025 could range between +15% and - 9%. Strzepek et al., (2001) estimated that in year 2018 the flow into AHD could be decrease by 10 to 50%.

Many mathematical models were used for simulating the configurations and management issues of Nile basin, and for assessing the impacts of different management alternatives. Omar and Moussa (2016) used the Water Evaluation and Planning (WEAP) model for the assessment of different scenarios in the year 2025 by implementing different water measures in Egypt. Moussa and Omar (2017) also developed the Water Balance Model for quantifying the impacts of climate change on water balances of three Egyptian governorates based on results of BlueM model for predicting the downstream release of Aswan High Dam (AHD).

The reuse of shallow groundwater and drainage, regardless its quality, is the first and immediate alternative to cover the gap between water supply and demand in Egypt. In water shortage conditions, the first priority is given to fulfilling this gap ignoring the impacts on agricultural productivity, soil characteristics, public health, and environment. The drainage reuse quantity is expected to increase in the future due to climate change projections and increasing water demands. Therefore, there should be a water security index expressing Egypt's characteristics, presenting the status of water resources' system, and considering water quality of different water supply components.

The main objective of this paper is to assess the water resources' system of Qena governorate by developing a Water Balance Model (WB Model) and a Water Security Quality-based Index (WSQI). Three scenarios will be assessed; the base case scenario in 2018, the realistic scenario in 2050 presenting the continuation of current rates and policies without taking any adaptation measures, and the optimistic scenario in 2050 considering several adaptation measures with regard to water shortage.

1.2 Study area description

Qena is the third governorate from the Egyptian southern border after Aswan and Luxor. It is bounded from the south by Luxor governorate, which separated from Qena at 2010, and from the north by Sohag governorate, the New Valley governorate from the west, and the Red Sea governorate from the east as shown in Figure (1).

Qena Governorate is considered one of the governorates with the predominant agricultural sector. The cultivated area is estimated at about 247 thousand Feddans. The province is characterized by cultivating sugar cane and bananas alongside wheat, corn, vegetables (tomatoes), alfalfa, sesame, and palm trees, in addition to some aromatic and medicinal plants. Sugar cane is the main crop and wheat comes as the second major winter crop, and corn is the second major summer crop.

Figure 1: Location of the Study area

2. METHODOLOGY

2.1. Water Resources in Qena governorate

Qena governorate shares surface water resources with Luxor governorate. They depend mainly on the canals of Kalabia and Asfoun that take water directly from the Nile upstream of Isna barrage. The length of Kalabia canal is 162 km and it serves Qena governorate from km 75.6 until its end with 86.4 km length to cover irrigation engineering area of (Qus - Qena - Deshna). There are 166 sub-canals derived from Kalabia canal within Qena Governorate, with a total length of 673 km to serve an area of 126 thousand feddans. Asfoun Canal has a length of 125 km and it serves Qena governorate from 64.75 km until the end of the canal with a length of 60.25 km. The total number of sub-canals from Asfoun canal are 173 canals with a total length estimated at 671 km to serve 121 thousand feddan.

Groundwater is one of the main factors affecting the desert development in Qena governorate, where the average conservative pumping rate is about 381 MCM in majority of these wells used in the irrigation of more than 94,000 Feddans of agricultural land and the rest is used in drinking water. Most of the groundwater is used as drinking water, reaches the consumer without treatment. The quality of the water is measured regularly in all wells. The main problem with groundwater is the presence of iron and manganese that alter the taste and aroma of the water (Environmental characterization of the governorate 2004).

Qena governorate is located in a dry climatic region characterized by heat, drought and scarcity of rain in the summer, with a small amount of rain in winter. The annual total of rainwater is estimated to be 3.83 mm, the average relative annual humidity is about 38%, and the average annual evaporation rate is about 11.3 mm.

Drainage water from agricultural lands is collected via a network of 39 open drains with a total length of 214 km, which end with three main drains; Sheikhia, El Ballas, and Hamed disposing into the Nile river at 265, 270.7, and 331.2 km from HAD, respectively.

The most Challenges facing water resources in Qena Governorate can be summarized in the limited quantity and quality of water resources, the low water use efficiency, the continuous population growth, the agricultural and urban expansion in desert lands, and the climate change projections.

2.2. Assessment tools for Qena water resources' system

The current study aimed at developing the Water balance model (WB) and the Water Security Quality-based Index (WSQI) to assess the current and future water resources system in Qena governorate.

2.2.1. Water Balance Model

The WB Model was a simple Microsoft Excel model developed by authors to estimate the different components of the future water balance for Qena governate. The developed WB Model was a mass balance model to calculate different water balance components estimated by formulas, rates and factors in the different components of the base case and future scenarios (Table 1). The calculation procedures of water balance in different scenarios can be summarized in two parts;

The first part based on estimating of the volume of water supply which is divided into conventional and non-conventional water resources. The conventional water resources are the Nile water, deep groundwater, rainfall, and desalination. The non-conventional water resources are the reused shallow groundwater and drainage water, which used only in case of water shortage.

