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Modelling of Climatic Change Impact on Water Balance in the Nile Delta Region

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Abstract:

Management of the traditional irrigation system of Egypt is considered one of the most complicated problems, as it is based on the efficient assessment of the irrigation network at different levels. However, that management process does not describe the sustainability of the irrigation system to face some serious challenges such as climatic and water supply changes. This could be analyzed by using the integrated concept of water balance, which helps to identify where and when water can be saved or lost in an irrigation system. In the present study, the Distributed Catchment Scale Model (DiCaSM) was applied to study the impact of climate and water supply changes on the water balance components in the Nile Delta region, Northern Egypt, comprising nine governorates with a total area of about 21,107 km^2. The study area had many problems, such as soil salinization, water quality issues, escalating the gap between water demand and availability, as well as limited information on different hydrological elements, in this regard; mathematical modelling is a reliable method to explain such problems at the regional scale. This research aims to investigate the severity of the climatic and water supply changes impacts; and how will the Nile Delta withstand and cope with such projected changes. The results obtained from this study, demonstrate the capability of the DiCaSM model to compute the different components of the Nile Delta water balance and to effectively simulate the ground water levels and recharge values. Furthermore, the model was employed to simulate different climate and water supply change scenarios for the area of interest.

Keywords **— Nile Delta, Climatic Changes, Water Balance.**

1. Introduction

In Egypt, the irrigation sector is, and will remain, the largest consumer of water, and, therefore, it faces the greatest challenge in its efforts to rationalize water use. This sector, mainly depends on the Nile water and consumes about 80~85% of the annual water supply. Industrial and domestic sectors are also considered main sectors to consume water in addition to the irrigation sector. All three sectors are incredibly growing due to population increase and accordingly there is a continuous increase in water demands. Also the climate changes are expected to impact deeply the water use and availability. Quantitative balance between the continuous increase in water demands and limited supply, taking into account the climate change, is necessary required to develop a sustainable water management process. Thus, hydrological models are the proper tools to simulate the water management situations as stated by Franz Hummel (2013) who applied Water balance Simulation model (WaSim) to investigate the impacts of climate change on hydrological quantities and the occurrence of extreme events for the Mediterranean region and neighboring countries in the Chiba basin in Tunisia. In a relevant issue, Sowalim et al. (2003) used the Decision Support Systems for Agro-technology Transfer models (DSSAT), to predict maize yield in Egypt. The model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and excess water from irrigation, vertical drainage, unsaturated flow, evaporation, and root water uptake processes. Arranz, R.et al. (2007) used the Water Evaluation and Planning System model (WEAP) to assess future water demands and resources in the Olifants catchment, South Africa. The model was employed to assess the impacts of the likely future water use on the water resources of the mentioned catchment. Strzepek et al. (2007) used the theoretical rainfall runoff model called Water Balance (WatBal) to study the climate change impacts on water resources and agriculture in Africa. Quilb`e et al. (2008) used the integrated modeling system (GIBSI) to assess the effect of land use scenarios on the hydrology of the Chaudi`ere River watershed in Canada, under future climatic conditions. The Distributed Catchment Scale model (DiCaSM), was applied in

various sites; such as in Brazil, by A. Montenegro and R. Ragab, (2010); in Italy by Lamaddalena (2010) and by R. Ragab and John Bromley (2010) in Cyprus. In this study, the DiCaSM model was used, to simulate and analyze different scenarios of climate and water supply changes. One of the main objectives of this study was to assess the water balance within the Nile Delta area for the existing water use and supply system (existing conditions), to illustrate its defects, propose the appropriate water management actions, and thereafter predict its outcomes. Another objective was testing different scenarios of climatic change impacts on the future escalating water demand versus water resources vulnerability due to temperature rise as well as water supply changes. The results showed a small level of uncertainty and subsequently, a higher confidence level.

The Nile Delta region is located in Northern Egypt, and is ranked among the world`s most richest agriculture areas. The region is enclosed by a highly arid environment with very scarce rainfall in a narrow strip along the north coast. Only 100 to 200 mm of rain falls on the Delta area is recorded throughout the year as reported by Francois Molle (2016), most of it falls in winter, and is considered the wettest region in the country, which has relatively moderate temperatures, with highs usually not exceeding 31 °C in the summer. The Delta`s hottest temperatures are in July and August, with maximum average of 34 °C. Winter temperatures are normally in the range of 9 °C at nights to 19 °C during daytime, with cooler temperatures and less rainfall. The Nile Delta region becomes quite humid during the winter season. Figure (1) below, presents the 9 sub-regions (governorates) had been involved in the simulation model process.