The second part based on estimating the volume of water demand which divided into the water consumption and the water usage. The total water usage is the actual consumption by different sectors in addition to losses. Water usage describes the total amount of water withdrawn from its source to be used. Water consumption is the portion of water usage that is not returned to the water system after being withdrawn. The efficiency of water system is calculated as the ratio between both water consumption and water usage. The difference between them is the water quantity lost. In agriculture, water consumption is the quantity of water consumed by crops for vegetated growth to evapotranspiration and building of plant tissues plus evaporation from soils and intercepted precipitation, while water usage includes water consumption and both the field application and conveyance water losses.

2.2.2. Water Security Quality-based Index

The current paper developed a new water shortage index, as all previous indexes either ignored the drainage reuse or focused on consumptive water rather than gross withdrawals. Therefore, it was necessary to develop a new index suitable for Egypt's conditions. In case water shortage increases, the drainage water reuse will be the immediate alternative to cover this gap. However, reuse of drainage water below the water quality standards reduces the agricultural productivity, deteriorate the soil, and harm the public health and environment. So, water quality was considered in the current index. The current water security index (WSQI) was calculated as following:

$$WSQI = \frac{\sum[WS \times Fq] \times 100}{WD}$$

Where,

WD : Sum of water demand.

WS : Water supply components including surface river flow, groundwater, rainfall, and reuse.

Fq : Variance factor considering water quality.

The Fq value was obtained based on different water quality parameters' values, each of which was transformed to a subindex either 1 if it was complied with the standards or 0 if it was not complied. Fq represented the average value of all parameters' subindices for total dissolved solids (TDS), nitrate (NO_3), total phosphorus (TP), biological oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO). The Fq value was only estimated for water supplies in agriculture including drainage water reuse, shallow groundwater, and Nile water, as irrigation water is being used without treatment. The drainage water in Qena governorate is available in three main drains; Sheikhia, El Ballas, and Hamed disposing into the Nile river at 265, 270.7, and 331.2 km from HAD, respectively. The water quality for drainage water is the average values of the three drains, which are very similar. Law 48 issued in 1982 and its amendment in 2013 is used in this paper for comparison and finding the new sub-indices.

WSQI ranges from 0 to 1 (Table 2), where 1 means the water resources fulfill the water demand in terms of water quantity and quality. Values lower than 1 indicate that the water resources fall short of sufficiency or quality.

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Table 1: Set of formulas representing different water balance components

Formula	**Components**	**Definitions**
$Q_{in} = Q_{\mathrm{bas}} \times f_1$	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	Factor of surface water according to climate change.
$A_{cult} = A_{\mathrm{bas}} + (R_{\mathrm{expansion}} - R_{urban}) \times N$	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
$Irr_{total} = A_{\mathrm{cult}} \times Irr_{fedan}$	Irr_{total}	Total irrigation withdrawals (BCM)
	Irr_{feddan}	Feddan consumption rate (m^3/feddan)
$Irr_{crop} = Irr_{total} \times e$	Irr_{crop}	Actual irrigation withdrawal by crops (BCM)
	E	Use efficiency of agricultural sector (%)
$Dom_{total} = PN \times C_{person}$	Dom_{total}	Total domestic demand (BCM)
	PN	Population number
	C_{person}	consumption rate per person (l/c/d)
$Dom_{loss} = Dom_{total} \times f_2$	Dom_{loss}	Domestic loss (BCM)
	f_2	Domestic losses factor
$WW_{treated} = PN \times CWW_{person} \times f_3$	$WW_{treated}$	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 (%)
$WW_{untreated} = (PN \times CWW_{person}) - WW_{treated}$	$WW_{untreated}$	Untreated wastewater discharge (BCM)
$Reuse=Irr_{total}+Dom_{total}+E+Aqua\ culture- Qin- Desalination- R-GW$	$Reuse$	Reuse to cover the water shortage (BCM) including drainage and shallow groundwater
	E	Evaporation (BCM)
	R	Rainfall (BCM)
	GW	Deep Groundwater (BCM)

Table 2: WSQI values and categories

Index	**Category**
1	Complete water security
0.90 – 0.99	Low water insecurity
0.85 – 0.89	Medium water insecurity
Less than 0.85	Absolute water insecurity

2.3. Tested scenarios

Three scenarios were assessed in this study; the base case scenario in the year 2018, the realistic future scenario in 2050, and the optimistic future scenario with adaptation measurers in 2050. For both future scenarios, the impact of climate change on Nile water flows to Egypt was selected as the worst predicted output from the study conducted by Strzepek and McCluskey (2007). This study was developed a rainfall-runoff model to represent a range of future scenarios by five different global circulation models. The study derived 20 scenarios based on two different emission scenarios (A2 and B2), as presented in Table 3. The result of CGCM2 model with A2-scenario was selected for year 2050 with 75 % of the current inflows to Nasser Lake in the Base Case scenario.