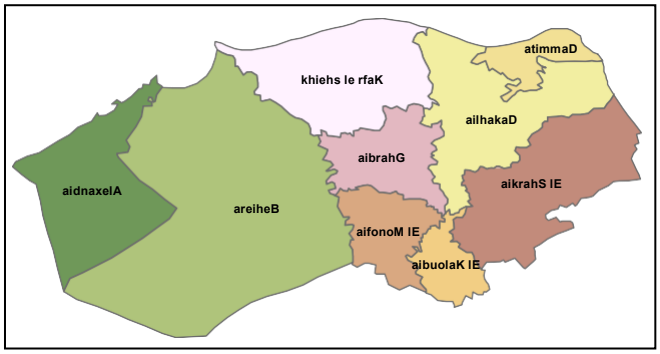

Figure (1). Nile Delta map, showing the nine governorates of the study area in Northern Egypt

2. Methodology

The growing gap between water demand and availability is considered one of the vital problems. In addition to climatic changes that will have great impacts on each element in the water balance equation; in this context, this research aims to investigate the severity of these impacts; and how will the Nile Delta withstand these impacts resulted from climatic changes.

The research was implemented using (DiCaSM) simulation model to estimate all water balance components. Thus, any climatic changes in temperature, irrigation supply or land use at the surface level were handled by the model, as well as the groundwater recharge data. By the aid of Arc Map 10.3 GIS application which was used to estimate the distributed data for each grid square in the area of interest. The first phase includes the study of the present situation, and geo-referencing all the involved parameters for the study area. The parameters include Agro-climatic zones, land elevations, and water resources network on a GIS spatial platform. Then an evaluation of the present "Water Balance" is to be conducted, from recent records of actual cropping pattern, topographic elevations, meteorological climatic data, soil types which were collected from different sources, to assess the adequacy of Water Balance up to date. The simulation stage for future conditions starts using the (DiCaSM) model results, as an initial step of Water Balance modeling, to estimate accurately water balance and to account for the future climate change impacts' scenarios. Moreover, the model applied different scenarios of Climatic and water availability, in order to predict the impacts of these different scenarios on irrigation requirements as well as groundwater recharge.

(DiCaSM) model was used to simulate the hydrology of the unsaturated zone of the study area, for a depth of a few meters. The model is originally designed to represent the implementation of an integrated water management strategy, in addition to its ability to simulate the hydrological cycle, accurately reflecting the operating processes in the area of interest, while applying different scenarios of climatic changes as well as land use or water supply changes, and the model runs on a daily time step. (DiCaSM) model uses a square grid unit, as shown in figure (2).

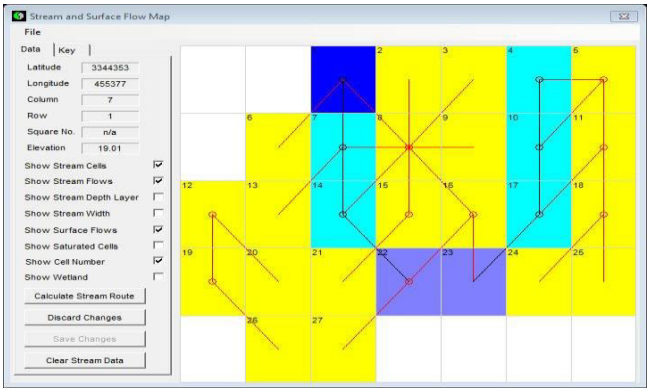

Figure (2). Stream location and flow directions for the Delta

Model input and data manipulation

Because of the large size of the study area, research required collection of numerous and various data sets on; survey, topography, morphology, soil type, climate, cropping pattern, groundwater levels, irrigation and drainage networks and systems. Many analysis techniques were employed to establish the study targets, including usage of data analysis

(statistics); and computer models (Excel and Arc Map GIS10.3) for data manipulation.

(DiCaSM) model was applied to the Nile Delta area, which was divided into 27cells (1600 km2 each), using data of the year 2015/2016, inputs were collected as follows:

- The meteorological data for the study area were collected, including max and min temperatures, relative humidity, sunshine hours, wind speed and rainfall intensity for the nine included provinces (Alexandria, Kafr EL Sheikh, Behera, Sharkia, Monofia, Gharbia, Dakahlia, Monofia, Damitta) in the Nile delta region. Data was obtained from the Power Data Access Viewer (2016), then being distributed by the Arc Map GIS 10.3, as shown in figure (3), and had been used as input for (DiCaSM) model.

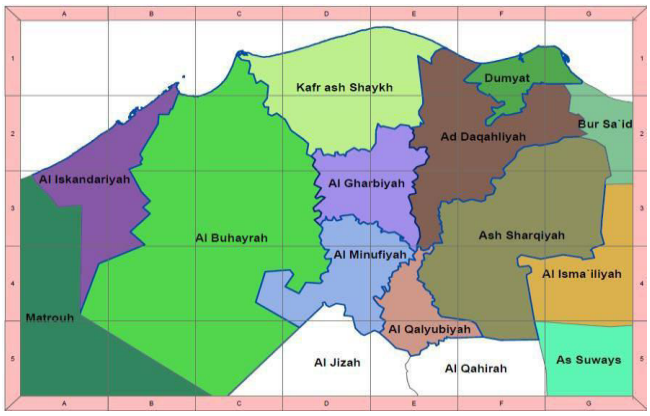

Figure (3). Nile Delta Governorates boundaries and grid distribution

- Soil-type information, including clay and sand percentage, Cation Exchange Capacity (CEC) and Organic Matter content (OM) of each soil layer cover the alluvial arable land and their interference with Desert fringes, were collected. Soil maps included 12 soil types, at a scale of 1: 100,000 in correspondent format, covering the whole area of the Nile Delta region were obtained from Shalaby et al. (2012). Then soil classification was distributed for each grid square and presented by the Arc Map GIS 10.3, as shown in figure (4).

- Updated cropping patterns in the study area for each governorate from the Central Agency for Mobilization and Statistics (2017, a).
- Actual surface water quantities released and drainage water records were used to estimate the reused quantities and net drainage water disposal was obtained from the Central Agency for Mobilization and Statistics (2016).
- Potable and Industrial water data were collected by the Central Agency for Mobilization and Statistics (2017, b).
- A full Google earth map was used to delineate the coastal shoreline of the study area as well as the boundary and topographic characteristics of each governorate. Through the United States Geological Survey (USGS); remotely sensing techniques provides different satellite images, Digital Elevation Model (DEMs) and the Shuttle Radar Topography Mission (SRTM) maps. Figure (5) shows the mentioned Map after applying Mosaic and extract tools. The DEM map was therefore used to extract reliable elevation information by the application of the zonal statistical method of the ARC-MAP, as shown in figure (6).