Table 3: Percentages of average changes in Nile flow to Nasser Lake

Global Circulation Models		**CGCM2**	**CSIRO2**	**ECHAM**	**HadCM3**	**PCM**
Year	**Baseline**	**2050**	**2050**	**2050**	**2050**	**2050**
Percentage of changes in A2-Scenario	100	75	92	107	97	100
Percentage of changes in B2-Scenario	100	81	88	111	96	114
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: It describes the world with high population growth, slow economic development and slow technological change. B2: It describes the world with intermediate population and economic growth, local solutions to economic, social, and environmental sustainability.						

2.3.1. Base Case scenario in 2018

This scenario represented the actual current conditions of the water resources system. The surface water of Qena Governorate was based on preserving Egypt's traditional share of the Nile water. Hence, Q_{in} and Q_{base} were the same with a value of 1.682 BCM/year, and the reduction factor (f_1) was assumed 1 (Table 4). Rainfall harvesting and torrential also supplied another 0.004 BCM/year to the system. The difference between total water usages; agricultural (Irr_{total}), and domestic and industrial demands (Dom_{total}) in one side and the total supply in the other side was covered by reuse. The known inputs to this case were the water usage of municipal and industrial sectors and their use efficiencies, by which the water consumptions were calculated.

For the agricultural sector, the water usage (Irr_{total}) was 7,000 m^3/feddan according to data collected from Qena Irrigation Directorate. The difference between Irr_{total} and Irr_{crop} is the water loss, which is divided into conveyance loss and field application loss. The conveyance loss is caused by evaporation and seepage via irrigation channels, while the field application loss is caused by percolation underneath the root zone in agricultural fields. The field application efficiency for the Qena was 60% considering surface irrigation as the dominant irrigation system, while the conveyance efficiency was 85% considering the length and the soil type of canal based on FAO (1989) indicative values. Therefore , the water use efficiency of agricultural sector (e) was 51% in this scenario. Accordingly, the calculated water consumption (Irr_{crop}) was 3,570 m^3/feddan, which should be guaranteed to fulfill the cropping pattern requirements of Qena governorate. If e changes in any future scenario, Irr_{crop} should remain 3,570 m^3/feddan.

Similarly, the water consumption for municipal and industrial sectors were calculated. The ratios of shallow groundwater and drainage reuse to the total reuse were 0.85 and 0.15, respectively, which were assumed in this scenario. This scenario was used for calibration.

As the reuse of drainage and shallow groundwater is only applied to cover the water shortage, the model calibration is conducted by comparing the predicted drainage reuse with the actual reuse in Qena governate in the base case scenario. For the base year (2018), all data of water balance components were collected from the Ministry of irrigation and water resources (MRWI), Water Distribution Unit, the Irrigation District, the Agricultural District, and the Affiliated Company for Water and Wastewater. After estimating the water consumption efficiencies of different sectors, the model estimated the water shortages, which were compensated by drainage water reuse. The percentage error was used to evaluate the trueness and exactness of the estimated drainage reuse value. The percentage error (PE) for the volume of drainage water reuse in the year 2018 was calculated as following:

$$PE = \frac{(Estimated\ result - Actual\ result)}{Actual\ result} \times 100 \qquad (1)$$

2.3.2. Realistic Future Scenario in 2050

The available Nile water in this scenario was based on a significant reduction in Egypt's traditional share of the Nile water according to results of **CGCM2** model. In this scenario, the surface water factor (f_2) was 0.75 of the current amounts, with a value of 1.2615 BCM/year.

For the Agricultural needs, this scenario assumed the continuation of implementing the same policies of the Base Case scenario accompanied by the same rates. Accordingly, Irr_{feddan} remained 7,000 m^3/year, and e remained 51%. The total agricultural water demand was higher than the Base Case scenario, due to the planned reclamation of 23,300 feddan. The ratio of shallow groundwater to drainage reuse was assumed 1 to 4 as of the current ratio of the Base Case scenario.

For the domestic needs and industry, this scenario assumed that the rate of population growth was 2.16%, so the estimated population (PN) reached to 6.3894 million, with consumption rate (C_{person}) of 180 liters/capita/ day. It was also assumed that water loss was 21% of the total household needs, as a result of not undertaking activities to reduce losses with dilapidated pipes, valves, connections and treatment plants, and not removing illegal connections or installing meters. The needs of industry outside drinking water networks jumped from 0.042 to 0.047 BCM.

2.3.3. Optimistic Future Scenario with Measures in 2050

This scenario considered the adaptation measures in order to substitute the water shortage due to climate change effects. The current paper also evaluated the selected measures according to the so-called SMART criteria, which guide setting reasons for failure or success of measures and activities. SMART criteria stand for; S: specific, the indicator clearly and directly relates to the outcome, and is described without ambiguities and parties have a common understanding of the indicator, M: measurable, the indicator is preferably quantifiable and objectively verifiable, and parties have a common understanding of the ways of measuring the indicator, A: achievable, the required data and information can actually be collected, R: relevant, the indicator must provide information which is relevant to the process and its stakeholders, and T: time-bound, the indicator is time-referenced, and is thus able to reflect changes and it can be reported at the requested time.

The adaptation measures in agriculture were;

(1) Increasing the efforts towards serving 100,000 feddans with laser-leveling increasing the field application efficiency by 5% in the served area (Omar & Moussa, 2016).

(2) The use of sprinkler irrigation in about 70,000 feddans increasing the field application efficiency by 15% in the served area (FAO, 1989).

(3) Implementing projects for lining the total length of 2,977 km of canals increasing the conveyance efficiency by 10% in the entire governorate.

Measures 1 and 2 targeted the field application efficiency, which increased from 60% in the Base Case scenario to 66% in this scenario. Measure 3 increased the conveyance efficiency from 85% to 95%. The package of measures increased e from 51% to 63%. In order to insure fulfilling the actual Irr_{crop} with 3,570 m^3/feddan with the improved e, the Irr_{feddan} decreased to 5667 m^3/feddan in this scenario.

Table 4: Values of WB model parameters in the three scenarios

Parameters	**Base Case**	**Realistic**	**Optimistic**	**Units**
f_1	1	0.75	0.75	Number
f_3	0.25	0.39	0.59	Number
PN	3.224573	6.3894	6.3894	Million Capita
C_{person}	180	180	160	Liter/day
$R_{expansion}$	0	0	0	m^2/year
R_{urban}	0	0	0	m^2/year
CWW_{person}	0.56	0.56	0.65	Liter/capita/day
Irr_{feddan}	7000	6500	6000	m^3/feddan

The adaptation measures in the domestic and industrial sectors assumed that the rate of population increase in the optimistic scenario was 2.16%, so PN reached 6.3894 million capita, and assuming also a decrease in the C_{person} from 180 to 160 liters/capita/day as a result of improving the citizens' standards of living and the high level of awareness and culture among the citizens. It has also been assumed that water loss decreased from 21%

to 15% in this scenario, as a result of conducting further activities in dilapidated pipes, valves, connections, and treatment plants, in addition to removing illegal connections or installing meters for them. The needs of industry outside drinking water networks jumped from 0.042 to 0.047 BCM as a result of the increased demand for some products associated with the increase in population, especially food industries.

3. Results and Discussion

The outputs of the WB model for the three tested scenarios were presented including the water usages and consumptions of all sectors and the quantities returning back to the system. The performance of three scenarios was evaluated by the outputs of WB model and the Water Shortage Quality-based Index. Then packages of solutions were formulated in the form of alternatives, each focusing on one of the scientific methods.

3.1. Base Case Scenario 2018

As shown in Figure 2, the total household usage in Qena in 2018 amounted to be 0.220 BCM of which 0.026 BCM was consumed, while the system returned as untreated sanitation (0.111 BCM), losses (0.05 BCM), and treated sanitation (0.037 BCM). Agriculture usage reached 1.799 BCM, of which 0.918 BCM was consumed, and the rest returned to the system. Industrial usage outside drinking water networks reached 0.042 BCM, of which 0.032BCM was consumed, and the rest returned to the system again. Based on the data collected from the Irrigation Directorate in Qena, the reused shallow groundwater quantity was 0.100 BCM. According to the mathematical model, the amount of drainage water reused to fill the water deficit was estimated at 0.376 BCM. Based on eq (1), the calculated amount of reuse was approximately equal to the current actual quantity, which confirmed the accuracy of the mathematical model used and the reliability of it in estimating the future balance.

Based on estimation of *Fq* subindices values for different parameters, WSQI for this scenario and the other two scenarios were presented in Table 5. Although the water shortage was fully covered, the WSQI showed a low water insecurity in the current scenario.

3.2. Realistic Scenario 2050

The output of the WB model of the Realistic Future scenario shows that the total traditional water resources were 1.265 BCM, while the total water needs increased to 2.529 BCM, and thus the water deficit was filled by reusing 1.011 BCM of drainage water and 0.253 BCM of shallow groundwater (Figure 3). As a result of increasing the drainage water reuse, the WSQI showed an absolute water insecurity in this scenario.

3.3. Optimistic Scenario 2050

Finally, the output of the WB model is shown in Figure 4, where the total traditional water resources were 1.265 BCM / year, while the total water needs decreased from 2.529 BCM in the Realistic scenario to 2.109 BCM due to the adaptation measures, and thus the water deficit was filled by reusing 0.675 BCM of drainage water and using 0.169 BCM of shallow groundwater. The WSQI showed a medium water insecurity in this scenario. This scenario showed a better status than the Realistic scenario and would allow for extra agricultural land reclamation.