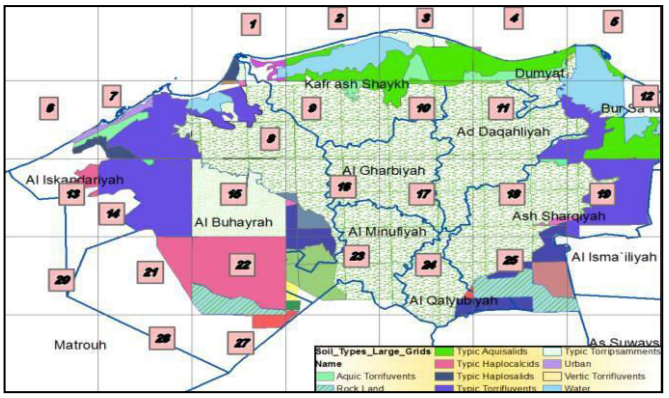

Figure (4). Digital Nile Delta soil Classification, produced by Arc map GIS 10.3

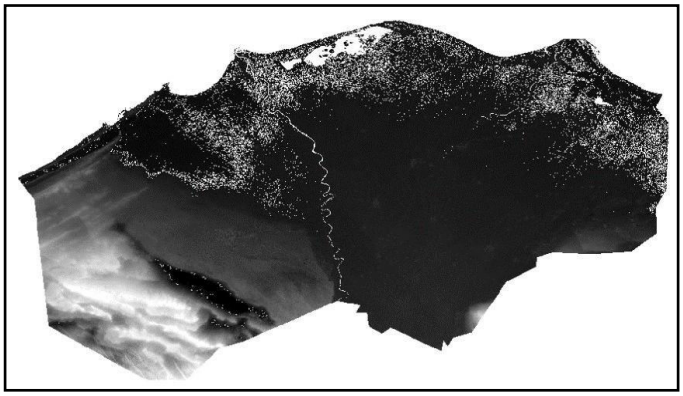

Figure (5). Nile Delta Region Map after Mosaic and extract by mask

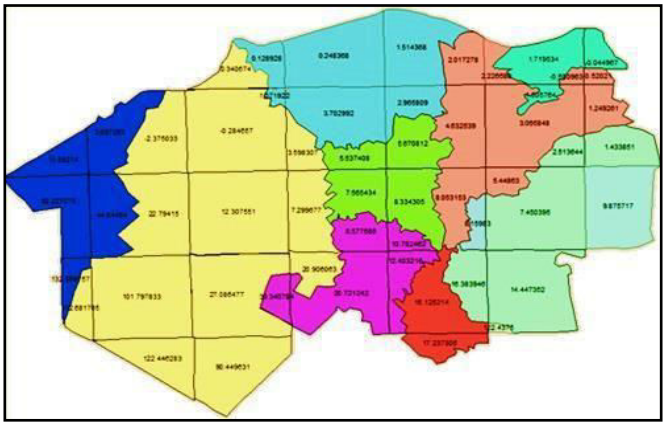

Figure (6). Grid square output elevation map, ARC Map GIS 10.3

ARC Map GIS 10.3 was employed to determine the boundary of each governorate in each grid square located in the study area. The calculated area was then used with the

cropping pattern data for each governorate; to produce the percentage of each crop for each grid square in the area of interest. Subsequently, each crop percentage in every governorate; was estimated for the two successive cropping seasons. Then, Arc Map was employed to determine the different meteorological data for each grid square, and the procedure was applied for the 27 grids.

Climate and water supply change scenarios

As the focus of this research was to investigate the impact of climate and water supply changes on water balance elements, common climate change scenarios were tested and applied as input to (DiCaSM) model to monitor the relevant differences between their results and the water balance indicators for the existing conditions. Particularly, Figure (7) shows the selected climate change scenarios that were based on the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel of Climatic Changes (IPCC) concerning Egypt, after Bryson Bates et al. (2008). Where each scenario represents the future change in atmospheric temperature in Celsius for the year of 2025 and then for the next 75 years in a 25-year time interval.

The combined effect of the climate change and water supply change was also introduced and tested by (DiCaSM) model, depending on the predicted data by Beyene et al. (2010). The percentages of water supply change for the mentioned periods were adopted and introduced to (DiCaSM) model.

The study objectives were accomplished throughout applying (DiCaSM) model and using all the involved parameters (meteorological data, soil data, cropping pattern data, served areas, elevations, and irrigation and drainage network; i.e. synoptic diagrams). In addition, the water demands within the study area were presented, including: domestic, industrial, and irrigation; that would balance with the available resources, including: precipitations, surface streams, reuse drainage water, and groundwater. Climate change scenarios were considered as presented in table (1) and the future water supply change for different time slices were presented in table (2).

All the previous data were analyzed and then used to run the model. The model outputs and analysis are presented in the next section.

3. Results

Annual simulation of the Nile Delta water budget under C.C. Scenario A1, keeping the present irrigation system of fixed schedules; the model results presented in figure (8), shows frequently repeat infiltration/recharging cycles, follows quantitatively and timely the fixed irrigation schedules, which seems from the simultaneously repeated events. The figure also reveals development and trends of the crops' consumptions along the 2 successive cropping seasons.

The diagram shows logic enveloping of the annual infiltration to the recharge, with a reasonable difference that represent surface drainage water. Whereas figure (9) demonstrates that with developing C.C. Scenario C2A1 into the model, it predicts a higher crop's consumptions against reduction in infiltration, and consequently reduction in ground water recharge. Thus, all systematic trends will remain idem, due to assumption of applying the same irrigation schedules. It is worth revealing that with further C.C.; higher consumption and less ground water recharge are expected.

Figure 10 below shows the annual consumption curve along with the total water supply diagram. The diagram shows a comparison between the two parameters for the targeted year 2025. It is clear that water supply is quite sufficient till the targeted year 2025, with minimal deficit at the beginning of the summer season. Water seemed to be wasted in the fallow-land season due to fixed irrigation schedules. Water supply peaks do not follow consumption peaks perfectly; which might cause shortages and losses.

4. Discussion

Impact of Climate change scenarios.

Depending on the C.C scenarios shown in Table (1) for the Nile Delta region, the impact of climate change on study area water resources had been assessed. Table 3 shows the impact of different climate change scenarios on ground water recharge and the total water demand.

The table indicates that for A_1 Scenario with no water supply change and temperature change from 1.07°C to 5.7°C the total demand will increase by 64.48 % while the total G.W recharge will decline by -7.1%. For A_2 Scenario with temperature change from 1°C to 4.5°C the total demand will increase by 50.06% while the total G.W recharge will decline by -5.51%. For B_1 Scenario with temperature change from 1°C to 2.6°C the total demand will increase by 29.34% as a result of temperature rise; while the total G.W recharge will decline by -3.23%. For B_2 Scenario with temperature rise from 1.4°C to 3.2°C the total demand increase will by 39.37% as a result of temperature rise; while the total G.W recharge will decline by -4.33%.