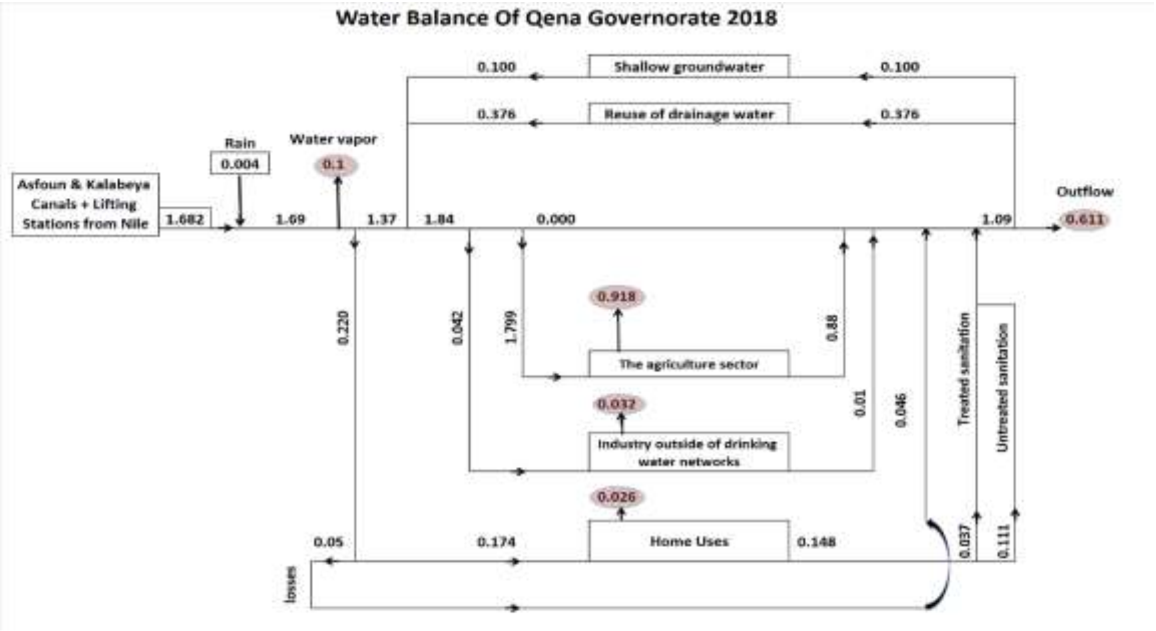


Figure 2: Water balance of the Base Case scenario

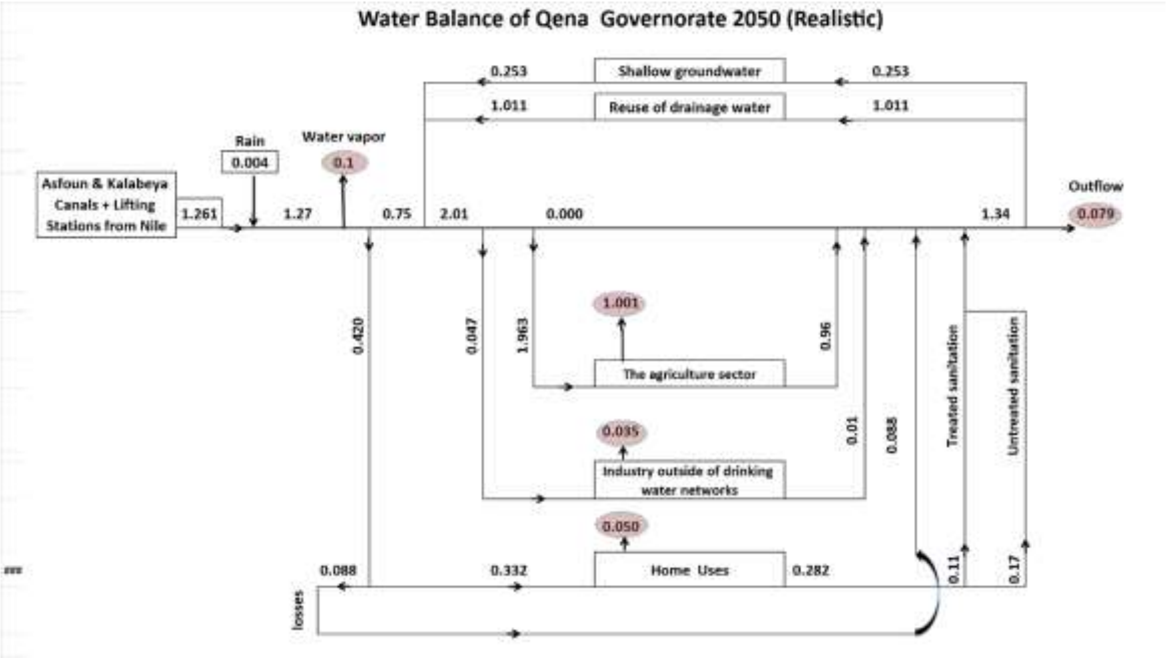


Figure 3: Water balance of the Realistic scenario in 2050

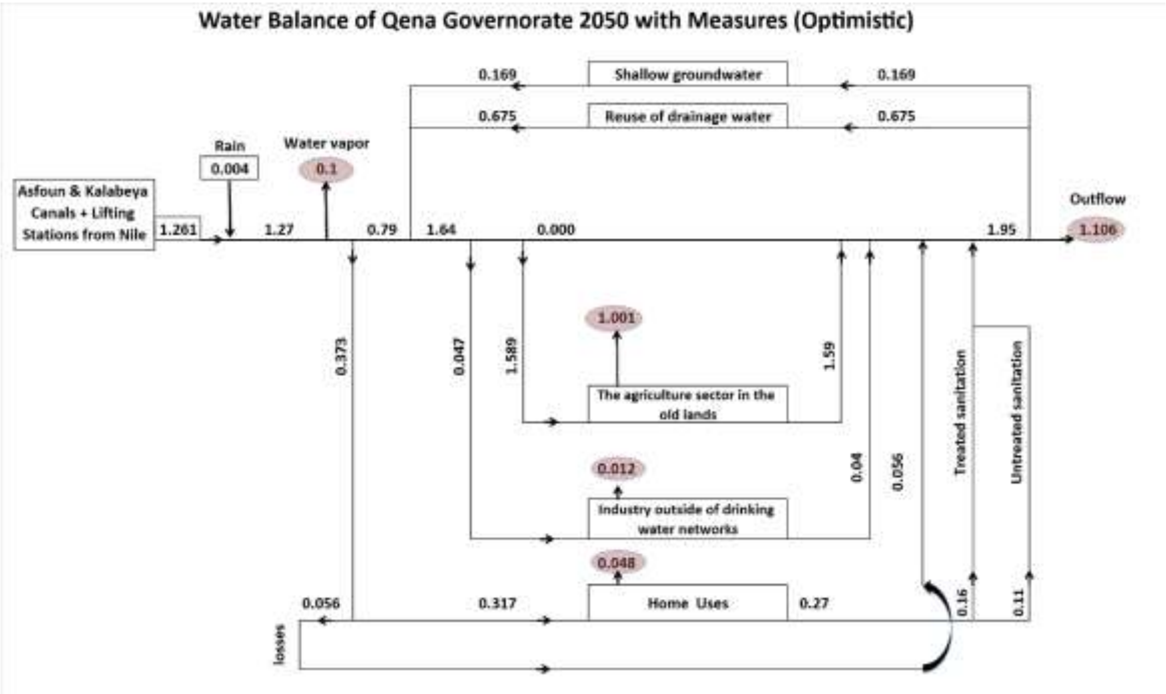


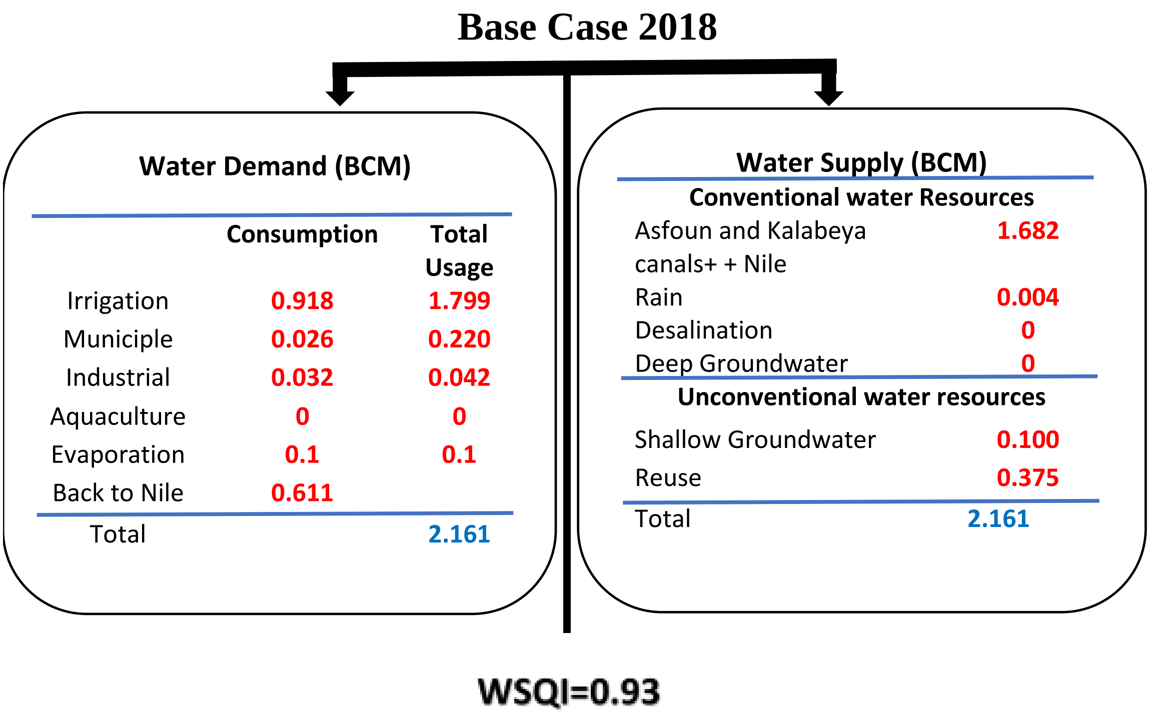
Figure 4: Water balance of the Optimistic Future scenario in 2050