Combined climate change and irrigation change scenarios.

Depending on the climate change and water supply change illustrated in table (1) and (2); the combined impact of the climatic changes and the water supply changes were simulated by (DiCaSM) model. Table 4 shows the impact of different climate change along with water supply change scenarios on ground water recharge and the total water resources demand.

Table (1). Climate change scenarios implemented to (DiCaSM) model

Simulation Sc.	Future Year	Emission Sc.	Season range of projected air temperature (temperature change in degree Celsius (+T))			
			Winter	Spring	Summer	Autumn
			Dec, Jan, Feb	Mar, Apr, May	Jun, July, Aug	Sep, Oct, Nov
C1A1	2025	A1	1.25	1.07	1.25	1.50
C2A1	2050		2.40	2.30	2.80	2.80
C3A1	2075		3.30	3.50	4.25	4.00
C4A1	2100		4.20	4.70	5.70	5.20
C1A2	2025	A2	1.00	1.00	1.10	1.10
C2A2	2050		1.70	1.70	2.10	2.00
C3A2	2075		2.5	2.7	3.3	3.05
C4A2	2100		3.30	3.70	4.50	4.10
C1B1	2025	B1	1.15	1.00	1.20	1.25
C2B1	2050		1.80	1.80	2.20	2.20
C3B1	2075		1.85	2.00	2.4	2.35
C4B1	2100		1.90	2.15	2.60	2.50
C1B2	2025	B2	1.40	1.09	1.40	1.50
C2B2	2050		1.80	1.80	2.30	2.30
C3B2	2075		2.25	2.35	2.9	2.75
C4B2	2100		2.70	2.90	3.50	3.20

From table (4); it can be seen that: for Scenario B1 with temperature change from 1°C to 2.6 °C and water supply change at the time slice (2010-2039) equal +9.02%; that the ground water recharge will increase by 3.21% as a result of increased water supply during this period, as well as the total demand, will increase by 26.71%. For the time slice (2040-2069) with water supply decrease by -10.98%, the ground water recharge will decrease by 8.90%, while the total demand will increase by 37.76%. For all the following time slices, as a result of the increased temperature and declined water supply, the total water demand will increase and inversely the ground water recharge will decrease.

Table (2). Future water supply change (%) for three future times-slices (2010–2039, 2040–2069, and 2070–2099), predicted for the Nile Delta Region

Month	A2			B1		
	(2010-2039)	(2040-2069)	(2070-2099)	(2010-2039)	(2040-2069)	(2070-2099)
Jan	6.00%	-12.57%	-14.00%	9.14%	-10.86%	-16.00%
Feb	6.00%	-12.75%	-14.00%	9.00%	-11.00%	-16.00%
Mar	5.95%	-12.62%	-14.05%	9.04%	-10.95%	-15.95%
Apr	6.00%	-12.75%	-14.00%	9.00%	-11.00%	-16.00%
May	6.04%	-12.64%	-13.96%	9.06%	-10.49%	-16.04%
June	6.00%	-12.77%	-14.00%	9.08%	-10.92%	-16.00%
July	6.00%	-12.71%	-14.00%	9.00%	-11.00%	-16.00%
Aug	6.03%	-12.70%	-13.97%	9.05%	-10.95%	-16.03%
Sep	6.05%	-12.79%	-13.95	9.07%	-10.93%	-16.05%
Oct	6.11%	-12.70%	-14.05%	8.92%	-11.08%	-15.95%
Nov	6.01%	-12.78%	-13.89%	8.89%	-11.11%	-16.11%
Dec	6.00%	-12.67%	-14.00%	9.00%	-10.98%	-16.00%
Annual Avg. Change	**6.00%**	**-12.70%**	**-13.99%**	**%9.02**	**-10.98%**	**-16.01%**