Table 5: Water Security Quality-based Index for the three tested scenarios

Scenario	**Water supply type**	**Water quality sub-indexes**	**Fq**	**Supply quantity**	**Water demand**	**WSQI**
Base Case Scenar	Nile Water	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	1.682		0.93

	Rain	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	0.004	2.162	
	Shallow groundwater	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.833	0.100		
	Drainage water	DO: 0, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.666	0.376		
Realistic Future 2050	Nile Water	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	1.261	2.529	0.84
	Rain	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	0.004		
	Shallow groundwater	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.833	0.253		
	Drainage water	DO: 0, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.666	1.011		
Optimistic Future 2050	Nile Water	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	1.261	2.109	0.88
	Rain	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 1	1	0.004		
	Shallow groundwater	DO: 1, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.833	0.169		
	Drainage water	DO: 0, pH: 1, BOD: 1, NO_3: 1, TP: 1, TDS: 0	0.666	0.675		

Figure 5, 6, and 7 presented both supply and usage sides of water balance and the value of WSQI in the three scenarios. It is obvious that the total water demand in the Optimistic Scenario 2050 was the lowest among all scenarios. It is also obvious that the difference between the water consumption and usage in the same scenario is the least. The three adaptation measures in the Optimistic Scenario improved the water use efficiency in agriculture, and hence enhanced the overall status of the water system.



Base Case 2018

Water Demand (BCM)

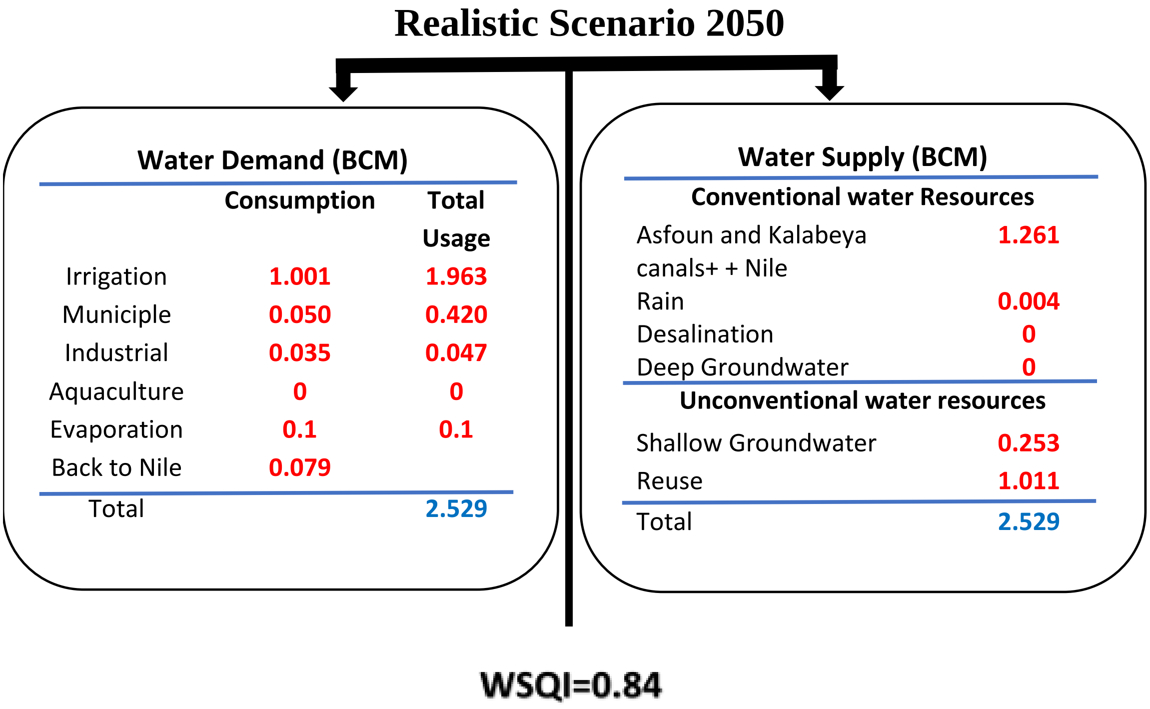
	Consumption	Total Usage
Irrigation	0.918	1.799
Municiple	0.026	0.220
Industrial	0.032	0.042
Aquaculture	0	0
Evaporation	0.1	0.1
Back to Nile	0.611	
Total		2.161

Water Supply (BCM)

Conventional water Resources	
Asfoun and Kalabeya canals+ + Nile	1.682
Rain	0.004
Desalination	0
Deep Groundwater	0
Unconventional water resources	
Shallow Groundwater	0.100
Reuse	0.375
Total	2.161