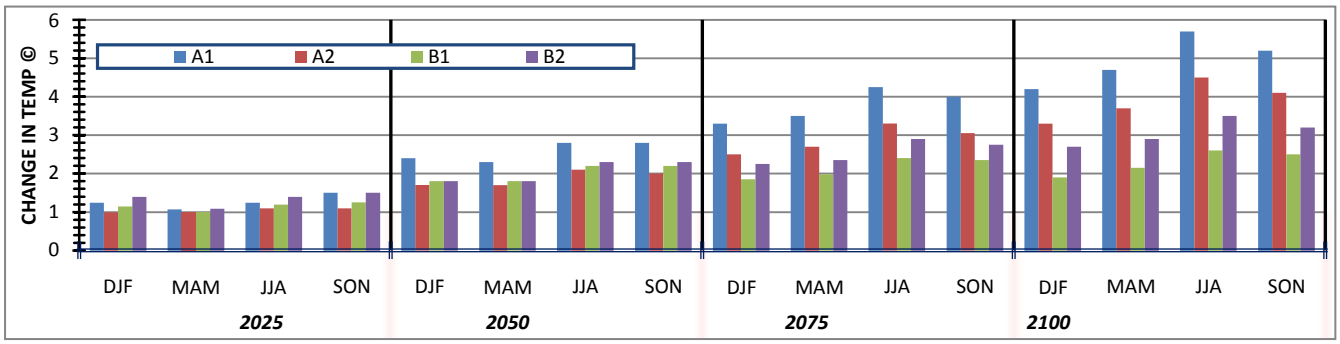

Figure (7). Applied climatic change scenarios forEgypt

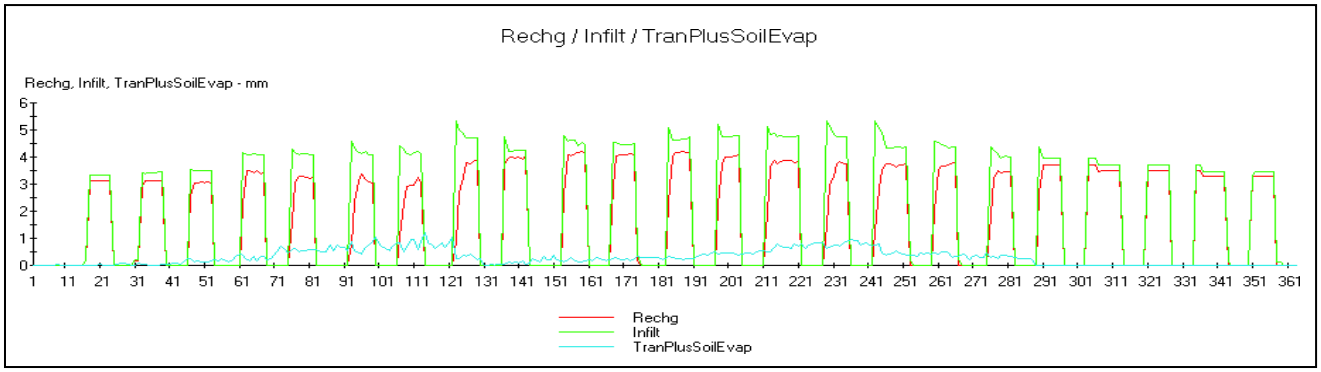

Figure (8). Time Series Model output sample showing infiltration, Total transpiration plus Soil Evaporation and recharge (C1A1)

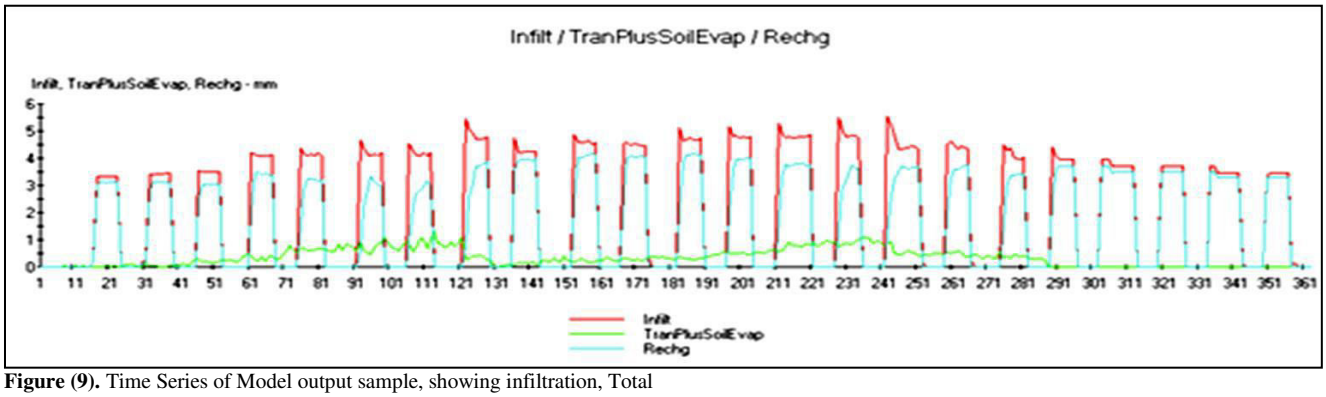

Figure (9). Time Series of Model output sample, showing infiltration, Total transpiration plus Soil Evaporation and recharge (C2A1)