WSQI=0.93

Figure 5: Water supply and demand sides and WSQI in the Base Case Scenario



Realistic Scenario 2050

Water Demand (BCM)

	Consumption	Total Usage
Irrigation	1.001	1.963
Municiple	0.050	0.420
Industrial	0.035	0.047
Aquaculture	0	0
Evaporation	0.1	0.1
Back to Nile	0.079	
Total		2.529

Water Supply (BCM)

Conventional water Resources	
Asfoun and Kalabeya canals+ + Nile	1.261
Rain	0.004
Desalination	0
Deep Groundwater	0
Unconventional water resources	
Shallow Groundwater	0.253
Reuse	1.011
Total	2.529

WSQI=0.84

Figure 6: Water supply and demand sides and WSQI in the Realistic Scenario 2050

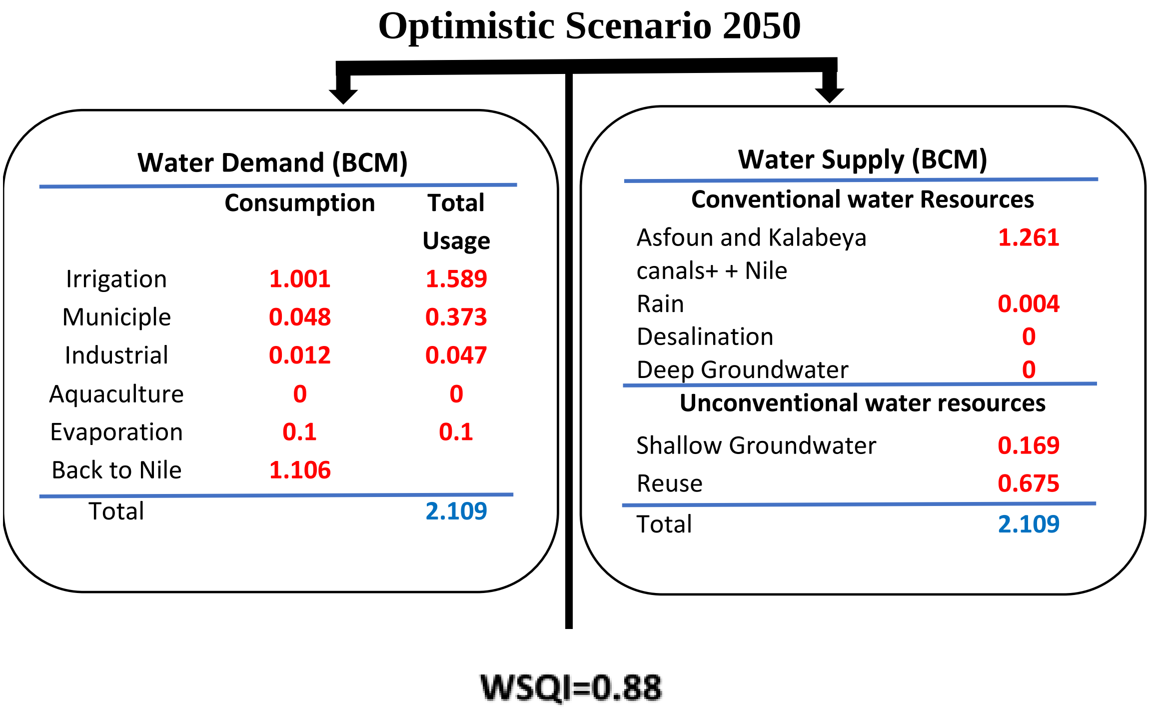


Figure 7: Water supply and demand sides and WSQI in the Optimistic Scenario 2050

1. CONCLUSION AND RECOMMENDATION

The climate change projection will alter the flow entering Lake Nasser. The current study investigates the impact of the worst flow alteration in 2050, which is predicted to be 75% of the current flow. The authors developed the WB Model and WSQI index to assess the water resources system in Qena governorate and to assess the impacts of different adaptation measures. The current water shortage in Qena governorate is 0.476 BCM and will increase to 1.264 BCM in 2050 in case of continuation of current policies. Although the current water shortage is fulfilled by reuse of shallow groundwater and drainage reuse, the WSQI showed a low water insecurity in terms of water acceptability. The package of adaptation measures in this study includes laser land leveling, application of sprinkler irrigation method, and lining of irrigation canals. This package will reduce the water use efficiency in agriculture from 51% to 63%, which reduces the water shortage and dependence on reuse of drainage water. The tested adaptation will reduce the future water shortage from 1.264 to 0.844 BCM and will change the water insecurity status from absolute to medium insecurity. The water security in Qena governorate will not only be achieved by covering the water shortage quantity, but also by providing acceptable quality of water supplies. The current paper recommends maximizing the enabling environment and investments for increasing the areas applying land leveling and sprinkler irrigation techniques, and lengths of lined canals as well as enhancing the water quality of drainage water.

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