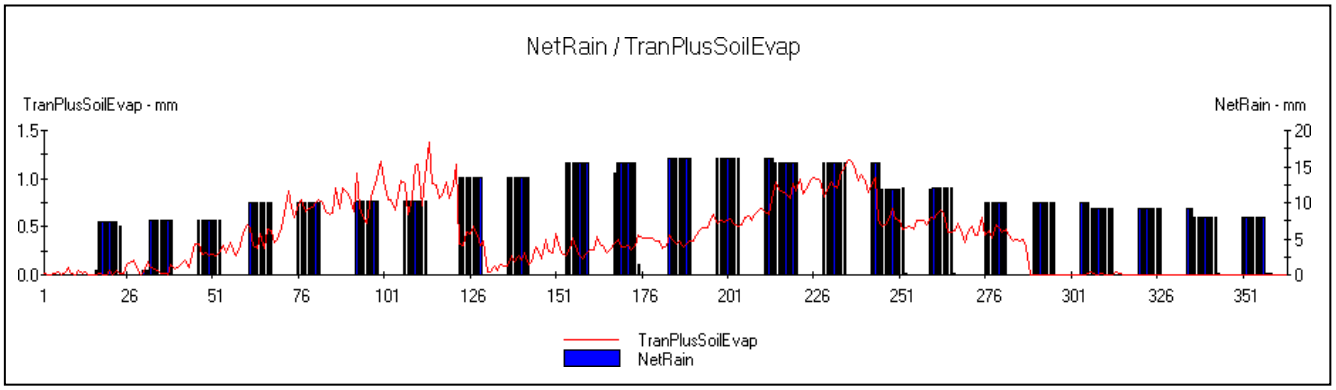

Figure (10). Time Series of Model output sample, showing Net irrigation /Total transpiration plus Soil Evaporation (C2A1)

Table (3). Impacts on the G.W Recharge and the percentage of water demand increase; according to different climate change scenarios

C.C Impact	A1			B1			A2			B2		
	To 2050	To 2075	To 2100	To 2050	To 2075	To 2100	To 2050	To 2075	To 2100	To 2050	To 2075	To 2100
G.W (% of decrease	-3.6%	-5.3%	-7.1%	-2.75%	-3 %	-3.23%	-2.59%	-4.03%	-5.51%	-2.83%	-3.64%	-4.33%
Total Demand (%) of increase	32.68%	47.94%	64.48%	25.03%	27.28%	29.34%	23.53%	36.65%	50.06%	25.75%	33.10%	39.37%

5. Conclusion

From the above mentioned study, and research results, the following main points can be concluded:

- The study introduced a needed technical details about the water situation in the Egyptian Nile delta, as well as developing the hydrological concepts and details of the area under study.
- The capability of the selected model for computing the different components of the Nile Delta water balance, and effectively simulate the ground water recharge values.
- For different studied scenarios of climate and water supply changes in Nile Delta Region, the study proved that the ground water recharge decreased as a result of evaporation increment.
- The worst impact of climate change studied scenarios, on water demand increase, was the A1 scenario, as it has the highest temperature rise range.
- With the combination of irrigation supply change, and the climate change in A2 & B1 scenarios, the crop consumption doesn't change, while the ground water recharge was affected more by decreasing the supply (for scenario A2 the decrease was -5.51% with no irrigation condition changes, and reaches -14.88% with irrigation condition changes). In scenario B1 from -3.23% with no irrigation changes condition and reaches 12.27% with irrigation changes condition.
- The study expects that the future simulated change scenarios will show an expected declination of the ground water recharge for the future periods, which incurrence the ground water to be contaminated by sea water intrusion vulnerability.

It is aimed that the study results will support the policy makers, by providing a full description and assessment of water budget in Nile Delta, and to reintegrate water management concepts, in addition to presenting techniques for the outmost increase of land and water productivity, so as to meet food security needs and improve living standards.

Table (4). Impacts on the G.W Recharge and the % of water demand increase; according to different climatic and water supply changes Scenarios

Scenario	B1				A2			
Future Year	To 2025	To 2050	To 2075	To 2100	To 2025	To 2050	To 2075	To 2100
(%) Recharge	3.21%	-8.90%	-12.06%	-12.27%	1.54%	-10.65%	-13.19%	-14.88%
(%) Total Demand	26.71%	37.76%	40.21%	42.07%	27.68%	44.74%	61.23%	76.51%
(%) Total Supply	9.07%	-11.04%	-16.11%	-16.11%	6.04%	-12.79%	-14.05%	-14.05%

Index of acronyms

A1, A2	: Climate Change Emission Scenarios.
Arc Map	: Main component of *Esri's GIS* suite of geospatial processing programs.
B1, B2	: Climatic Change Emission Scenarios.
C.C.	: Climatic Change.
CEC	:Cation Exchange Capacity

DEMs :Digital Elevation Model
DiCaSM : (IHMS)DISTRIBUTED CATCHMENT SCALE MODEL Center of Ecology and Hydrology, Walling Ford University, UK, Project Leader: Dr. Ragab Ragab, (V3.3.46 N4)
DSSAT : Decision Support Systems for Agro-technology Transfer models.
G.W. : Ground Water.
GIBSI : Gestion Intégrée des Bassins Versants à l'Aide d'un Système Informatisé
GIS : Geographical Information System
IPCC : Intergovernmental Panel Of Climatic Change
OM : Organic Matter
SRES : Special Report on Emissions Scenarios
SRTM : Shuttle Radar Topography Mission
USGS : United States Geological Survey.
WaSim : Water Evaluation and Planning System.
WatBal : Water Balance
WEAP : Water balance Simulation Model.

References

1. *A. Montenegro and R. Ragab* , "Hydrological response of a Brazilian semi-arid catchment to different land use and climate change scenarios: a modeling study". Hydrological Processes, 24, 2705–2723, 2010
2. *Arranz, R.; McCartney, M.*, "Application of the Water Evaluation and Planning (WEAP) model to assess future water demands and resources in the Olifants catchment", South Africa. Colombo, Sri Lanka: International Water Management Institute. (IWMI Working Paper 116) pp. 103, 2007.
3. *Bryson Bates at al.*, Intergovernmental panel on climate change, IPCC Technical Paper VI, WMO/UNEP, 2008.
4. *Central Agency for Mobilization and Statistics*, Annual Bulletin for Irrigation and water Resources Statistics, Ref. No.71/22126-2015, Issue December, 2016.
5. *Central Agency for Mobilization and Statistics*, Annual Bulletin of statistical crop area and Plant production, Ref. No. 71-221122-2015, Issue January. 2017.
6. *Central Agency for Mobilization and Statistics*, Annual Bulletin for potable water and sewage 2015/2016, Ref. No. 17-11112-2016, Issue June. 2017.
7. *Francois Molle, Ibrahim Gaafar, Doaa Ezzat El-Agha, Edwin Rap*, Water and salt management in the Nile Delta: Report No.9, DOI: 10.13140/RG.2.2.24418.43208 Irrigation Efficiency and the Nile Delta Water Balance. Australian Center for International Agricultural Research, IWMI, WMRI. 2016.
8. *Franz Hummel et al.*, Setting up the water balance simulation model WaSiM for the assessment of climate change impacts in Chiba basin, Tunisia: The International Conference on Modeling, Simulation and Applied Optimization (ICMSAO 2013), 2013.
9. *N. Lamaddalena et al.*, "Assessing the results of scenarios of climate and land use changes on the hydrology of an Italian catchment: modeling study", Hydrological Processes, 24, 2693–2704, 2010
10. *Power Data Access Viewer on line website*. (https://power.larc.nasa.gov/data-access-viewer), 2016.
11. *Quilb`e R, Rousseau AN, Moquet J-S, Savary S, Ricard S, Garbouj MS.*, "Hydrological responses of a watershed to historical land use evolution and future land use scenarios under climate change conditions". Hydrology and Earth System Sciences 12: pp.101–110,2008.
12. *Ragab R, Bromley J.*, Integrated Hydrological Modelling System-IHMS. Part 1. The hydrological processes and general structure. Hydrological Processes, 2010.
13. *Shalaby, A., R. R. Ali and A. Gad*, "Land degradation monitoring in the Nile Delta of Egypt, using remote sensing and GIS". International Journal of Basic and Applied Sciences. Vol. 1 No.4. 2012. pp. 292-303, 2012.
14. *Sowalim, S. M., S. M. El-Marsafay and S. A. Ouda.*, "Simulating the effect of irrigation skipping on maize yield and its attributes". Annals of Agric. Sci. Moshtohor. 41(4), pp. 1449-1457, 2003.
15. *Strzepek K, McCluskey A.*, "The impacts of climate change on regional water resources and agriculture in Africa". World Bank Policy Research Working Paper No. 4290, 2007
16. *Tazebe Beyene et al.*, "Hydrologic impacts of climate change on the Nile River Basin: Implications of the 2007 IPCC Climate Scenarios", Climatic Change journal, June 2010, Volume 100, Issue 3–4, pp. 433–461, 2010.